2011-04-30

Proceedings of the 8th Annual Acquisition Research Symposium; Volume II

Monterey, California. Naval Postgraduate School

NPS-AM-11-018

PROCEEDINGS

OF THE

EIGHTH ANNUAL ACQUISITION RESEARCH SYMPOSIUM THURSDAY SESSIONS VOLUME II

Acquisition Research: Creating Synergy for Informed Change

May 11–12, 2011

Published: 30 April 2011

Prepared for the Naval Postgraduate School, Monterey, California 93943

ACQUISITION RESEARCH PROGRAM
GRADUATE SCHOOL OF BUSINESS & PUBLIC POLICY
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The research presented at the symposium was supported by the Acquisition Chair of the Graduate School of Business & Public Policy at the Naval Postgraduate School.

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Preface & Acknowledgements

During his internship with the Graduate School of Business & Public Policy in June 2010, U.S. Air Force Academy Cadet Chase Lane surveyed the activities of the Naval Postgraduate School's Acquisition Research Program in its first seven years. The sheer volume of research products—almost 600 published papers (e.g., technical reports, journal articles, theses)—indicates the extent to which the depth and breadth of acquisition research has increased during these years. Over 300 authors contributed to these works, which means that the pool of those who have had significant intellectual engagement with acquisition issues has increased substantially. The broad range of research topics includes acquisition reform, defense industry, fielding, contracting, interoperability, organizational behavior, risk management, cost estimating, and many others. Approaches range from conceptual and exploratory studies to develop propositions about various aspects of acquisition, to applied and statistical analyses to test specific hypotheses. Methodologies include case studies, modeling, surveys, and experiments. On the whole, such findings make us both grateful for the ARP's progress to date, and hopeful that this progress in research will lead to substantive improvements in the DoD's acquisition outcomes.

As pragmatists, we of course recognize that such change can only occur to the extent that the potential knowledge wrapped up in these products is put to use and tested to determine its value. We take seriously the pernicious effects of the so-called "theory–practice" gap, which would separate the acquisition scholar from the acquisition practitioner, and relegate the scholar's work to mere academic "shelfware." Some design features of our program that we believe help avoid these effects include the following: connecting researchers with practitioners on specific projects; requiring researchers to brief sponsors on project findings as a condition of funding award; "pushing" potentially high-impact research reports (e.g., via overnight shipping) to selected practitioners and policy-makers; and most notably, sponsoring this symposium, which we craft intentionally as an opportunity for fruitful, lasting connections between scholars and practitioners.

A former Defense Acquisition Executive, responding to a comment that academic research was not generally useful in acquisition practice, opined, "That's not their [the academics'] problem—it's ours [the practitioners']. They can only perform research; it's up to us to use it." While we certainly agree with this sentiment, we also recognize that any research, however theoretical, must point to some termination in action; academics have a responsibility to make their work intelligible to practitioners. Thus we continue to seek projects that both comport with solid standards of scholarship, and address relevant acquisition issues. These years of experience have shown us the difficulty in attempting to balance these two objectives, but we are convinced that the attempt is absolutely essential if any real improvement is to be realized.

We gratefully acknowledge the ongoing support and leadership of our sponsors, whose foresight and vision have assured the continuing success of the Acquisition Research Program:

- Office of the Under Secretary of Defense (Acquisition, Technology & Logistics)
- Program Executive Officer SHIPS
- Commander, Naval Sea Systems Command
- Army Contracting Command, U.S. Army Materiel Command
- Program Manager, Airborne, Maritime and Fixed Station Joint Tactical Radio System

- Program Executive Officer Integrated Warfare Systems
- Office of the Assistant Secretary of the Air Force (Acquisition)
- Office of the Assistant Secretary of the Army (Acquisition, Logistics, & Technology)
- Deputy Assistant Secretary of the Navy (Acquisition & Logistics Management)
- Director, Strategic Systems Programs Office
- Deputy Director, Acquisition Career Management, US Army
- Defense Business Systems Acquisition Executive, Business Transformation Agency
- Office of Procurement and Assistance Management Headquarters, Department of Energy

We also thank the Naval Postgraduate School Foundation and acknowledge its generous contributions in support of this Symposium.

James B. Greene, Jr.
Rear Admiral, U.S. Navy (Ret.)

Keith F. Snider, PhD
Associate Professor

The Acquisition Research Program Team

Rear Admiral James B. Greene, Jr. USN (Ret.)—Acquisition Chair of the Naval Postgraduate School since 2003. RADM Greene develops, implements, and oversees the Acquisition Research Program in the Graduate School of Business and Public Policy. He interfaces with DoD, industry, and government leaders in acquisition; facilitates graduate student research; and conducts guest lectures and seminars. Before serving at NPS, RADM Greene was an independent consultant focusing on defense industry business development strategy and execution (for both the public and private sectors), minimizing life cycle costs through technology applications, alternative financing arrangements for capital-asset procurement, and “red-teaming” corporate proposals for major government procurements.

RADM Greene served as the Assistant Deputy Chief of Naval Operations (Logistics) in the Pentagon from 1991–1995. As Assistant Deputy, he provided oversight, direction and budget development for worldwide U.S. Navy logistics operations. He facilitated depot maintenance, supply chain management, base/station management, environmental programs and logistic advice, and support to the Chief of Naval Operations. Some of his focuses during this time were leading Navy-wide efforts to digitize all technical data (and, therefore, reduce cycle-time) and to develop and implement strategy for procurement of eleven Sealift ships for the rapid deployment forces. He also served as the Senior Military Assistant to the Under Secretary of Defense (Acquisition) from 1987–1990; as such, he advised and counseled the Under Secretary in directing the DoD procurement process.

From 1984–1987, RADM Greene was the project manager for the AEGIS project. This was the DoD’s largest acquisition project, with an annual budget in excess of $5 billion/year. The project provided oversight and management of research, development, design, production, fleet introduction, and full life cycle support of the entire fleet of AEGIS cruisers, destroyers, and weapons systems through more than 2,500 industry contracts. From 1980–1984, RADM Greene served as director, committee liaison, Office of Legislative Affairs, followed by a tour as the executive assistant to the Assistant Secretary of the Navy (Shipbuilding and Logistics). From 1964–1980, RADM Greene served as a Surface Warfare Officer in various duties, culminating in Command-at-Sea. His assignments included numerous wartime deployments to Vietnam as well as to the Indian Ocean and the Persian Gulf.

RADM Greene received a BS in electrical engineering from Brown University in 1964; he earned an MS in electrical engineering and an MS in business administration from the Naval Postgraduate School in 1973.

RADM Greene received the 2009 Richard W. Hamming Annual Faculty Award for Achievement in Interdisciplinary Activities. The selection was based on his work in leading and administering the Naval Postgraduate School's Acquisition Research Program.

Dr. Keith F. Snider—Associate Professor of Public Administration and Management in the Graduate School of Business & Public Policy at the Naval Postgraduate School, where he teaches courses related to defense acquisition management. He also serves as principal investigator for the NPS Acquisition Research Program since 2004.

Snider has a PhD in public administration and public affairs from Virginia Polytechnic Institute and State University, an MS in operations research from the Naval Postgraduate School, and a BS from the United States Military Academy at West Point. He served as a field artillery officer in the U.S. Army for 20 years, retiring at the rank of lieutenant colonel. He is a former member of the Army Acquisition Corps and a graduate of the Program Manager’s Course at the Defense Systems Management College.

Professor Snider’s recent publications have appeared in *American Review of Public Administration*, *Administration and Society*, *Administrative Theory & Praxis*, *Journal of Public Procurement*, *Acquisition Review Quarterly*, and *Project Management Journal.*

Dr. Snider received the 2009 Richard W. Hamming Annual Faculty Award for Achievement in Interdisciplinary Activities. The selection was based on his work in leading and administering the Naval Postgraduate School's Acquisition Research Program.

Karey L. Shaffer—Program Manager, General Dynamics Information Technology, supporting the Acquisition Research Program at the Graduate School of Business & Public Policy, Naval Postgraduate School. As PM since 2003, Shaffer is responsible for operations and publications in conjunction with the acquisition chair and the principal investigator. She has also catalyzed, organized, and managed the Acquisition Research Program symposiums hosted by NPS. Shaffer served as an independent project manager and marketing consultant on various projects. Her experiences as such were focused on creating marketing materials, initiating web development, assembling technical teams, and managing project life cycles, processes, and cost-savings strategies. Shaffer has also served as the operations manager for the Montana World Trade Center (MWTC). In this capacity, Shaffer developed operating procedures, policies, and processes in compliance with state and federal grant law. Concurrently, she managed $1.25 million in federal appropriations, developed budgeting systems, and helped secure a $400,000 federal technology grant. As the operations manager, she also launched the MWTC's Conference site, managed various marketing conferences, and taught student practicum programs and seminars. Shaffer holds an MBA from San Francisco State University and earned her BA in business administration (with a focus on international business, marketing and management) from the University of Montana.

Tera Yoder—Program Support Specialist for General Dynamics Information Technology in support of the Acquisition Research Program at the Graduate School of Business and Public Policy, Naval Postgraduate School. Yoder has been with the Acquisition Research Program since the summer of 2007. She facilitates technical writing support, with a focus on consistency and timeliness directive to the NPS students' level of instruction and their educational goals of excellence. Yoder also provides on-site program support, assuming responsibility for tasks associated with daily ARP operations and with the completion of the sponsored report publication process. She graduated in 2009 with distinction from California State University Monterey Bay with a degree in liberal studies and a minor in rhetoric and writing. She is currently working on an MBA at Texas A&M University–Commerce, with an expected graduation date of May 2013.

Adrianne Malan—Senior Editor for General Dynamics Information Technology in support of the Acquisition Research Program at the Graduate School of Business and Public Policy, Naval Postgraduate School. Malan has a BA in English literature and an MA in British literature, both from Brigham Young University (BYU). Malan is a former visiting instructor at BYU, where she taught Writing and Rhetoric, Fundamentals of Literary Interpretation and Criticism, and Advanced Writing about the Arts and Humanities. Malan has also worked as an editing intern and an editing internship coordinator for International Outreach, an academic program that publishes country-specific curriculum manuals for elementary and secondary instruction. She has also presented her academic work at various literary conferences. Malan lives in Virginia with her husband and daughter.

Nicole Langi—Associate Editor for General Dynamics Information Technology in support of the Acquisition Research Program at the Graduate School of Business and Public Policy, Naval Postgraduate School. Langi has a BA in international cultural studies from Brigham Young University-Hawaii and an MA in Teaching English to Speakers of Other Languages (TESOL) from the Monterey Institute of International Studies. In graduate school, Langi specialized in curriculum design and has completed several curriculum design projects for English language programs in the U.S., Egypt, and Azerbaijan. She has also worked as the Special English Programs coordinator at the Monterey Institute of International Studies in the English as a Second Language (ESL) Department. As an ESL instructor, she has taught a variety of students, including international master's degree students, Azerbaijani diplomats, and Taiwanese businessmen. Langi has given presentations at various professional conferences on curriculum design and ESL teaching methodology, and she continues to participate in the international TESOL organization. She lives in Utah with her husband and daughter.

Rebecca Cheney—Associate Editor for General Dynamics Information Technology in support of the Acquisition Research Program at the Graduate School of Business and Public Policy, Naval Postgraduate School. Cheney has a BA in international studies from Utah State University, an MA in Teaching English to Speakers of Other Languages (TESOL), and a certificate in language program administration, both from the Monterey Institute of International Studies (MIIS). She has worked as the Special English Programs coordinator and as the Language Teacher Training Program coordinator at MIIS in the English as a Second Language (ESL) Department. She has also taught in these programs as well as in various intensive English programs at MIIS. Cheney has taught ESL in Taiwan and English for Academic and Professional Purposes in Baku, Azerbaijan at the Azerbaijan Diplomatic Academy for both the MA in diplomacy and international affairs program and the advanced foreign service program. She has worked as an editorial assistant for the *Modern Language Journal*, as an editor of six languages for ICON Health & Fitness, Inc., and as a freelance editor. She resides in Monterey, CA.

Shellee Dooley—Transcription Support for General Dynamics Information Technology in support of the Acquisition Research Program for the Graduate School of Business & Public Policy at the Naval Postgraduate School. Dooley has been with the GDIT team since October 2008. She attended the College of Eastern Utah and Weber State College on an academic scholarship. She previously owned Transcription Services, Inc., in Anchorage, AK, and was office manager for a large off-shore oil heavy-lift company in Singapore. Before joining GDIT, she taught business courses—including business management, accounting, and finance—at Xi'an International Studies University and South China University of Technology with the BYU China Teachers Program through the Kennedy Center for International Studies. Dooley is married and has two children and four grandchildren. She resides in Utah.

Laura Hatcher—Transcription Support for General Dynamics Information Technology in support of the Acquisition Research Program for the Graduate School of Business & Public Policy at the Naval Postgraduate School. Hatcher has been with the GDIT team since October 2010. She attended Brigham Young University and graduated with a BA in political science with an emphasis in Law. She previously was a manager of administration for two high-tech firms in Orem, UT, and Salt Lake City, UT. Before joining GDIT, she worked for a transcription company in Anchorage, AK. Hatcher is married and has two children. She resides in Minnesota.

Sandy George—Associate Editor for General Dynamics Information Technology in support of the Acquisition Research Program at the Graduate School of Business and Public Policy, Naval Postgraduate School. George studied English at Reed College and received a BS in psychology with an English minor from Brigham Young University (BYU). She received an EdM from Harvard University Graduate School of Education, with a specialization in risk and prevention. She has worked in the fields of education and mental health, with children, adolescents, and adults. She also has experience as an academic program manager and language arts curriculum developer. George lives in Austin, TX, with her husband and two daughters.

Lauralee Hyer—Associate Editor for General Dynamics Information Technology in support of the Acquisition Research Program at the Graduate School of Business and Public Policy, Naval Postgraduate School. Hyer has a BA in English and an MFA in creative writing, both from Brigham Young University. At BYU Hyer was a Composition and Rhetoric instructor and assisted in developing new curriculum requirements. She also worked as the publications coordinator and managed editorial internships for Intercultural Outreach, an academic program that publishes country-specific curriculum manuals for elementary and secondary instruction. Hyer is actively involved in the writing world and has received multiple regional and national writing awards and participated in BYU's English department reading series. She currently lives in Utah with her husband.

Rachel Whitaker—Associate Editor for General Dynamics Information Technology in support of the Acquisition Research Program at the Graduate School of Business and Public Policy, Naval Postgraduate School. Whitaker earned a BA in English and a minor in editing from Brigham Young University in 2007. She worked as the junior copywriter at Trivani, a startup health company in Utah, for a year before becoming the company's sole writer and editor, responsible for the planning and development of all online and print content. In 2009, Whitaker joined Uppercase Living, a Utah home décor company, as senior writer and editor. Whitaker founded Rachel Whitaker Creative in 2010 and now freelances for a variety of companies and industries in the U.S. She lives in Utah with her husband.

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Announcement & Call for Symposium Proposals

The Graduate School of Business & Public Policy at the Naval Postgraduate School announces the **9th Annual Acquisition Research Symposium** to be held **May 16-17, 2012 in Monterey, California.**

This symposium serves as a forum for the presentation of acquisition research and the exchange of ideas among scholars and practitioners of public-sector acquisition. We seek a diverse audience of influential attendees from academe, government, and industry who are well placed to shape and promote future research in acquisition.

The Symposium Program Committee solicits proposals for panels and/or papers from academicians, practitioners, students and others with interests in the study of acquisition. The following list of topics is provided to indicate the range of potential research areas of interest for this symposium: **acquisition and procurement policy, supply chain management, public budgeting and finance, cost management, project management, logistics management, engineering management, outsourcing, performance measurement, and organization studies.**

Proposals must be submitted by **November 7, 2011**. The Program Committee will make notifications of accepted proposals by **December 12, 2011**. Final papers must be submitted by **April 2, 2012**.

Proposals for papers (plan for a 20 minute presentation) should include an abstract along with identification, affiliation, and contact information for the author(s). Proposals for panels (plan for a 90 minute duration) should include the same information as above as well as a description of the panel subject and format, along with participants' names, qualifications and the specific contributions each participant will make to the panel.

Submit paper & panel proposals to www.researchsymposium.org

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GRANTS.GOV -- NPS-BAA-11-002
The Acquisition Research Program
Open until 5:00 p.m. PDST 13 June 2011

Primary objective is to attract outstanding researchers and scholars to investigate topics of interest to the defense acquisition community. The program solicits innovative proposals for defense acquisition management and policy research to be conducted during fiscal year (FY) 2011 (1 Oct 2010 – 30 Sep 2011) and FY 2012 (1 Oct 2011 – 30 Sept 2012).

Defense acquisition management and policy research refers to investigations in all disciplines, fields, and domains that (1) are involved in the acquisition of products and/or services for national defense, or (2) could potentially be brought to bear to improve defense acquisition. It includes but is not limited to economics, finance, financial management, information systems, organization theory, operations management, human resources management, and marketing, as well as the "traditional" acquisition areas such as contracting, program/project management, logistics, and systems engineering management.

This program is targeted in particular to U.S. universities (including U.S. government schools of higher education) or other research institutions outside the Department of Defense (DoD).

Award Info: The Government anticipates making multiple awards up to $120,000 each for a basic research period of twelve months. The awards will take the form of grants or cooperative agreements. NPS plans to complete proposal evaluations and notify awardees in September 2011. The actual date of grant award will depend on availability of funds and the capabilities of the grants office. Prior year awards occurred in the August – January timeframe. Awardees may request approval of pre-award costs (up to three months), or they may request adjustments in the grant period of performance.

Eligibility: All responsible sources from academia and industry may submit proposals under this BAA using GRANTS.GOV. U.S. Government agencies are not eligible to receive awards through GRANTS.GOV submissions.

Interested parties from U.S. government schools of higher learning (i.e. NPS, AFIT, DAU, etc.), Navy laboratories and warfare centers as well as other DoD civilian agency laboratories **should submit requested information (Vol. 1, 2 & 3) in a single PDF attachment** to Ms. Karey Shaffer klshaffe@nps.edu, **no later than 13 June 2011**, to be included in the evaluation review process.

Full Text: Attached & at www.grants.gov **. Addendums to this call will be posted at Grants.gov and will not be sent via e-mail.**

To locate the call quickly:

1) Go to www.grants.gov

2) Use **Quick Links** on the far right hand corner under **FOR APPLICANTS**, **Grant Search**.

3) Type in **NPS-BAA-11-002** under Search by Funding Opportunity Number.

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Acquisition Research Chair Remarks: RADM James B. Greene, Jr, USN (Ret.)

Rear Admiral James B. Greene, Jr. USN (Ret.)—Acquisition Chair of the Naval Postgraduate School since 2003. RADM Greene develops, implements, and oversees the Acquisition Research Program in the Graduate School of Business and Public Policy. He interfaces with DoD, industry, and government leaders in acquisition; facilitates graduate student research; and conducts guest lectures and seminars. Before serving at NPS, RADM Greene was an independent consultant focusing on defense industry business development strategy and execution (for both the public and private sectors), minimizing life cycle costs through technology applications, alternative financing arrangements for capital-asset procurement, and "red-teaming" corporate proposals for major government procurements.

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Keynote: Lieutenant General William N. Phillips, USA, Principal Military Deputy to the Assistant Secretary of the Army (Acquisition, Logistics, & Technology)

LTG William N. (Bill) Phillips became the Principal Military Deputy to the Assistant Secretary of the Army (Acquisition Logistics and Technology) and Director, Acquisition Career Management on February 1, 2010. In his previous assignment, he was the Commanding General, Joint Contracting Command-Iraq/Afghanistan in Baghdad, Iraq from February 2009 to January 2010. Prior to that assignment, LTG Phillips served as Commanding General, Picatinny Arsenal, NJ; Program Executive Officer Ammunition; and Commander, Joint Munitions and Lethality Life Cycle Management Command from May 2007 to January 2009. He also served as Deputy Program Executive Officer, Aviation, Redstone Arsenal, AL.

Commissioned a Second Lieutenant of Field Artillery on May 28, 1976, LTG Phillips entered Active Duty at Fort Sill, OK, serving with 3rd Battalion, 18th Field Artillery. In 1979, he completed Rotary Wing Aviation Training at Fort Rucker, AL, and was assigned to 25th Infantry Division, Schofield Barracks, HI. He was later assigned to United States Army Aviation Center, Fort Rucker, joining the Aviation Branch. In 1986, LTG Phillips completed a Training With Industry tour with McDonnell Douglas Helicopter Company in Mesa, AZ, and was assigned to Army Aviation Systems Command as the Contracting Officer for AH-64 Apache, AH-1, UH-1 aircraft, and Assistant Program Manager for Longbow Apache. He deployed as Chief of Contracting, Joint Task Force Bravo, Honduras. In 1991, he was assigned as Aviation Brigade S1, 2nd Infantry Division, Korea. In 1992, LTG Phillips was assigned as Chief of Flight Operations, Defense Plant Representative Office (DPRO), Boeing Helicopters, Philadelphia. From July 1994 to June 1996, he commanded DPRO McDonnell Douglas, Huntington Beach. In June 1997, LTG Phillips was assigned as Director for Information Management for the Assistant Secretary of the Army (Research, Development and Acquisition) and managed the Army's Procurement Information Systems. He commanded Defense Contract Management San Francisco from September 1999 to June 2001. From July 2001 to August 2004, he served as Director, Unit Set Fielding and Acting Director of Integration for the Army G-8.

LTG Phillips holds a Bachelor of Science degree from Middle Tennessee State University, a Master of Science degree in Procurement and Materials Management from Webster University, and a Master of Personnel Management, Troy State University. He is a graduate of Command and General Staff College, Defense Systems Management College, and Industrial College of the Armed Forces.

His awards include the Defense Superior Service Medal, Legion of Merit (3 OLC), Bronze Star Medal, Defense Meritorious Service Medal (1 OLC), Army Meritorious Service Medal (2 OLC), Army Commendation Medal (2 OLC), Joint Service Achievement Medal, Iraq Campaign Medal, and Army Staff Identification Badge. In 2001, he was named the Army's Acquisition Commander of the Year.

LTG Phillips is a native of Bell Buckle, TN, and is married to the former Marilyn Hopkins of Shelbyville, TN.

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Panel 14 – Major Programs: The Good, the Bad, and the Ugly

Thursday, May 12, 2011	
9:30 a.m. – 11:00 a.m.	**Chair: Vice Admiral W. Mark Skinner,** USN, Principal Military Deputy, Assistant Secretary of the Navy (Research, Development, & Acquisition) ***An Assessment of the DoD's 2010 Portfolio of Major Defense Acquisition Programs*** Michael Sullivan, GAO ***Cost and Time Overruns for Major Defense Acquisition Programs: An Annotated Brief*** David Berteau, Guy Ben-Ari, Joachim Hofbauer, Gregory Sanders, Jesse Ellman, and David Morrow, Center for Strategic & International Studies ***Straight Talk: Major Program Manager Views of Defense Acquisition*** Roy Wood and Al Moseley, DAU

Vice Admiral W. Mark Skinner—Principal Military Deputy, Assistant Secretary of the Navy, (Research, Development & Acquisition). Vice Admiral Skinner assumed his duties August 9, 2010.

Skinner was born in Houston, Texas and graduated from the United States Naval Academy in June 1977.

As a flag officer, he was the program executive officer for Tactical Aircraft Programs and commanded Naval Air Warfare Center, Weapons Division, and served as assistant commander, Test and Evaluation, Naval Air Systems Command. Skinner held both operational and shore commands, to include commanding officer Patrol Squadron 47, chief test pilot and commanding officer of Naval Force Aircraft Test Squadron, and program manager for a chief of naval operations special project.

He is a graduate of the Navy Test Pilot School and served in Force Warfare Aircraft Test Directorate, where he was recognized as Directorate Test Pilot of the Year in 1986. Additionally, he received a degree in Financial Management from the Naval Postgraduate School, where he graduated as a Conrad Scholar and was awarded the Department of Navy award for excellence in financial management and the Rear Admiral Thomas R. McClellan award for excellence in administrative sciences.

His awards include Legion of Merit (3 awards), Meritorious Service Medal (4 awards), Navy Commendation Medal (2 awards), Navy Achievement Medal, and other unit deployment citations and ribbons.

An Assessment of the DoD's 2010 Portfolio of Major Defense Acquisition Programs

Michael Sullivan—Director, Acquisition and Sourcing Management, U.S. Government Accountability Office. This group has responsibility for examining the effectiveness of the DoD's acquisition and procurement practices in meeting its mission performance objectives and requirements. In addition to directing reviews of major weapon system acquisitions such as the Joint Strike Fighter, F-22, Global Hawk, and various other major weapon acquisition programs, Mr. Sullivan has developed and directs a body of work examining how the Department of Defense can apply best practices to the nation's largest and most technically advanced weapon systems acquisition system. This work has spanned a broad range of issues critical to the successful delivery of systems, including technology development, product development, transition to production, software development, program management, requirement-setting, cost estimating, and strategic portfolio management. Most recently, he has directed the GAO's annual assessment of major weapon systems programs for the Congress and GAO's work with Congress in establishing acquisition policy reforms. Mr. Sullivan has been with the GAO for 24 years. He received a bachelor's degree in political science from Indiana University and a master's degree in public administration from the School of Public and Environmental Affairs, Indiana University. [sullivanm@gao.gov]

Abstract

This presentation will include the GAO's observations on the performance of the DoD's 2010 portfolio of 98 major defense acquisition programs; data on selected factors that can affect program outcomes; an assessment of the knowledge attained by key junctures in the acquisition process for a subset of 40 programs, which were selected because they were in development or early production; and observations on the department's implementation of acquisition reforms.

Since 2008, the DoD's portfolio of major defense acquisition programs has grown from 96 to 98 programs, and its investment in those programs has grown to $1.68 trillion. The total acquisition cost of the programs in the DoD's 2010 portfolio has increased by $135 billion over the past two years, of which $70 billion cannot be attributed to quantity changes. The GAO observed that a small number of programs are driving most of this cost growth; however, half of the DoD's major defense acquisition programs do not meet cost performance goals agreed to by the DoD, the Office of Management and Budget, and the GAO. Further, 80% of programs have experienced an increase in unit costs from initial estimates, thereby reducing the DoD's buying power on these programs. The GAO continues to find that newer programs are demonstrating higher levels of knowledge at key decision points, but most are still not fully adhering to a knowledge-based acquisition approach, putting them at a higher risk for cost growth and schedule delays. For the programs that the GAO assessed in depth, the GAO found that a lack of technology maturity, changes to requirements, increases in the scope of software development, and a lack of focus on reliability were all characteristics of programs that exhibited poorer performance outcomes. Last year, the GAO reported that the DoD had begun to incorporate acquisition reforms that require programs to invest more time and resources at the beginning of the acquisition process, refining concepts through early systems engineering, and building prototypes before beginning system development. Many, but not all, planned acquisition programs are adopting these practices. As the GAO has previously recommended, more consistently applying a knowledge-based approach, as well as improving implementation of acquisition reforms, can help the DoD achieve better outcomes for its portfolio of major weapon system programs.

Cost and Time Overruns for Major Defense Acquisition Programs: An Annotated Brief

David Berteau—Senior Adviser and Director, CSIS Defense-Industrial Initiatives Group, covering defense management, programs, contracting, and acquisition. Mr. Berteau's group also assesses national security economics and the industrial base supporting defense. Mr. Berteau is an adjunct professor at Georgetown University, a member of the Defense Acquisition University Board of Visitors, a director of the Procurement Round Table, and a fellow of the National Academy of Public Administration. He also serves on the Secretary of the Army's Commission on Army Acquisition and Program Management in Expeditionary Operations. [DBerteau@csis.org]

Guy Ben-Ari—Deputy Director, Defense-Industrial Initiatives Group at the Center for Strategic International Studies. Mr. Ben-Ari works on projects related to the U.S. technology and industrial bases supporting defense. His current research efforts involve defense R&D policies, defense economics, and managing complex defense acquisition programs. Mr. Ben-Ari holds a bachelor's degree in political science from Tel Aviv University, a master's degree in international science and technology policy from the George Washington University, and is currently a PhD candidate (ABD) at the George Washington University.

Joachim Hofbauer—Fellow, Defense-Industrial Initiatives Group at the Center for Strategic and International Studies (CSIS). Mr. Hofbauer specializes in U.S. and European defense acquisition and industrial base issues and their impact on the transatlantic defense market. Before joining CSIS, he worked as a freelance defense analyst in Germany and the United Kingdom. His analysis has been published in several U.S. and German defense publications. Mr. Hofbauer holds a BA in European studies from the University of Passau and an MA with honors in security studies, with a concentration in defense analysis, from Georgetown University.

Gregory Sanders—Fellow, Defense-Industrial Initiatives Group at CSIS. Mr. Sanders gathers and analyzes data on U.S. defense acquisition and contract spending as international defense budgetary and trade trends. He has also studied data visualization and ways to use complex data collections to create succinct and innovative tables, charts, and maps. Mr. Sanders holds an MA in international relations from the University of Denver and a BA in government and politics, as well as a BS in computer science, from the University of Maryland.

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Abstract

Cost and time overruns in Major Defense Acquisition Programs (MDAPs) have become a high-profile problem attracting the interest of Congress, government, and watchdog groups. According to the GAO, the 98 MDAPs from FY2010 collectively ran $402 billion over budget and were an average of 22 months behind schedule since their first full estimate. President Obama's memorandum on government contracting of 4 March 2009 also highlighted this issue.

This paper presents findings of research on the root causes of cost and schedule delays for 92 MDAPs active in 2010 and 12 cancelled programs. The results do not establish causality but they do indicate multiple notable correlations. Inaccurate cost estimates are responsible for the strongest correlation with net cost growth changes and are associated with 40% of the accumulated cost overruns. In addition, the start year has little impact on the compound annual growth rate of cost overruns. This suggests that relatively better performance of newer programs may prove illusionary as programs age. Finally, fixed price contracts appear to have relatively smaller overruns, although this may tell us more about which programs are likely to receive fixed price contracts rather than what effect fixed price contracts may have on program performance.

Introduction

Cost and time overruns in Major Defense Acquisition Programs (MDAPs) have become a high-profile problem attracting the interest of Congress, government, and watchdog groups. According to the GAO, the 98 MDAPs from FY2010 collectively ran $402 billion over budget and were an average of 22 months behind schedule since their first full estimate. President Obama's memo on government contracting of 4 March 2009 also highlighted this issue.

This paper[1] presents findings of research on the root causes of cost and schedule delays for MDAPs, incorporating 2010 SAR data.

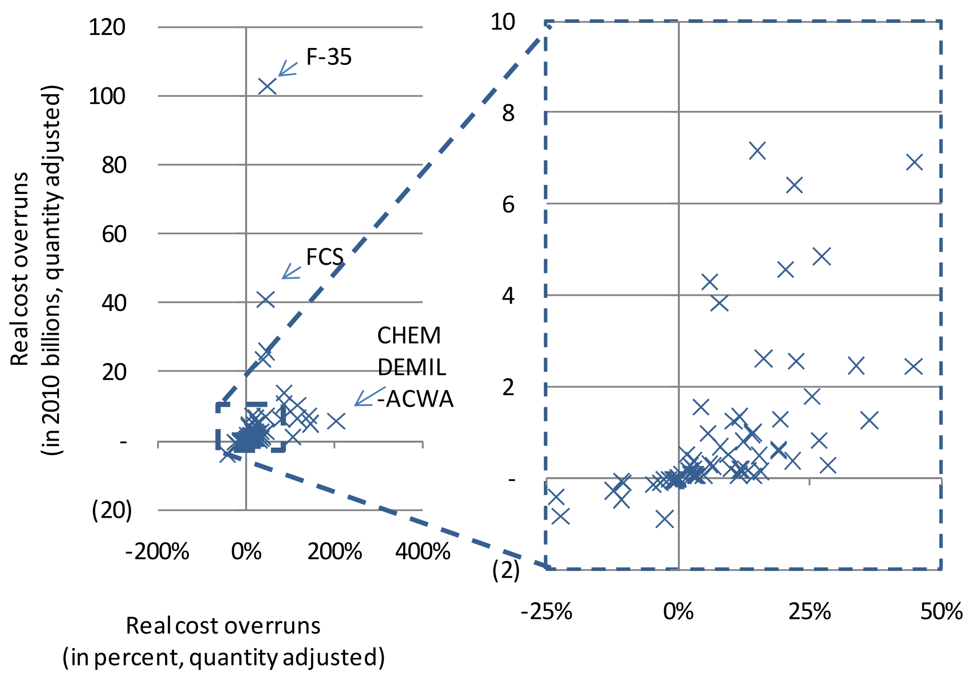

Figure 1. Relative Cost Overruns vs. Absolute Cost Overruns for FY2009 MDAPs

Note. The sample includes 92 FY2010 MDAPs with a baseline estimate beyond Milestone B in the June 2010 SAR as well as twelve additional cancelled programs, notably including the Future Combat System (FCS). The source for this figure was Selected Acquisition Reports; the analysis was by CSIS Defense-Industrial Initiatives Group.

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[1] Nicholas Lombardo was a contributing researcher on this report.

Problem Definition

Past studies on this topic either have not offered rigorous data analysis or were focused on a critical but still narrow aspect of the problem, such as technical maturity. Meanwhile, Congressional leadership often focuses on different issues such as contract type and competition. As a result, acquisition reform efforts like the Weapon Systems Acquisition Reform Act of 2009 are hampered by an insufficient analytical basis.

For instance, in its annual assessment of selected weapon systems, the Government Accountability Office (GAO) predominantly focuses on knowledge-based factors such as technology, maturity, and associated program decisions as causes for these problems. Former Under Secretary of Defense for Acquisition, Technology, and Logistics, John Young, claimed in a memorandum on 31 March 2009 that many of the allegations of the GAO are based on inadequate analytical methods and that consequently many of the results are misleading.

This disagreement is exemplary of the diverging set of opinions that exists regarding the root causes of MDAP cost overruns and schedule delays. The result amplifies disagreement regarding potential fixes. On the government side, Senator McCain identified the usage of cost plus contracts as a major source for cost increases and Secretary Gates pointed towards the contract structures as a key source of cost and schedule overruns in some MDAPs. Defense contractors, on the other hand, regularly cite the altering of requirements in advanced program stages as an important factor for cost increases.

The currently ongoing process of reforming and fixing the defense acquisition system still lacks the foundation of a detailed evaluation of the causality chain of cost overruns and program delays of MDAPs. This lack of understanding of underlying mechanisms makes the design of adequate solutions inherently difficult and renders them potentially ineffective. This study directly aims at developing the urgently needed knowledge base that will better guide efforts to correct the growing trends of cost increases and schedule overruns.

Methodology

This report analyzes a series of variables—namely realism of baseline program cost estimates, government management and oversight, the role of contractors and lead military Services, levels of competition, and contract structures—to determine what factors might contribute to or be correlated with the observed cost overruns in the execution of MDAPs.

This research draws on three primary data sources:

1. Selected Acquisition Reports (SARs): The SARs track Major Defense Acquisition Programs, reporting on their schedule, unit counts, total spending, and progress through milestones. The unit of analysis is the programs themselves, making it the ideal source for top level analysis.
2. Federal Procurement Data System (FPDS): The FPDS is a database of every government contract, with millions of entries each year. Each entry has extensive data on the contractors, contract type, competition, place of performance, and a variety of other topics as mandated by Congress. Cross-referencing individual contracts with MDAPs is possible using the system equipment codes (which match up with those of the MDAPs). This source provides the most in-depth data on the government contracting process.
3. Department of Defense budget documents: In addition to budget data, these documents provide topical information on each MDAP and its

subcomponents. They will primarily be used to categorize projects as well as to support and double check spending figures from the other two sources.

The report focuses on MDAPs from the FY2010 MDAP list. Within this sample group the analysis is limited to 104 MDAPs with cost estimates set at Milestone B or beyond, including MDAPs that were cancelled between 1999 and today. That gate is meant to be a hurdle that requires programs to reach a certain level of technological maturity. As a result Milestone B "is normally the initiation of an acquisition program" ("Acquisition History Project," n.d.). This common starting point ensures that only programs in a relatively mature acquisition phase are compared. Cancelled programs are included to avoid the selection bias that results from excluding several of the worst performing proposals from analysis. Figure 1 provides an overview of the cost overruns of these 104 programs.

Unfortunately, full data are not available on all 104 MDAPs when examining contract type and competition, because not all of the programs have at least 50% of the SARs contract value accounted for in 2004–2009 FPDS data. As a result, the "unclear" category is used to signify this missing data in competition and contract type findings. In addition, FPDS totals for program spending are sometimes higher than the funding status according to the SARs. In those cases, the SAR totals are treated as the more reliable figure.

These snapshots provide an adequate starting point for detecting correlations between a series of potentially relevant factors and cost growth. The charts reflect the basic information arranged across a variety of data elements, but they do not constitute a sufficient basis for establishing causality or policy changes, for which further analysis would be needed.

Analysis

This analysis focuses on examining the impact of baseline cost estimates, quantity, and schedule changes, as well as engineering problems, the extent of competition, contract structure, the lead branch of military service, and the identity of the prime contractor on the cost performance on MDAPs.

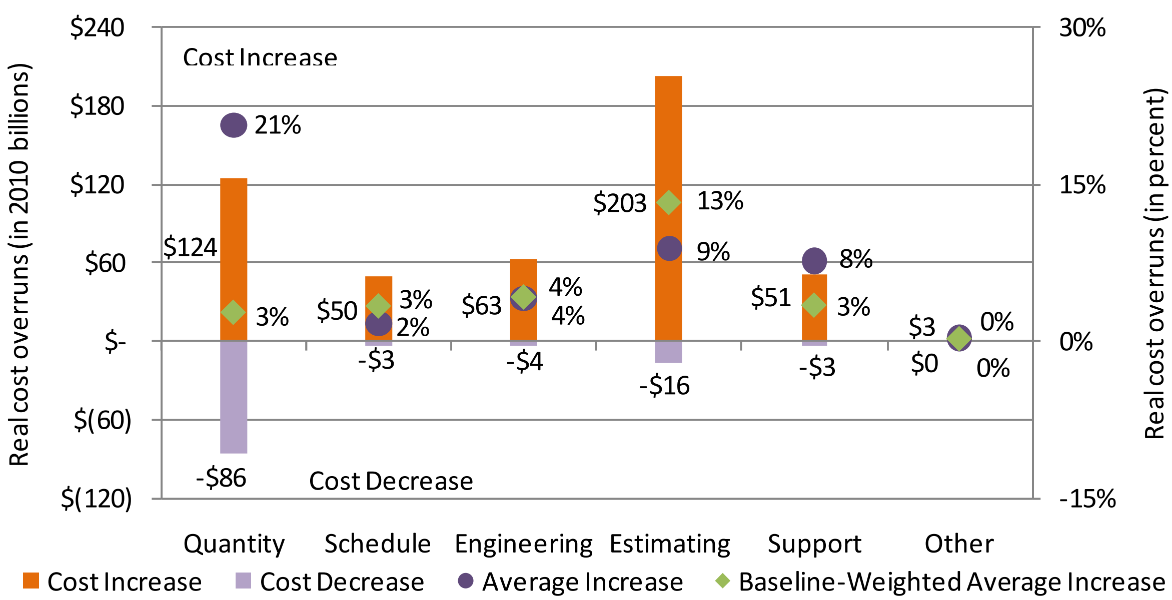

Figure 2. Functional Reasons for Cost Overruns

Note. The source for this figure was Selected Acquisition Reports; the analysis was by CSIS Defense-Industrial Initiatives Group.

Breaking down cost growth by functional areas as provided in the SARs identifies variances in the estimating process as the primary driver for cost growth, being responsible for $202.8 billion in cost growth for the 104 MDAPs analyzed.

Another noteworthy observation from Figure 2 is the fact that the cost savings achieved through quantity changes equals approximately two thirds of the cost growth originating from changes in unit numbers. This is not encouraging, as for programs with upfront research and development costs, reducing the number of units lowers the overall program cost but it increases the per-unit cost, effectively curtailing the government's buying power. In turn, cost increases deriving from increases in the number of units require a higher overall program budget but lower the price per unit.

Nunn-McCurdy breaches, for instance, are based on the growth in the per-unit acquisition cost rather than overall program cost in order to account for this fact. This presentation therefore focuses on quantity-adjusted cost changes. The Selected Acquisition Reports do not list the exact methodology for quantity adjustments; unfortunately, the adjustment is not equivalent to the sum of cost adjustments that are not attributed to quantity changes. This complicates analysis of the functional reasons for cost growth.

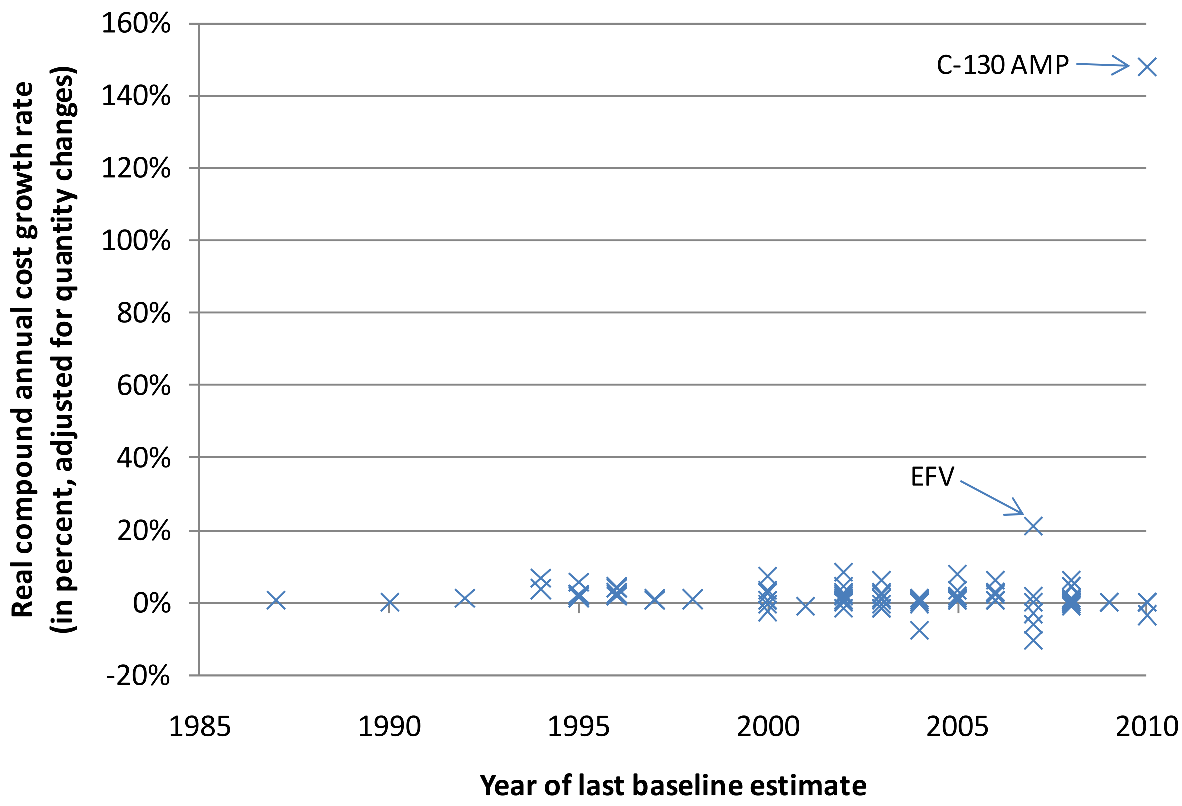

Figure 3. Time-Cost Correlation

Note. The source for this figure was Selected Acquisition Reports; the analysis was by CSIS Defense-Industrial Initiatives Group.

The next explanatory variable examined for its impact on program performance is the time-cost growth correlation. If cost increases accrue over time, then programs with an older baseline estimate would tend to accumulate relatively higher cost increases. The data for the analyzed programs show that older programs indeed experience larger overruns.

However, Figure 3 shows that when measured in compound annual growth rate[2] rather than aggregate relative cost growth, the time-cost growth correlation is almost constant. The C-130 AMP project is distorting this trend because its estimate was not changed when it was given a new baseline in 2010. Notwithstanding C-130 AMP, this growth correlation not only provides further evidence for the assertion that cost growth occurs steadily throughout the program lifespan, but it also suggests that younger programs are not performing better than older programs.

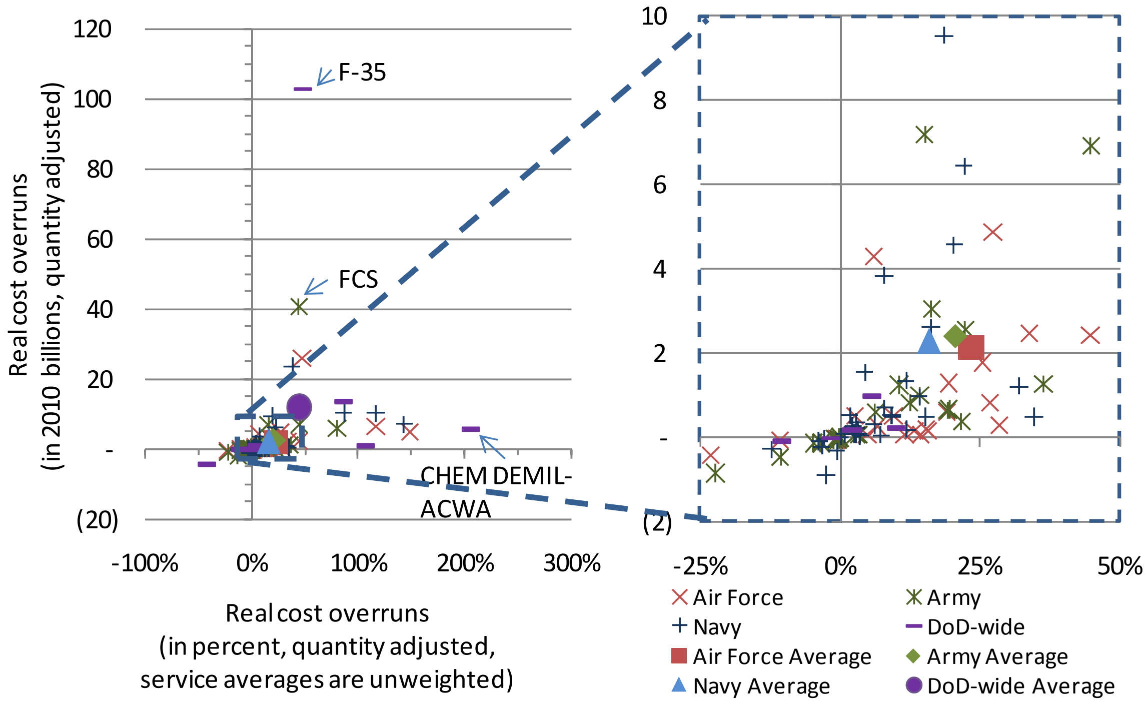

Figure 4. Cost Overruns by Lead Service (I)

Note. The source for this figure was Selected Acquisition Reports; the analysis was by CSIS Defense-Industrial Initiatives Group.

The analysis of the correlation between the lead branch of military service responsible for MDAPs and cost growth patterns reveals that programs led by the Army appear to have fewer, smaller overruns, followed by the Navy and then the Air Force, whereas DoD-wide programs tend to accrue significantly larger cost overruns. The picture alters slightly when utilizing baseline-weighted averages with the Navy showing the least overruns followed by the Army, the Air Force, and DoD-wide programs. The considerable difference for the Army's results—11% on average versus 20% for baseline-weighted averages—is driven by the cancelled Future Combat System. It is important to note that DoD-wide includes both programs managed by DoD agencies and joint programs such as the Joint Strike Fighter.

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[2] The compound annual growth rate describes the average year-to-year cost growth of program spending since its baseline. Thus if comparing two programs with the same percentage of cost growth since their baseline estimate, the program with an earlier baseline year would have a smaller compound annual growth rate.

The outcome of this data analysis might be skewed based on the relatively small sample group utilized in this analysis. For instance, it appears that the DoD-wide category might be heavily influenced by the negative cost developments in the Joint Strike Fighter program. As for the other components, further analyses with larger sample groups are required to validate observed trends.

Any conclusions from Figure 4 identifying superior program management of existing programs by Service are premature, even if additional data and analysis were to confirm this variation in cost performance based on lead Service. A number of other factors may explain the differences, such as a tendency toward less risk-prone MDAPs. Further research will be needed to analyze the underlying causality and detect the true root causes for these trends.

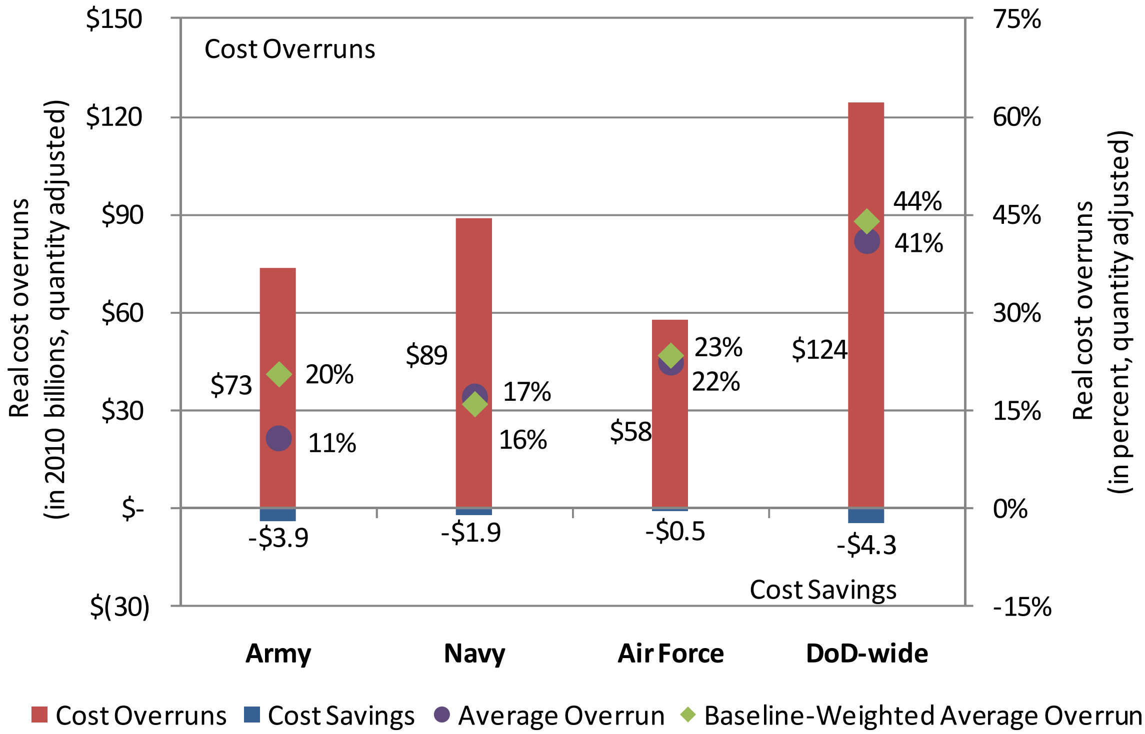

Figure 5. Cost Overruns by Lead Service (II)

Note. The source for this figure was Selected Acquisition Reports; the analysis was by CSIS Defense-Industrial Initiatives Group.

Figure 5 supports the conclusion of the previous chart, with the poorest cost performance in DoD-wide managed MDAPs, while Army and Navy MDAPs, depending on what kind of average is utilized, display the smallest cost overruns. In absolute terms, the Air Force shows the lowest total in real cost overruns. Notably, while the Navy performs relatively well on a percentage basis, it also has the largest share of overruns in absolute terms for any of the three Service branches. This can be attributed to the size and duration of many Navy programs.

This comparison provides further support for the assertion that MDAPs managed by the Army and the Navy suffer smaller overruns, while DoD-wide managed MDAPs tend to accrue larger overruns. However, the level of analysis conducted so far does not allow for any firm conclusions on the actual role of any Service's program management skills in these trends.

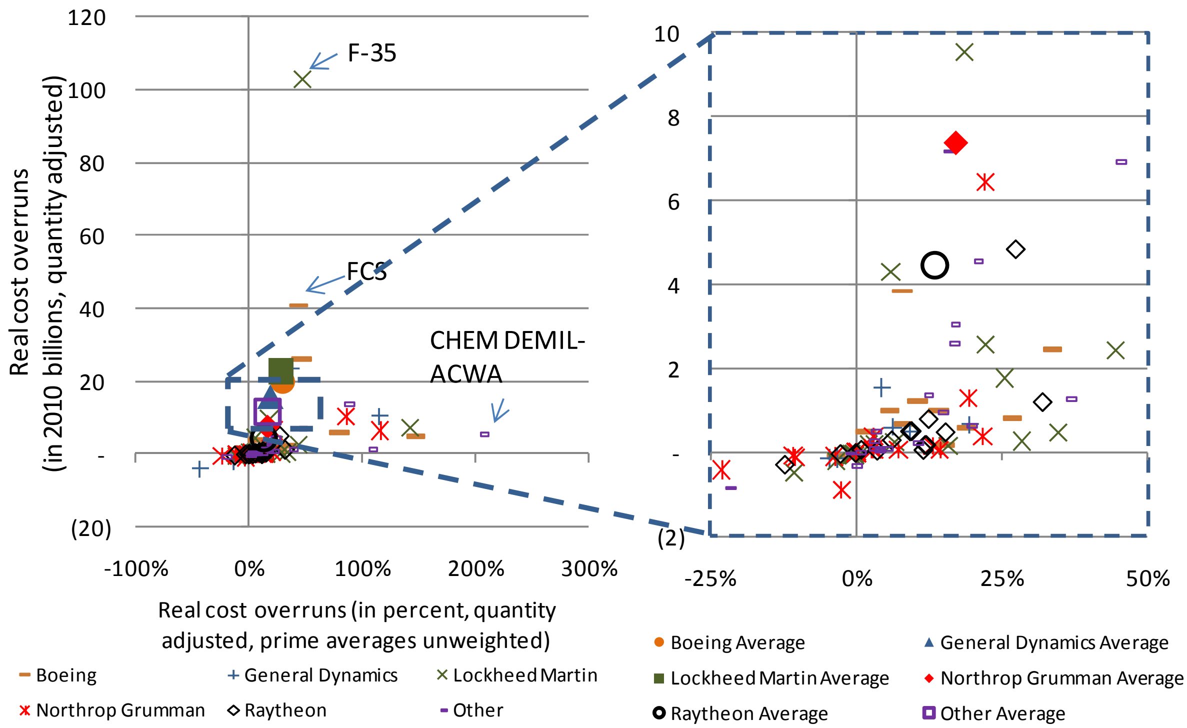

Figure 6. Cost Overruns by Prime Contractor (I)

Note. The source for this figure was Selected Acquisition Reports; the analysis was by CSIS Defense-Industrial Initiatives Group.

Another predictor for program performance could be the identity of the prime contractor for a given program. One striking trend in Figure 6 that is visible for the "big five" U.S. defense companies is the fact that Raytheon on average appears to be associated with significantly better cost performance outcomes than other defense companies. Due to a lack of data granularity, the other companies category includes joint ventures and projects that are split between multiple contractors.

The preliminary character of the analysis does not fully validate any findings of superior management or outcomes. In addition, even if confirmed, it would be premature to start praising any company for better program execution because other factors such as specialization in technologically more mature program areas might be the true drivers behind this trend. As was the case for the breakdown by lead Service, further research will be needed to analyze the underlying causality.

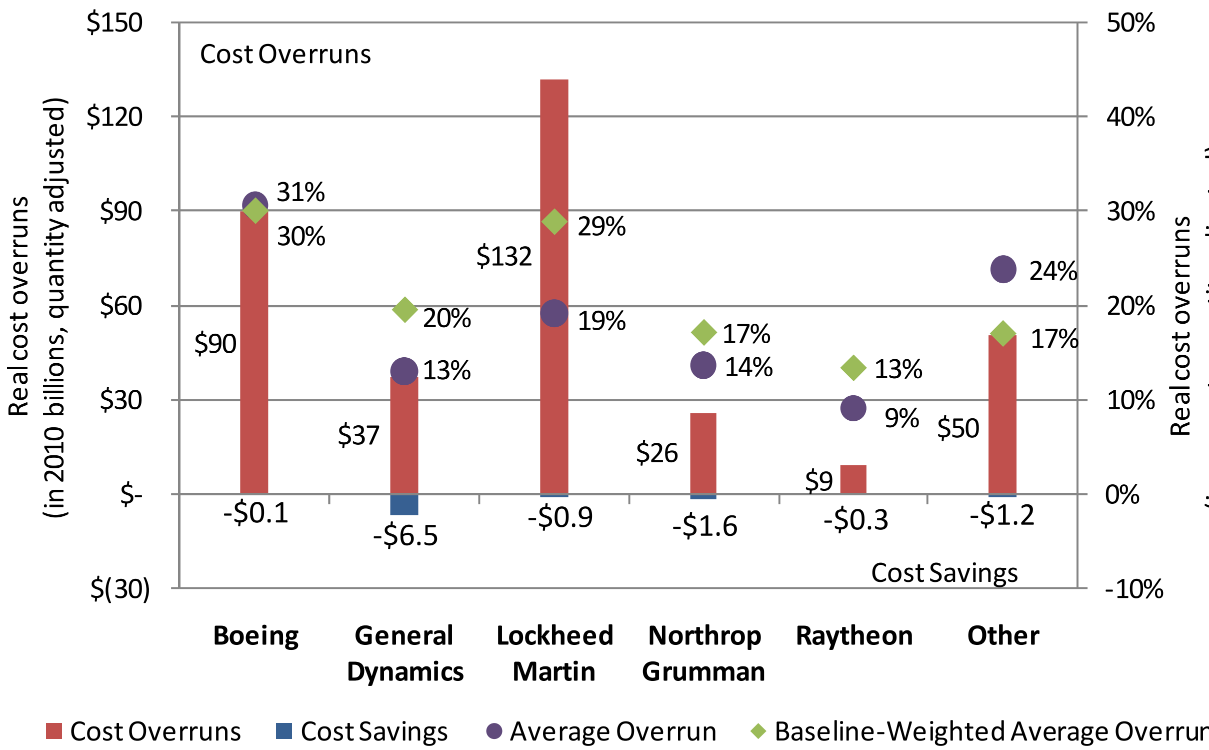

Figure 7. Cost Overruns by Prime Contractor (II)
Note. The source for this figure was Selected Acquisition Reports; the analysis was by CSIS Defense-Industrial Initiatives Group.

The comparison between the share of cost growth and the share of contract value for MDAPs, aggregated by prime contractor, correlates with the finding that MDAPs for which Raytheon is the prime contractor appear to exhibit the best cost performance amongst the big five defense companies. When it comes to the remainder of the big five, Figure 7 shows that their average performance varies based on the means used to measure it with different results when the programs are weighted by the baseline estimate than if all of the MDAPs are treated as having an equal weight. Again, this variance gives reason to be cautious in extrapolating from these results.

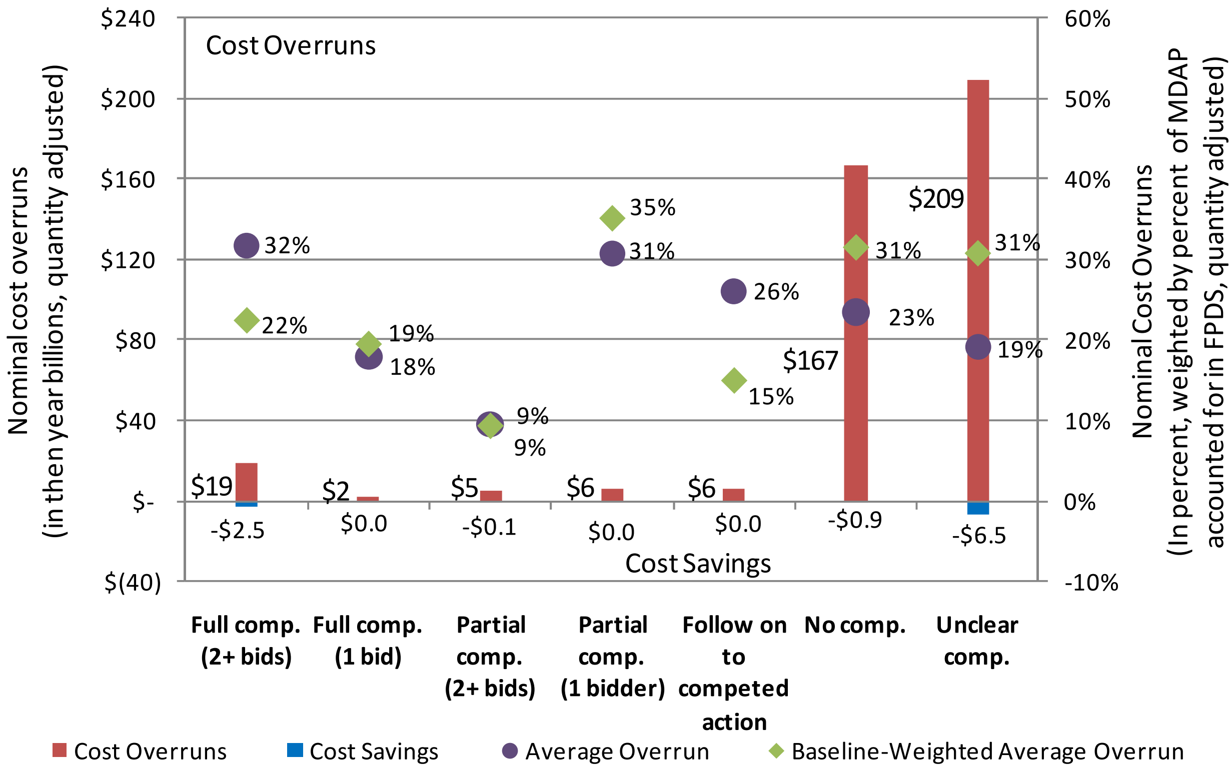

Figure 8. Cost Overruns by Type of Competition

Note. The source for this figure was Selected Acquisition Reports; the analysis was by CSIS Defense-Industrial Initiatives Group.

The type of contract award process could potentially also be correlated with the cost performance of MDAPs. The findings in Figure 8 are decidedly mixed. In absolute dollar terms, competitive contracts produce less cost growth than contracts awarded with no competition or under unclear circumstances. This is driven by the comparative scarcity of competed contract dollars in the sample. As a result, when comparing relative cost overrun rates the results are different. Only partial competition[3] with multiple bidders displays a notably better outcome.

Perhaps surprisingly, full and open competition with multiple bidders performs on average worse than no or unclear competition. Only when considering baseline-weighted averages does full and open competition with multiple bidders perform better than no or unclear competition. Based on the SAR's data, this can be attributed to full and open competition with multiple bidders having the highest percentage of estimating variance of any of the categories. This result is consistent with the hypothesis that bidders may propose lower costs in order to win price-based competitions. However, further study would be needed to determine whether full and open competitions also suffer from a selection bias or other unexplained cause.

[3] Partial competition refers to forms of competition other than full and open because the number of bidders is legally limited.

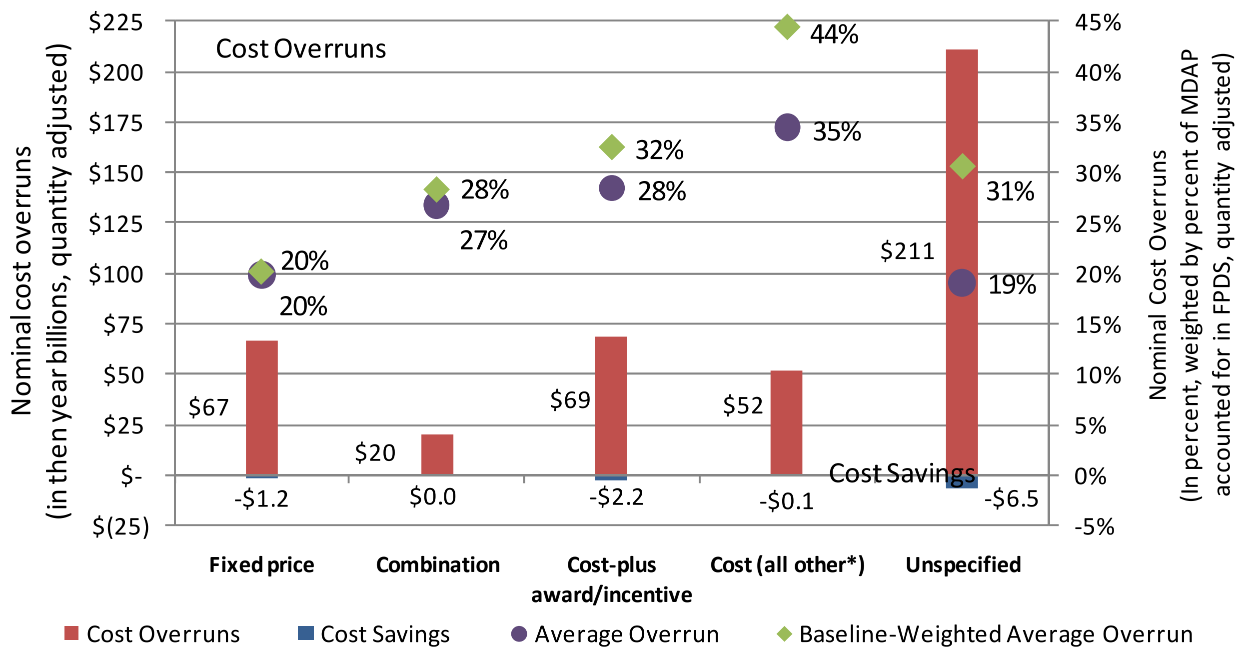

Figure 9. Cost Overruns by Contract Type

Note. *Cost (all other) includes time and materials contracts as well as labor hours contracts. The source for this figure was Selected Acquisition Reports; the analysis was by CSIS Defense-Industrial Initiatives Group.

Contract structure provides another possible determining factor for the performance of MDAPs. One key observation from Figure 9 is that fixed price contracts appear to have on average less cost growth and the cost all other contract types appear to have more, when comparing the share of cost growth and the share of contract value for MDAPs. An interesting finding is the fact that unspecified contract types, while responsible for the majority of cost overruns in absolute terms, perform best when measured based on baseline-weighted averages.

Acquisition reformers often point toward cost-plus contracts as a factor driving cost overruns. This argument is supported by the high average cost overrun percentages of both categories of cost plus contracts. The type of fee structure used also appears relevant, because cost-plus award/incentive contracts have lower relative cost growth than all other forms of cost reimbursement contracting although this is driven in part by the outsized influence of the F-35 project which falls within the cost (all other) category. However, fixed price contracts are more commonly the vehicle of choice for mature technology in full rate production, which are generally considered low risk.

Findings

This report provides a foundation for future researchers and reformers grappling with the problem of cost overruns in major defense acquisition projects. The results discussed below have been validated by the two most recent Selected Acquisition Reports, and together with the underlying data and methodology provide a roadmap for future work.

The strongest correlation with net cost growth is shown in Figure 2: changes in cost estimates are responsible for around 40% of the accumulated cost overruns. Of similar importance, Figure 3 shows that the start year has little impact on the compound annual growth rate of cost overruns. This suggests that the relatively better performance of newer programs may prove illusionary as programs age. Finally, Figure 9 shows that fixed price contracts appear to have relatively smaller overruns, although this may tell us more about which programs are likely to receive fixed price contracts rather than what effect fixed price contracts may have on program performance.

There are three logical avenues for future research to build on these results. First, additional factors could be added to the mix to help allocate responsibility to the underlying characteristics of an MDAP versus the methods chosen to implement it. Second, the dataset could be steadily expanded to include completed projects and to widen the historical scope and sample size of the project. Third, researchers could examine cost growth throughout the history of a select number of programs and also better control for the effects of updated baselines on older projects. Finally, the government could facilitate all three approaches and enable a range of assessments by allowing outside researchers to access the data that underlies the Selected Acquisition Reports.

Reformers and others studying this issue can take the next step by accessing the data, which will be posted at the Defense-Industrial Initiatives Group website (http://www.csis.org/diig) in time for the May 2011 Naval Postgraduate School conference. The authors intend to stay fully engaged with this issue as the root causes underlying the crisis in MDAP cost growth are being identified and addressed.

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Straight Talk: Major Program Manager Views of Defense Acquisition

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Abstract

Current efforts by the Office of the Secretary of Defense (OSD) and the Under Secretary of Defense for Acquisition, Technology, and Logistics (USD[AT&L]) to improve acquisition outcomes are focused on addressing perceived problems that create inefficiencies in major programs. Program Manager (PM) Forums were established by senior acquisition leaders within OSD to hear directly from a sampling of major PMs to help key OSD leaders understand PM perspectives and issues. This study analyzes the results from six PM Forums attended by 148 major PMs between November 2007 and November 2010, and it provides a synthesis and presentation of current programmatic issues and trends.

Introduction

The Department of Defense (DoD) plans to spend about $189 billion for its acquisition programs in fiscal year 2011 and increase its investment in procurement during that period by nearly 8%, from $105 billion to $113 billion (Congressional Research Service, 2010). Although the DoD's submarines, destroyers, combat ships, carriers, fighter aircraft, missiles, and helicopters are widely regarded as unrivaled in superiority, for decades, many of the DoD's weapon systems acquisitions have experienced—and continue to experience—schedule delays and cost overruns (GAO, 2006). These overruns not only cost taxpayers, but they have also undermined the warfighting capabilities of U.S. military forces. The individuals responsible and accountable for the health of weapon systems acquisitions are the program managers.

The nation depends on program managers to be able to effectively and efficiently run major, complex weapon systems acquisitions. Yet, today's program managers face unprecedented challenges. Wartime threats are asymmetrical and evolve quickly. Weapon systems are increasingly sophisticated, networked, and interdependent. Development cycles that need to be faster are often slowed by legitimate changes in warfighting requirements, extensive oversight, and ever more complicated laws, regulations, and business practices.

In November 2007, OSD acquisition leaders established PM Forums to help them better understand the most pressing issues PMs believe they are facing. Since then, there have been six PM Forums, attended by a total of 148 major program managers. This paper analyzes the results of those six PM Forums and provides a synthesis and presentation of programmatic issues and trends as viewed by the program managers at the tip of the execution spear.

Literature Review

The Role of the Program Manager

A program manager (PM) is the "designated individual with responsibility for and authority to accomplish program objectives for development, production, and sustainment to meet the user's operational needs" (DAU, 2009, p. 15). Accountable to the DoD's Milestone Decision Authority (MDA), the specific role of the PM is as follows:

> To direct the development, production, and initial deployment (as a minimum) of a new defense system. This must be done within limits of cost, schedule, and performance, as approved by the PM's acquisition executive. The PM's role, then, is to be the agent of the military service or Defense agency in the defense acquisition system to ensure the warfighter's modernization requirements are met efficiently and effectively in the shortest possible time. (DAU, 2009, p. 15)

For management purposes, all defense acquisition systems fall into one of three Acquisition Categories, or ACAT levels:

- Acquisition Category I, or Major Defense Acquisition Program (MDAP): a program with a designated value of more than $365 million in research, development, test, and evaluation expenditures or more than $2.19 billion in procurement expenditures.
- Acquisition Category II: a program with a designated value of more than $140 million in research, development, test, and evaluation expenditures or more than $660 million in procurement expenditures.
- Acquisition Category III: a program that does not meet either Acquisition Category I or II criteria. (DAU, 2009, p. 20)

DoD policy requires that a PM be designated for each acquisition program. The PM for the most complex ACAT I programs are typically military officers at the grade of O-6 or senior civilians at the GS-15 level. In 2009, there were 102 Acquisition Category I programs in the unclassified domain (Carter, 2009). ACAT I PMs are confronted with the dynamic challenge to deliver the most complex and expensive systems on time and under budget with superior warfighting performance.

Challenges in Defense Acquisition

In 1985, the Packard Commission was charged by President Ronald Reagan to conduct a comprehensive defense management study of the budgeting process, procurement system, legislative oversight, and organizational and operational arrangements among Congress, the Office of the Secretary of Defense (OSD), the Joint Chiefs of Staff (JCS), the Military Departments, and the regional commanders (A Formula for Action, 1986). The commission report concluded that there were fundamental and systemic problems within the defense acquisition system creating major undesired consequences. It reported the following:

> These problems are deeply entrenched and have developed over several decades from an increasingly bureaucratic and overregulated process. As a result, all too many of our weapon systems cost too much, take too long to

> develop, and, by the time they are fielded, incorporate obsolete technology. (A Formula for Action, 1986, p. 5)

Given the complicated management environment involving many stakeholders as well as internal and external pressures on the DoD, the commission report also concluded that PMs spent the majority of their time briefing and reporting on their programs, rather than managing them. The report stated,

> In effect, [the PM] is reduced to being a supplicant for, rather than a manager of, his program. The resulting huckster psychology does not condition the program manager to search for possible inconsistencies between performance and schedule, on the one hand, and authorized funding, on the other. Predictably, there is a high incidence of cost overruns on major weapon systems programs. (A Formula for Action, 1986, p. 5)

Twenty-five years later, with few systemic improvements to the underlying system, PMs are still faced with the dual challenges of managing both an extremely complex program and a bloated and bureaucratic acquisition system in search of the sweet spot among performance, schedule, and authorized funding. Some of the obstacles identified by the Packard Commission were reiterated in a later study: the 2006 Defense Acquisition Performance Assessment, or DAPA study. These include the following:

Unstable Acquisition System

A major PM challenge is operating in an unstable acquisition system. The 2006 DAPA report refers to this as government-induced instability. It is a cycle unto itself: unpredictable program cost, schedule, and performance beget leadership that loses confidence in the acquisition system, which begets more intervention and oversight, which begets adjustments in budget and schedule requirements. This cycle can begin with requirements developers who specify system performance that is well beyond what the technological state-of-the-art can deliver in the needed timeframe. Acquisition teams can also create undisciplined and escalating derived requirements, which in turn drive costs beyond the program's baseline. Comptrollers are often asked to "fix" a broken portfolio of programs, unilaterally adjusting program budgets and creating additional "churn" in planning and execution. These behaviors significantly add cost and lengthen development and production cycles (Kadish, 2006).

Requirements and Resources Gaps

Another major PM challenge is gaps between requirements and resources that are often not closed before or during program development. It is no secret that the DoD starts more acquisition programs than it can ultimately afford, creating an environment in which PMs must continually compete for funding. Winners proceed on plan, but losers must restructure their programs on the fly to continue to execute within the reduced funding. Stretching program schedules, reducing numbers or capabilities of systems, or reducing testing are all favorite ways to do this but have serious downstream impacts to costs, deliveries, and capabilities. It should also come as no surprise that DoD programs often proceed past milestones with immature technologies. Perverse incentives exist in the system to reward a program that proceeds without really knowing whether its technologies will work as intended. Once programs are started and have the initial commitment of funding, stakeholder advocates will continue to support the programs because their continuation benefits communities, constituents, and contractors (GAO, 2005).

Little Control Over Funding

Another major PM challenge is little control over funding. In other words, PMs cannot count on stable funding. When funding cuts happen, and they often do, PMs spend hours addressing funding-related problems to their senior acquisition leaders regarding impacts from these cuts that often translate to commitment challenges to contractors (GAO, 2005). Part of the problem is that in reality and practice, the budget, requirements, and acquisition system operate independently of each other rather than being efficiently integrated. In simplistic terms, the values of each are often misaligned with each other, as noted in the following:

- The…acquisition process values *how* to buy, striving to balance cost, schedule, and performance.
- The requirements process values the *why* and *what* to buy, focusing on obtaining the ability to achieve mission success at the lowest cost in lives.
- The budget process values *how much* and *when* to buy and focuses on control and oversight to balance the instability that advocacy creates. (Kadish, 2006, p. 4)

Indeed, many acquisition reform studies and initiatives have occurred alongside the Packard Commission and DAPA studies to address these and other acquisition issues.

More Acquisition Reform

The Weapon Systems Acquisition Reform Act (WSARA) of 2009 was passed by the 111th Congress on May 22, 2009. It made several changes to the acquisition process for acquiring Major Defense Acquisition Programs (MDAP) and Major Automated Information Systems (MAIS). Key provisions of the law include appointments of a Director of Systems Engineering, a Director of Cost Assessment and Program Evaluation (CAPE), and a Director of Developmental Test and Evaluation. It gave combatant commanders more influence in the requirements process, made changes to the Nunn–McCurdy Act pertaining to critical cost growth, and revised DoD conflict-of-interests guidelines for MDAP contractors (Weapon Systems Acquisition Reform Act of 2009, 2009).

An even more recent congressional acquisition reform initiative is the Implementing Management for Performance and Related Reforms to Obtain Value in Every (IMPROVE) Acquisition Act of 2010. While WSARA aimed to reform weapons system acquisitions, the IMPROVE bill's primary emphasis is on adding value in the acquisition of services and information technology programs. The act focuses on four specific areas: the defense acquisition system, the defense acquisition workforce, financial management, and the industrial base (Implementing Management for Performance and Related Reforms to Obtain Value in Every Acquisition [IMPROVE] Act, 2010).

Given the intense scrutiny and extensive acquisition reform initiatives over the years, why are there still problems and challenges for major PMs today? This study of PM Forums sought to hear directly from a sampling of major PMs and thereby gain a better understanding of the PMs' perspectives on the issues they face every day. A description of the methodology of this study follows.

Methodology

Sample

The target of this study was a group of invited PMs of ACAT I and II programs who attended the PM Forums from November 2007 to November 2010. This exclusive group of 148 senior (most were O-6 or GS-15 equivalent) program managers represented significant acquisition experience and provided a glimpse into their lived experiences on the front lines of the acquisition process.

PM Forum History

In February 2007, the Deputy Under Secretary of Defense for Acquisition and Technology (DUSD[A&T]) initiated the idea of a forum in collaboration with ACAT I PMs attending the executive PM course at the DAU. A central tenet of the forum would be "straight talk" directly from major PMs without the filters of Program Executive Officers and Service Acquisition Executives. This would allow PMs to convey, in a non-attribution environment, their unvarnished opinions of what was going well—and not so well—in the acquisition process and to seek OSD guidance and even resolution on tough programmatic issues.

In a memo dated September 26, 2007, the USD(AT&L) created the first PM Forum to be held in conjunction with the annual Program Executive Officer/Systems Command Commander's Conference in November 2007. Subsequent two-day forums have been held semi-annually, sponsored by the USD(AT&L) and hosted by the DAU at Fort Belvoir, VA.

Data Collection

Data have been collected from 148 PMs who attended the six PM Forums from November 2007 to November 2010. These PMs represented 12 defense acquisition agencies (see Table 1).

Table 1. Number of PMs Attending Forum by Acquisition Defense Agency
(Moseley, 2010)

Acquisition Agencies	Nov 2007	Apr 2008	Nov 2008	May 2009	Nov 2009	Nov 2010
BTA	1	2	0	2	0	0
DISA	3	4	3	3	1	2
DLA	0	0	2	0	0	0
MDA	2	3	2	2	1	0
NGA	1	1	0	1	1	1
NSA	0	1	0	0	2	1
USAF	8	6	3	5	4	3
USA	9	3	7	3	4	6
USN	5	4	5	4	5	6
USMC	1	1	1	1	1	2
USSOCOM	2	0	3	1	1	0
USTRANSCOM	0	0	2	0	0	0
Total	32	25	28	22	20	21

Services and agencies nominated approximately 30 major PMs to attend each forum. PMs were asked to be prepared to discuss their top three programmatic issues. The group is kept to a manageable number so that PMs can shape the forum dialogue with OSD senior acquisition leaders. Forum rules value open, two-way communication and interactive discussions with a focus toward action-oriented outcomes.

Formulation of major PM issues was facilitated using a proven software tool called ThinkTank by GroupSystems. ThinkTank is a team collaboration tool used for innovation, decision-making, and leadership to enhance the performance of leaders in business, government, and professional services. Besides the DoD, the tool has been used by NASA, IBM, Proctor and Gamble, PricewaterhouseCoopers, and many others (GroupSystems, 2010). Utilizing a trained DAU facilitator, the software tool focuses on extracting the PMs' top programmatic issues through the process defined in Figure 1.

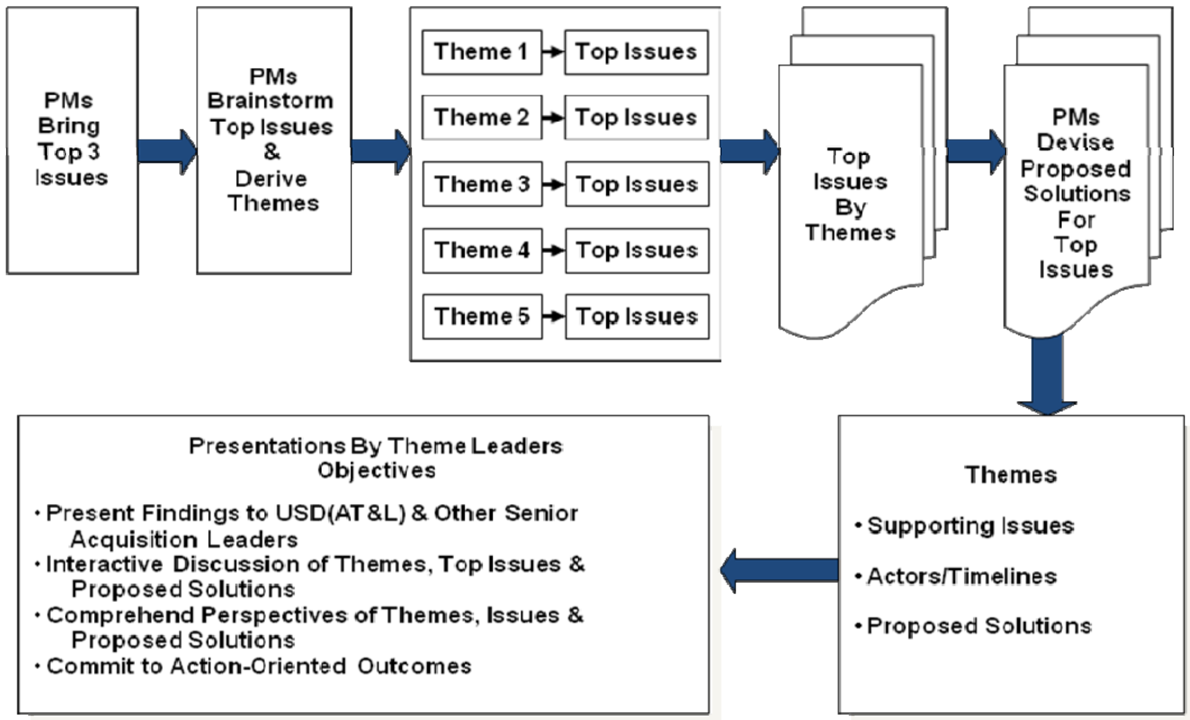

Figure 1. Formulation of Program Manager Top Issues and Proposed Solutions
(Moseley, 2010)

During the sessions, the PMs enter their top three programmatic issues into ThinkTank and then brainstorm their entries into a set of common themes that emerge from the team discussions.

After the themes had been agreed upon, the PMs are divided into small teams. Each team selects a theme and a team leader, then builds a list of recommended solutions to the problems that have been identified within their theme. They create a presentation and present their findings to the larger group and the OSD officials. Each team's presentations include supporting issues, the actors required to assist in resolving the issues, the timeline for issue resolution, and the team's proposed solution set. During each presentation, the PMs engage in "straight talk" with the OSD senior acquisition leaders, who have shown a keen interest in understanding the PMs' perspectives and then have committed to actions based on the PM recommendations.

Results and Discussion

PM Straight Talk

Table 2 reports the summary of the major themes from the six PM Forums.

Table 2. Summary of Major Themes From Six PM Forums
(Moseley, 2010)

8 Nov 2007 32 PMs	3 Apr 2008 25 PMs	6 Nov 2008 28 PMs	28 May 2009 22 PMs	5 Nov 2009 20 PMs	4 Nov 2010 21 PMs
OSD Policy & Staff	Funding Stability	Qualified/ Experienced Acquisition Workforce	IT Acquisition & Implementation	Manpower Skills & Knowledge Shortage	Requirements/ Testing
Requirements	People, Staffing & Skills	Funding & Contracting	Oversight & Excessive Documentation	Funding Instability & Minimal Reprogramming Authority (Reduces PM Flexibility & Mgt Control & Causes Frequent Program Restructures)	IT & Software-Intensive Systems
Program Management Resources	Speed of Acquisition	Controlling Requirements	Policy	Requirements Instability, Growth & Inadequate Definition Drive Cost & Schedule Execution Issues	Contracting: Process—Management—Procurement Timeline
Resources—Personnel	Integration, Interoperability & Interdependency	Inconsistent Policy & Oversight	Staffing & Personnel	Policy Unclear, Inconsistent, & Burdensome	Funding Flexibility & Workforce Experience
Lack of End-to-End System of Systems Engineering Process	Industrial Base		Requirements & Funding	Focus of OSD Staff Misplaced	Leadership Intent: Disconnected Implementation
Testing	Oversight/ Governance			Issues with Contracting & Industrial Base	
Industry	Requirements				

PMs captured major issues within each theme as supporting issues. For the supporting issues, PMs identified key stakeholders/actors that should help address or resolve the issues, and a set of proposed solutions for each issue. Since the supporting issues derived from the major themes were too numerous to report in this paper, only a sampling of the major themes, subsequent supporting issues, and proposed solutions from only one of the many themes for each forum are presented.

PM Forum #1. Thirty-two PMs attended the November 2007 forum and reported the following major themes:

- *Program Management Resources*,
- OSD Policy and Staff,
- Requirements,
- Resources—Personnel,
- Lack of End-To-End System of Systems Engineering Process,
- Testing, and
- Industry.

Of the seven major themes, supporting issues and proposed solutions are provided for the major theme *Program Management Resources*. PMs were adamant that funding instability was affecting baseline management; there were "unfunded mandates" consisting of Unique Identification, Information Assurance, Net-Ready Key Performance Parameters, Selective Availability Anti-Spoofing Module/Global Air Traffic Management, and Mode 5/S Compliance; supplemental funding was driving the PMs to a higher ACAT oversight; and there was a lack of Service commitment for Joint programs. Table 3 shows the PMs' supporting issues and proposed solutions for major theme *Program Management Resources*.

Table 3. PMs' Supporting Issues & Proposed Solutions for *Program Management Resources*
(Moseley, 2010)

Supporting Issues	Proposed Solutions
Funding Instability Affecting Baseline	▪ Permit multi-year procurement authority ▪ Support for baseline adjustments caused by external stakeholders ▪ Permit capital funding
Unfunded Mandates	▪ Any policy issued must have funding to implement ▪ Communicate required funding impact review with Services
Supplemental Funding	▪ Industrial Base is not always able to execute the funding ▪ Waive ACAT I program documentation and requirements for ACAT II programs
Joint Program Lack of Service Commitment	▪ Properly adjust Service TOA when Agency program is transitioned after development. E.g., DARPA projects transitioned to Joint Agency or Service adversely effects TOA

PMs proposed eight solutions. For example, to address the issues of funding instability affecting baselines and unfunded mandates, PMs advocated for multi-year procurement authority, the support for baseline adjustments caused by external stakeholders, the permission for capital funding, funding support for any policies issued, and the need to communicate funding impacts through reviews with the Services.

PM Forum #2. The following major themes were documented by 25 PMs who attended the April 2008 forum:

- *Funding Instability*;
- People, Staffing, and Skills;
- Speed of Acquisition;
- Integration, Interoperability, & Interdependency;

- Industrial Base;
- Oversight/Governance; and
- Requirements.

The major theme *Funding Instability* was selected to provide the supporting issues and proposed solutions. In this forum, PMs pointed out that funding cuts were forced and unpredictable, that there was a lack of flexibility to plan a resilient program, that the DoD did not use the most probable cost for program baselines, and the DoD subscribed to a current-year focus rather than an overall life cycle cost focus. Table 4 shows the PMs' supporting issues and proposed solutions derived from the major theme *Funding Instability*.

Table 4. PMs' Supporting Issues & Proposed Solutions for *Funding Instability*
(Moseley, 2010)

Supporting Issues	Proposed Solutions
Forced & Unpredictable Cuts	▪ First answer should be no - second answer should be yes only with data driven/risk based APB/EMA revisions—this should be implemented by Component Acquisition Executives (CAE) ▪ Require fully funded increments—this should be an OSD policy that is implemented by the CAE
Lack of Flexibility to Plan Resilient Program	▪ OSD & CAEs should advocate for the Economic Order Quantity policy to Congress (lot size, multi-year, value based)
Not Using Most Probable Cost for Program Baseline	▪ Budget to 80% confidence level (Policy OSD, Industry/C/S Implementation) ▪ Allow visible government management reserve—this should be an OSD policy implemented by Industry & CAEs
Current-Year Focus verses Overall Life Cycle Cost Focus	▪ Create ROI account or Weapons Capital Fund ▪ Payback to the account the fund required ▪ Share saving with the contractor, program office—this should be an OSD policy implemented by the CAEs

PMs proposed eight solutions to resolve the supporting issues. For example, to resolve the issues of the lack of flexibility to plan a resilient program and the non-use of the most probable cost for the program baseline, PMs advocated for OSD and the Component Acquisition Executives to gain Congress' approval for the establishment of an economic ordering quantity policy that would be value based and aimed at lot sizes and multi-year procurements. They also advocated for visible government management reserve that would be an OSD policy implemented by both Industry and the Component Acquisition Executives.

PM Forum #3. The following major themes were documented by 28 PMs who attended the November 2008 forum:

- *Qualified/Experienced Acquisition Workforce*,
- Funding & Contracting,
- Controlling Requirements, and
- Inconsistent Policy & Oversight.

The PMs argued that for the major theme *Qualified/Experienced Acquisition Workforce*, the supporting issues were recruiting, training, retention, experience, and lack of billets. The PMs' supporting issues and proposed solutions are shown in Table 5.

Table 5. PMs' Supporting Issues & Proposed Solutions for *Qualified/Experienced Acquisition Workforce*
(Moseley, 2010)

Supporting Issues	Proposed Solutions
Recruiting	▪ Establish mentoring/intern programs ▪ Pursue relationships with local/state colleges ▪ Stream-line hiring timeline/process ▪ Consider wounded warrior programs
Training	▪ Establish acquisition training for requirement officers ▪ Institute refresher courses ▪ Consider/review reducing length of DAU's PMT401 course
Retention	▪ Provide the Services with compensation options ▪ Establish focused incentives
Experience	▪ Manage resource officer rotations ▪ Require defense sector PM experience for SAEs & staffs ▪ Facilitate an "A Team" concept
Lack of Billets	▪ Review force structure requirements/balance

To address or resolve the supporting issues, PMs proposed 13 solutions. For instance, in the areas of experience and lack of billets, PMs advocated for better management of resources as they apply to officer rotations, the requirement for defense sector PM experience for the Service Acquisition Executives and their staffs, the facilitation of an "A Team" concept, and the review of force structure requirements to ensure balance.

PM Forum #4. Twenty-two PMs who attended the May 2009 forum presented the following major themes:

- *Policy*,
- IT Acquisition & Implementation,
- Oversight & Excessive Documentation,
- Staffing & Personnel, and
- Requirements & Funding.

During this forum, PMs insisted that acquisition policies were inconsistent, unclear and overly complex, and difficult to implement as it pertained to the major theme *Policy*. PMs proposed nine solutions to fix the supporting issues, as shown in Table 6.

Table 6. PMs' Supporting Issues & Proposed Solutions for *Policy*
(Moseley, 2010)

Supporting Issues	Proposed Solutions
Policies are inconsistent	▪ Establish process for policy change approval & implementation (e.g., change control, roles & responsibilities, interdependencies) ▪ Ensure timing of policy implementation is part of every policy change ▪ Force rigor into policy change process by mandating use of metrics & historical analysis ▪ Mandate establishment of supporting processes
Policies are unclear & overly complex	▪ Mandate agency level review of all candidate policy changes ▪ Audit & baseline existing policy volume & complexity. Moratorium on changes in interim ▪ Establish best practices for determination of minimum documentation required for milestones
Policies are difficult to implement	▪ Mandate ADM/PMD dialogue between MDA & PM before final signature to eliminate surprise ▪ Mandate minimum implementation durations & success criteria for policy changes

For example, to address or resolve the issue of policies that are unclear and overly complex, the PMs advocated for an agency-level review of all candidate policy changes, for an audit and then baseline of existing policy volume and complexity, and for a moratorium on changes in the interim. They also wanted to see the establishment of best practices in the determination of minimum documentation required for milestones.

PM Forum #5. The following major themes were presented by 20 PMs in the November 2009 forum:

- *Requirements Instability, Growth & Inadequate Definition Drive Cost & Schedule Execution Issues*;
- Manpower Skills & Knowledge Shortage;
- Funding Instability & Minimal Reprogramming Authority (Reduces PM Flexibility & Management Control & Causes Frequent Program Restructures);
- Policy Unclear, Inconsistent, & Burdensome;
- Focus of OSD Staff Misplaced; and
- Issues with Contracting & Industrial Base.

The PMs documented four supporting issues as essential to the major theme *Requirements Instability, Growth & Inadequate Definition Drive Cost & Schedule Execution Issues*: Director of Operational Test & Evaluation (DOT&E) levies excessive testing requirements; there are unfunded mandates such as anti-tamper; there are inadequate requirements definition and ability to perform adequate cost estimation prior to Milestone A (MS-A); and there is a lack of consistent requirements/program initiation process between the DoD and the Intelligence Community. Table 7 shows the PMs' supporting issues and proposed solutions for the major theme *Requirements Instability, Growth & Inadequate Definition Drive Cost & Schedule Execution Issues*.

Table 7. PMs' Supporting Issues & Proposed Solutions for Requirements Instability, Growth & Inadequate Definition Drive Cost & Schedule Execution Issues
(Moseley, 2010)

Supporting Issues	Proposed Solutions
DOT&E levies excessive testing requirements	▪ Consolidate single authority for funding and requirements by VCJCS
Unfunded mandates such as anti-tamper	▪ Implement adequate policy to ensure new requirements have associated funding in year of execution by USD/AT&L
Inadequate requirements definition and ability to perform adequate cost estimation prior to MS-A	▪ Implement improved disciplined process & accountability for affordable test execution by DOT&E
Lack of consistent requirements/program initiation process between DoD & Intelligence Community	▪ Establish improved, linked policy between JCIDS & acquisition processes to support earlier, adequate requirements definition by USD/AT&L & J8

PMs proposed four solutions. For example, to address or resolve the issue of inadequate requirements definition and ability to perform adequate cost estimation prior to Milestone A, PMs advocated for the implementation of an improved disciplined process and accountability for affordable test execution by the Director of Operational Test & Evaluation.

PM Forum #6. The following major themes were presented by 21 PMs in the November 2010 forum:

- *Contracting: Process—Management—Procurement Timeline*,
- Requirements/Testing,
- IT & Software-Intensive Systems,
- Funding Flexibility & Workforce Experience, and
- Leadership Intent: Disconnected Implementation.

The PMs derived the following supporting issues from the major theme *Contracting: Process—Management—Procurement Timeline*: the Defense Contract Audit Agency (DCAA) audit process is overly conservative and risk adverse; there is a double standard in the process (auditing takes the contractor 30–45 days but 6–18 months for the government); the contracting workforce is inexperienced; the contracting process exacerbates funds management issues; OSD & Services overlap as they pertain to process over product; and the certification to Competition in Contracting Act (CICA) and Truth in Negotiations Act (TINA) and certified cost and pricing data/Earned Value Management System (EVMS) actions are redundant and overly burdensome for lower value contracts. Table 8 shows the PMs' supporting issues and proposed solutions for the major theme *Contracting: Process—Management—Procurement Timeline.*

Table 8. PMs' Supporting Issues & Proposed Solutions for *Contracting: Process—Management—Procurement Timeline*
(Moseley, 2010)

Supporting Issues	Proposed Solutions
DCAA audit process overly conservative/risk adverse (double standard: it takes contractors 30-45 days & government 6-18 months)	▪ Review DCAA audit processes to allow less than 100% perfection in audits—look to raise audit thresholds (OSD/DPAP)
Inexperienced contracting workforce	▪ PCOs need to take PM training and vice versa—case based vs. "how-to"/checklist
Contracting process exacerbates funds management issues	▪ PCOs & buyers need to partner with the PM/Technical team to ensure government is a smart buyer – PK team generally not experts in the domain ("too much independence" today)
Process over Product: OSD & Services overlap	▪ Ensure PCOs accountable to the PM while still fulfilling responsibilities (OPCON vs. ADCON)
Certification to CICA (Competition In Contracting Act) & TINA (Truth In Negotiations Act) & certified cost & pricing data/Earned Value Management System (EVMS) actions are redundant and overly burdensome for lower value contracts	▪ There is too much regulation: FARs, DFARs, AFFARs, AFFAR Sup, ARFARS, OSD Policy, Service Policy, Command Policies, & Functional Policy. Protests have made us risk averse; the workforce doesn't have bandwidth and experience/judgment to tailor the process; and approval levels are too high & dollar thresholds are too low

PMs proposed five solutions to overcome this major theme. For instance, to address or resolve the issues of an inexperienced contracting workforce and the PMs' perspective that the contracting process exacerbates funds management issues, PMs advocated that PCOs take program management training and vice versa in a case-based learning environment. PMs also advocated that PCOs and buyers needed to partner with the program management and technical team to ensure that the government is a smart buyer, because the contracting team, in general, does not have expertise in the domain. This must be done to eliminate the independence seen today.

The results presented in this paper represent data from 148 major PMs from 12 defense acquisition agencies who attended six PM Forums held from November 2007 to November 2010. Senior OSD acquisition leaders heard directly from these PMs in the form of "straight talk" as they articulated proposed solutions for a plethora of burning programmatic issues. Referring back to Table 2 and conducting a comparative analysis, several major themes kept repeating themselves across the forums.

Trends

After conducting a comparative analysis of the major themes during the six PM Forums, the themes that repeated themselves were program management resources, policy and oversight, requirements, acquisition workforce, the contracting process, the industrial base, IT acquisition, and testing (See Table 9).

Table 9. Comparative Analysis of the Repetition of Major Themes in PM Forums (Moseley, 2010)

	PM Forums in Which Major Themes Were Repeated					
Major Themes	Nov 2007	Apr 2008	Nov 2008	May 2009	Nov 2009	Nov 2010
Program Management Resources	X	X	X	X	X	X
Policy/Oversight	X	X	X	X	X	X
Requirements	X	X	X	X	X	X
Acquisition Workforce	X	X	X	X	X	X
Contracting Process			X		X	X
Industrial Base	X	X			X	
IT Acquisition				X		X
Testing	X					X

However, the themes that were consistent over all six forums were as follows: program management resources, policy and oversight, requirements, and the acquisition workforce. The contracting process was a major issue in three forums: November 2008, November 2009, and November 2010. Likewise, the industrial base surfaced as a major issue in three forums: November 2007, April 2008, and November 2009. IT acquisition surfaced twice as a major issue in later forums: May 2009 and November 2010. Testing was more sporadic. It surfaced as a major issue only in the first and sixth PM Forum. It is interesting to note that in the November 2010 forum, the PMs captured all major themes from past forums with the exception of the industrial base.

While there is no direct evidence that the PM Forum discussions led to changes in the acquisition system, it appears that the seeds for several major initiatives may have been planted with OSD during these events. In particular, major workforce improvement initiatives, including the Defense Acquisition Workforce Development Fund (10 USC 1705, 2008), expedited hiring authority, and contractor insourcing may have a significant positive impact on the acquisition workforce issues raised by the PMs. Similarly, some PM requirements issues are being addressed through recent legislation mandating training of the requirements management workforce and establishment of Configuration Control Boards (CCBs) to help PMs control requirements creep. Finally, several recent USD(AT&L) efficiency initiatives are aimed at reducing the oversight burden and streamlining burdensome and expensive acquisition documentation (Carter, 2010).

Despite all of the reforms in acquisition to make the process better, one continued drumbeat of PMs that remains unanswered since the first PM Forum in 2007 is the issue of unpredictable funding. The Planning, Programming, Budgeting, and Execution (PPBE) system, an arcane relic from the 1960s, is an inflexible, calendar-driven system that is rife with perverse incentives. PMs are measured and rewarded on their obligation and expenditure of funds with little regard to how or why the taxpayers' monies were spent. The fundamental mismatch between an event-driven program and the calendar-driven PPBE system often leaves the PM a Hobson's choice of losing or reprogramming money to adjust the schedule for a program event, or pressing ahead in the face of a clear need to slow down (or speed up) to fix a program technical or schedule issue. PPBE adjustments within one program often create ripple effects and churn in the wider program portfolio. "Colors of money" can have equally perplexing impacts. While a program may have an abundance of procurement dollars, for example, they may be short on research and development funds. Since the monies are not interchangeable, a crisis ensues, even though the PM has, in aggregate, sufficient funds for the program. To date, no one has offered a viable substitute for the PPBE system. PMs continue to indicate that they spend substantial amounts of time managing workarounds.

Conclusion

The Office of the Secretary of Defense (OSD) and the Under Secretary of Defense for Acquisition, Technology, and Logistics (USD(AT&L)) saw a need to improve acquisition outcomes by establishing PM Forums. These forums are venues where PMs can provide "straight talk" to OSD senior acquisition leaders. Six forums have been held since 2007 and attended by 148 major PMs from 12 defense acquisition agencies. Of the major issues and proposed solutions presented by PMs, issues in program management resources, policy and oversight, requirements, and the acquisition workforce still persist. Acquisition initiatives are ongoing and are attempting to address these tough, persistent issues. The effectiveness of these initiatives will undoubtedly continue to be evaluated by PMs in future forums.

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Panel 15 – Analysis for Enhanced Acquisition Decision-Making

Thursday, May 12, 2011	
9:30 a.m. – 11:00 a.m.	**Chair: J. David Patterson,** Executive Director, National Defense Business Institute, The University of Tennessee ***The Effect of Processes and Incentives on Acquisition Cost Growth*** Doug Bodner, Bill Rouse, and I-Hsiang Lee, Georgia Institute of Technology ***The Failures and Promises of an Operational Service-Oriented Architecture: The ROI of Operational Effectiveness in Addition to Acquisition Efficiency at the Navy's Op Level of War*** Richard Suttie, U.S. Naval War College, and Nicholas Potter ***The Theory and Feasibility of Implementing an Economic Input/Output Analysis of the Department of Defense to Support Acquisition Decision Analysis and Cost Estimation*** Eva Regnier and Dan Nussbaum, NPS

David Patterson—Executive Director, National Defense Business Institute, University of Tennessee. Mr. Patterson is establishing an institution inspiring business innovation for both government and industry at the University of Tennessee in the College of Business Administration by providing practical, sound assistance in creating economically efficient and effective Defense business and acquisition programs. He is responsible for preparing funding proposals and budgets and for recruiting and managing university staff, professors, other faculty members, and key subject-matter experts engaged in relevant research and resource development tasks.

Prior to his current duties, he was the Principal Deputy Under Secretary of Defense (Comptroller). As the Principal Deputy, he was directly responsible for advising and assisting the Under Secretary of Defense (Comptroller) with development, execution, and oversight of the DoD budget, exceeding $515 billion, with annual supplemental requests of more than $160 billion. He was also responsible for developing legislative strategies and developing and implementing DoD financial policy, financial management systems, and business modernization programs. In June 2005 Mr. Patterson was appointed to lead the Defense Acquisition Performance Assessment Project, a comprehensive evaluation of every aspect of the Defense Department acquisition system and decision making processes.

From August 2003 to June 2005, Mr. Patterson held duties as The Special Assistant to the Deputy Secretary of Defense. In the capacity as Special Assistant, Mr. Patterson was responsible for managing the Deputy Secretary of Defense's personal staff as well as providing direction and advice to the Office of the Secretary of Defense Staff on a wide range of national security operations and policy subjects. He contributed to the Department of Defense support to the United States' mission to establish free and economically successful societies and governments in Iraq and Afghanistan. Additionally, Mr. Patterson supported the Deputy Secretary in the areas of military commissions for detainees in the Global War on Terrorism and major defense acquisition programs.

Before returning to government service, Mr. Patterson was a founding and managing partner at Bucher, Hutchins, Kohler and Patterson, Inc., where he led the firm's commercial consulting practice, developing management strategies for acquiring new business. From 1999 to 2001, he was the Vice

President and Site Manager for Steven Myers and Associates' support to Lockheed Martin Corporation's winning Joint Strike Fighter competitive proposal preparation.

Between 1993 and 1999, Mr. Patterson held a variety of responsible, executive positions at McDonnell Douglas Corporation (later The Boeing Company), beginning as the Senior Manager for Market Research and Analysis on the C-17 military air cargo aircraft and later as Director, International Business Development. He was responsible for developing and executing the business capture strategy that won U.S. Government Defense Acquisition Board approval to procure 80 additional C-17s, completing the first contract for 120 aircraft. Mr. Patterson led the Boeing business development team that launched the initiative to introduce a commercial version of the C-17; the BC-17.

Mr. Patterson served in the Air Force from 1970 to 1993, retiring in the rank of colonel. During that time, he held responsible leadership and management positions, with assignments at the air wing level as a C-5A aircraft commander and Deputy Operations Group Commander, at major command headquarters, Headquarters, U.S. Air Force, the Office of the Chairman, Joint Chiefs of Staff and the Office of the Secretary of Defense, Inspector General. In 1986, Mr. Patterson was the Air Force Fellow at the American Enterprise Institute. He served in Vietnam flying O2As as forward air controller.

The Effect of Processes and Incentives on Acquisition Cost Growth

Doug Bodner—Senior Research Engineer, Tennenbaum Institute, Georgia Institute of Technology. Dr. Bodner's research focuses on computational analysis and decision support for design, operation, and transformation of organizational systems. His work has spanned a number of industries, including automotive, electronics, energy, health care, military acquisition, paper and pulp, semiconductors, and telecommunications. He is a senior member of the Institute of Electrical and Electronics Engineers (IEEE) and the Institute of Industrial Engineers (IIE), and a member of the Institute for Operations Research and Management Science (INFORMS). He is a registered professional engineer in the state of Georgia. [doug.bodner@gatech.edu]

Bill Rouse—Executive Director, Tennenbaum Institute, Georgia Institute of Technology. Dr. Rouse is also a professor in the College of Computing and School of Industrial and Systems Engineering. He has written hundreds of articles and book chapters and has authored many books, including most recently *People and Organizations: Explorations of Human-Centered Design* (Wiley, 2007), *Essential Challenges of Strategic Management* (Wiley, 2001), and the award-winning *Don't Jump to Solutions* (Jossey-Bass, 1998). He is editor of *Enterprise Transformation: Understanding and Enabling Fundamental Change* (Wiley, 2006), co-editor of *Organizational Simulation: From Modeling & Simulation to Games & Entertainment* (Wiley, 2005), co-editor of the best-selling *Handbook of Systems Engineering and Management* (Wiley, 1999), and editor of the eight-volume series *Human/Technology Interaction in Complex Systems* (Elsevier). Among many advisory roles, he has served as Chair of the Committee on Human Factors of the National Research Council, a member of the U.S. Air Force Scientific Advisory Board, and a member of the DoD Senior Advisory Group on Modeling and Simulation. Rouse is a member of the National Academy of Engineering, as well as a fellow of four professional societies—Institute of Electrical and Electronics Engineers (IEEE), the International Council on Systems Engineering (INCOSE), the Institute for Operations Research and Management Science, and the Human Factors and Ergonomics Society. [bill.rouse@ti.gatech.edu]

I-Hsiang Lee—Graduate Research Assistant, Tennenbaum Institute. Mr. Lee is a PhD student in the School of Industrial & Systems Engineering at the Georgia Institute of Technology and is working on research of organizational simulation. He received a BSE in Computer Science and Information Engineering from National Taiwan University, Taiwan. He also holds an MS in Computer Science and an MEng in Operation Research and Information Engineering from the University of California at Santa Barbara and Cornell University, respectively. [ethan@gatech.edu]

Abstract

Cost growth continues to be a serious concern in major acquisition programs. A variety of causes have been identified for cost growth, including low initial cost estimates, complex acquisition processes, and immature technologies. Incentive-based systems have been employed in an attempt at cost savings, with mixed results at best. This paper examines the role of process and incentive characteristics in cost growth. In particular, we study process concurrency, types of incentive contracts employed and the transfer point from cost-plus to fixed-price contracts, and the resulting effects on cost growth in the F-35 Joint Strike Fighter program. The F-35 program currently is in low-rate initial production. The emerging paradigm of organizational simulation is used in this study, since it combines process representations to model acquisition processes and agent representations to model multi-actor behavior, including reaction to incentives. Simulation experiments are conducted and analyzed to determine the effects of the factors described above on cost growth.

Introduction

Cost growth has been a significant problem in major DoD acquisition programs. A recent report from the Government Accountability Office (GAO) notes that, for the fiscal year 2008 portfolio of weapons systems, there has been cost growth of $296 billion (GAO, 2009). In addition, since 2008, GAO (2011) notes that there has been $135 billion in total cost growth, $70 billion of which cannot be explained by changes in quantities ordered. Cost growth can result in fewer systems being produced than envisioned or desired (e.g., F-22), or in program cancellation (e.g., Navy Area Missile Defense). In the current and projected fiscal environment, there is considerable pressure to rein in cost growth.

Cost growth is a complex phenomenon involving technical issues, decision-making, contractor performance, and uncertainty. Therefore, it is not easily addressed or sometimes even properly understood. One way to study systems exhibiting uncertainty is computer simulation, in which a model of the system to be studied is specified and then analyzed to determine the system's performance with respect to different criteria under different conditions. In computer simulation, experiments can be conducted without using the real system, which is advantageous for many types of systems that simply would not be used for experimentation. Here, we are interested in studying acquisition processes, which encompass technical issues and technical decision-making, and incentives, which affect contractor performance and decision-making.

The remainder of this paper is organized as follows. The Acquisition Processes, Incentives, and Cost Growth section discusses the issues involved in cost growth from a process and incentive perspective. The Model Description section introduces and describes a model of the acquisition enterprise using organizational simulation, a relatively new paradigm for simulating enterprise systems. The Experimental Example section presents some simulation results illustrating the model concepts. The final section concludes with a discussion on future research.

Acquisition Processes, Incentives, and Cost Growth

Cost growth occurs for a variety of reasons, including uncertainty and lack of knowledge about technology, design, and manufacturing (GAO, 2009a). Candreva (2009) points to the role of institutional factors in organizational failures such as cost growth. Our previous research has addressed cost by focusing on the process aspects of acquisition. For instance, we have demonstrated that evolutionary acquisition processes can yield quicker deployment of capability than traditional acquisition processes, but at potentially higher cost due to overhead from the increased frequency of development cycles (Pennock & Rouse, 2008). System modularity tends to reduce the overall life cycle cost when sustainment is considered and can mitigate higher costs associated with larger production levels, thus reducing the effect of cost growth (Bodner, Rahman, & Rouse, 2010). However, such process modeling does not capture the effect of incentives, which can be an effective approach to achieving contractor performance, if properly applied (Tremaine, 2008).

Incentives and contract structures potentially play an important role in cost control. The two main types of contract structures are cost-plus, in which the government reimburses the contractor for costs incurred and pays an additional amount for profit, and fixed-price, in which the government pays a fixed price for a set deliverable (e.g., number of systems). Typically, the particular type of contract structure is used based on the risk profile of the program. Programs associated with high levels of research and development tend to use cost-plus contracts, since research and development entail significant risk for the contractor. Cost-plus contracts shift that risk to the government. Fixed-price contracts, on the other hand, are used for production, in which costs are more certain. Fixed-price contracts shift risk to the contractor.

Incentives traditionally have been implemented via such contract mechanisms as cost-plus-incentive-fee (CPIF) or cost-plus-award-fee (CPAF). An incentive fee rewards cost control, while an award fee rewards performance related to non-cost outcomes. Outcomes may relate to system capabilities (e.g., speed, altitude) or targets over time, such as the emerging concept of performance-based logistics (Kratz & Buckingham, 2009). Award fees may be structured to occur within certain evaluation periods, and a rollover may be used to transfer an unearned fee to a future period in which it can be earned. Competition, as opposed to non-competition, can also be considered as an incentive for a contractor (Birkler et al., 2001), although use of competition is constrained in areas such as aircraft acquisition, due to industry consolidation (Birkler et al., 2003). An award fee structure for spiral development of software-intensive systems is presented by Reifer and Boehm (2006).

The fundamental idea is to tie the incentive to the desired outcomes. This has not always worked in practice, however. A recent GAO report finds that the current DoD practice of using award and incentive fees is ineffective (GAO, 2005). Award fees often are provided despite the contractor's not having met performance criteria, and incentive fees have not been shown to motivate contractors to control costs. In addition, DoD does not have a system to allow sharing of case studies demonstrating successful use of award or incentive fees.

Recent studies have addressed increasing the effectiveness of award fees and incentive fees. Using an analytic approach, Hildebrandt (2009) develops guidelines for effective decision-making and information availability structures applied to incentive contracts. Under some arrangements, the information required may be demanding. Four programs are examined by Gilbreth and Hubbard (2008) to develop recommendations for effective incentive use. These recommendations include adequate training and feedback, plus several specific recommendations for award fees (using a base fee, setting the award fee based on outcomes rather than time, relating the award fee to the outcomes achieved, and using rollovers judiciously). These results are confirmed and extended by a continuation of the study that examined 25 programs (Tremaine, 2008).

Consider the F-35 program, which is developing and producing three variants of a next-generation tactical fighter for three Service applications (Air Force, Navy, and Marines). This program currently is in low-rate initial production (LRIP). The program has seen significant cost growth and schedule slippage (GAO, 2009b). There are a variety of causes cited, including immature technologies in development, ongoing design changes, inefficient production processes, and incomplete testing (GAO, 2011). Concerns due to the cost of the program have caused the National Commission on Fiscal Responsibility and Reform to recommend significant reductions in quantities to be procured (NCFRR, 2010) and have also prompted discussions of cancelling the Marine variant (short takeoff and landing). Nevertheless, the program has recently entered into its fourth phase of LRIP with a switch from a cost-plus contract to a fixed-price contract.

In addition, the F-35 program is of interest due to the highly distributed nature of the design and production network of contractors. In previous aircraft programs (e.g., F-16), the aircraft was largely designed and built by the prime contractor, with sourcing of somewhat simple components from suppliers. With the F-35, major subsystems are sourced for design and production to other contractors, many of which are international (Kapstein, 2004). Hence, the problem of government's incentivizing the contractor really becomes more complex, as the prime contractor, in the role of lead systems integrator (LSI), must in turn incentivize partners and other contractors.

The intent here is not specifically to study the F-35 program but rather to study the interaction of process and incentive issues raised by the program in the context of cost growth.

Model Description

This research uses the emerging paradigm of organizational simulation (Rouse & Boff, 2005) to study the problem of acquisition cost growth. Traditional simulations used to study organizations can be divided into three major paradigms: discrete-event (Law & Kelton, 2000), system dynamics (Sterman, 2000), and agent-based (Hillebrand & Stender, 1994). Discrete-event simulation tends to emphasize the transactional nature of process-based systems. System dynamics, on the other hand, represents continual accumulation processes affected by feedback flows and lags. Both are suitable for studying process-based systems, depending on the particular level of model resolution and focus. Agent-based simulation is relatively new and emphasizes the interaction of actors in a system. Thus, it has seen significant use in social science research applications. Of interest here is its application to economic behavior.

Organizational simulation uses elements of these three paradigms to model process and actor behaviors in organizational systems. It has been used in several domains thus far, including research and development investment (Bodner & Rouse, 2007), health care delivery (Rouse & Bodner, 2009), and computer server design and development (Bodner, Mutnury, Cases, & Rouse, 2009).

Process Model

Per DoD acquisition policy, acquisition is divided into a number of phases whereby a program evolves from concept to deployed systems. These phases consist of concept refinement, technology development, system development and demonstration, production and deployment, and operations and support. Various milestones and reviews exist in the process and serve as gates through which the program must have made sufficient technical progress to pass. As the program progresses, costs are incurred and are monitored against estimated costs. In addition, at various points in the process, contracts are awarded that cover specific deliverables relative to an acquisition phase. At these points, the amount of the contract, the deliverables, and the structure of the contract are in play. The process model is shown in Figure 1.

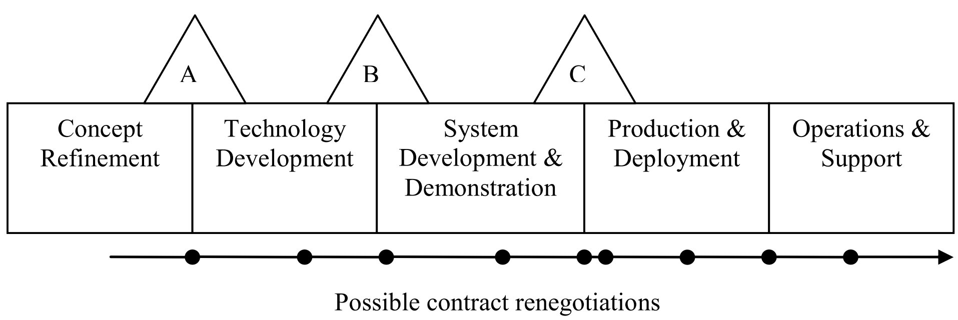

Figure 1. Acquisition Processes

Note that sometimes concurrency occurs, especially between system testing (in system development & demonstration) and low-rate initial production (in production and deployment). While this can expedite system delivery, it also entails risks, since manufacturing an unproven system may entail redesign and rework if undiscovered flaws exist. This risk relates directly to potential cost growth.

Actor Model

The actor model consists of the set of actors, their behaviors, and their interactions with one another. The government is one actor, and then contractors are modeled as separate actors.

Given that we are interested in incentives, we use the principal-agent framework as the basis for modeling actor interactions. The principal-agent framework is used in micro-economics to model the interaction of two actors, one of which (the principal) utilizes another (the agent) to perform a task (Kreps, 1990). This framework introduces a number of problems such as moral hazard and information asymmetry. Typically, the principal must design a contract mechanism that works to motivate the agent and hopefully addresses any problem situations.

In the case of acquisition, the government serves as the principal and the prime contractor as its agent. In turn, other contractors may be agents to the prime contractor's role as principal. In a complex supply network, the principal-agent representation can be used to model the many different tiers of contractors that exist, as shown in Figure 2. Note that a contractor can be an agent to multiple other contractors. Sometimes this is known to the principals; other times, it is not known. In addition, a contractor may be an agent to multiple contractors located in different programs (i.e., different supply networks under different prime contractors, who may be competitors). Thus, the principal-agent relations in a real supply network can be quite complex. Such complexity is usually not solvable by analytic models, leaving simulation as an important method in their study.

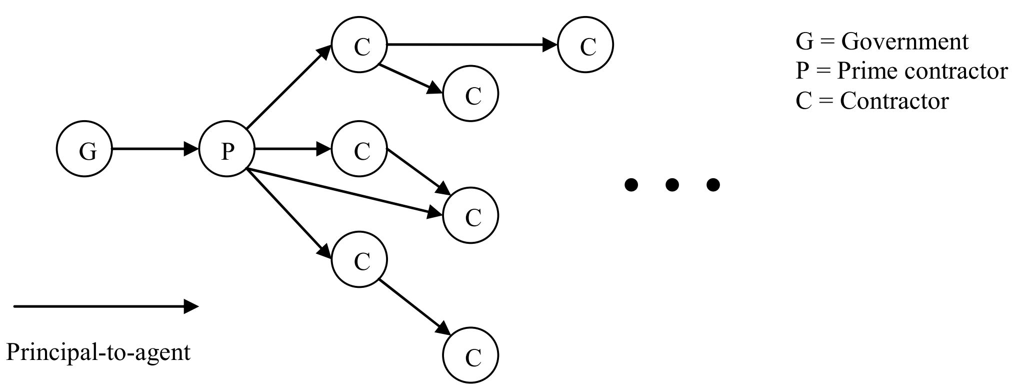

Figure 2. Actor Network

Incentive Model

Here, we describe a simplified incentive model that can serve as the basis for a principal-agent model of acquisition. Assume that the government is the principal and that the prime contractor is its agent. The agent has a utility function representing value received from working for the principal. We assume a functional form as shown in Equation 1, where *U* represents the utility, *w* represents the contractual payment from principal to agent (with diminishing marginal returns), and *a* represents the effort expended by the agent. In the case where there is no contract, the agent maintains a reservation utility U_r.

$$U(w, a) = \sqrt{w} - a \tag{1}$$

To simplify, we assume that the agent can expend a high level of effort a_h or a low level of effort a_l during the contractual term. Obviously, $a_h > a_l$. Now suppose that the principal and agent enter into a performance-based contract whereby the agent is paid according to its performance during the period. Again, for the sake of simplicity, we assume three levels of performance (low, medium, and high). Payment is as follows.

- The agent is paid x02 if performance is low.
- The agent is paid x12 if performance is medium.
- The agent is paid x22 if performance is high.

Obviously, $x_0 < x_1 < x_2$. The performance is uncertain, but it is based in part on the level of effort expended by the agent. Let *P*(*a*) be the performance level achieved by the agent as a function of effort, and assume that there are three levels of performance—P_0 (low), P_1 (medium), and P_2 (high) —with $P_0 < P_1 < P_2$. We model the performance according to the following functional form.

$$P(a_l) = \begin{cases} P_0 & with\ probability\ p_0^l \\ P_1 & with\ probability\ p_1^l, where\ \sum_{i=0}^{2} p_i^l = 1 \\ P_2 & with\ probablity\ p_2^l \end{cases} \tag{2}$$

$$P(a_h) = \begin{cases} P_0 & with\ probability\ p_0^h \\ P_1 & with\ probability\ p_1^h, where\ \sum_{i=0}^{2} p_i^h = 1 \\ P_2 & with\ probablity\ p_2^h \end{cases} \tag{3}$$

The terms p_i^l and p_i^h represent, respectively, probabilities associated with mapping the agent's effort (low or high) to performance outcomes. Even if the agent expends high effort, there is a probability of low or medium performance. We assume, however, that low effort is more highly correlated with low performance than with high performance and vice versa. Thus, we assume that $p_0^l > p_1^l > p_2^l$ and $p_0^h < p_1^h < p_2^h$.

With regard to the contractual agreement, there are three scenarios. The agent can decline the contract, the agent can accept the contract and expend low effort, or the agent can accept the contract and expend high effort. In the former case, the agent's utility is simply the reservation utility U_r. In the latter two cases, the agent's expected utility is given in Equation 4.

$$E\left[U(a_j)\right] = \sum_{i=0}^{2} p_i^j x_i - a_j, for\ j = l, h \tag{4}$$

The contract can be viewed from the perspective of either the principal or the agent. The principal, of course, wants the agent to expend maximum effort so as to maximize the chance of high performance. On the other hand, the principal does not want to overpay the agent. Thus, one way in which the principal's objective can be stated is to minimize the payment subject to the condition that the agent expends high effort.

$$\text{Minimize} \quad \sum_{i=0}^{2} p_i^h x_i^2 \tag{5}$$

From the agent's perspective, the only value from expending high effort occurs when the expected utility from high effort is greater than both the reservation utility and the expected utility of expending low effort. That is,

$$E[U(a_h)] \geq U_r \tag{6}$$

$$E[U(a_h)] \geq E[U(a_l)] \tag{7}$$

Combining Equations 5–7 yields a constrained optimization problem, which is solvable if the values for parameters are known and fixed.

Cost-Plus Model

As the agent works on behalf of the principal, it incurs costs for effort. We assume, in general, that the cost incurred a_t over time horizon t during a particular acquisition phase has a fixed set-up cost a_0 and then is linear in time with respect to a constant burn rate m, where m is dependent on the level of effort and where t is measured from the beginning of the phase.

$$a_t = a_0 + mt \tag{8}$$

From a cost-plus perspective, for the agent to be interested in the contract, payment from the principal must cover the agent's cost and then provide a profit. Moreover, the utility from the principal's payment and the agent's cost (Equation 1) must be greater than the agent's reservation utility.

In cost-plus arrangements, the duration of the acquisition phase can be estimated but often varies from the estimate, driving cost growth. Ideally, the principal desires that the agent expend high effort, expecting performance to be high. From this, the principal can estimate the time remaining in an acquisition phase, as well as a cost.

Let T be the total completion time needed for an acquisition phase. Let $\hat{T}_0^r$ be the initial estimate for time remaining (i.e., $\hat{T}_0^r$ is an estimate for T), and let $\hat{T}_t^r$ be the remaining left for completion at time t (i.e., once the phase has commenced). At the end of each year t, the time remaining can be updated as follows, where the agent's performance is measured in time progression toward completion.

$$\hat{T}_{t+1}^r = \hat{T}_t^r - P(a) \tag{9}$$

Note that the phase would end when $\hat{T}_t^r$ reaches zero for some t, at which time T becomes known. Assuming that the principal pays the agent annually for the contract duration, the principal's cost c_t in year t can be computed.

$$c_t = \begin{cases} x_0^2 & \text{if the agent's performance is low} \\ x_1^2 & \text{if the agent's performance is medium} \\ x_2^2 & \text{if the agent's performance is high} \end{cases} \tag{10}$$

Let C_T be the total cost to the principal for the acquisition phase, and let $\hat{C}_T^t$ be the estimate for C_T at time t. Letting C_t be the cost incurred by the end of year t, total costs can be tracked and the estimated phase cost can be updated.

$$C_t = C_{t-1} + c_t \tag{11}$$

$$\hat{C}_T^t = C_t/(1 - (\hat{T}_t/(t + \hat{T}_t))) \tag{12}$$

Letting $\hat{C}_t^0$ be the initial estimate of costs to be incurred by year *t* (t = 1, 2,… $\hat{T}_0^T$) allows incremental cost growth to be measured as $C_t - \hat{C}_t^0$ and total cost growth to be estimated as $\hat{C}_T^t - \hat{C}_T^0$.

Fixed-Price Model

Suppose that the principal uses a fixed-price contract for the agent's work. We assume a firm fixed-price contract, rather than an instrument that allows some cost to be transferred from the agent to the principal. Hence, cost growth is not an issue for the principal. This situation typically occurs in production, where there is less outcome risk. Here, economies of scale are usually present. In micro-economics, economies of scale are modeled using a Cobb-Douglas production function (Kreps, 1990). Let *X* be the amount of input resources, in terms of labor, capital, and materials; *N* be the output in terms of number of units produced; and *b* be the scale factor. The fundamental relation between input and output is shown in Equation 13.

$$N = X^b \tag{13}$$

If *b* > 0, then there are increasing returns to scale, meaning that the production is more efficient as more units are produced. This discussion assumes application in production, although the model may be extended to other phases. Assuming a constant per-unit cost of input *B*, the total cost of the production phase can be modeled as follows:

$$C_T = BX = BN^{1/b} \tag{14}$$

The term $\alpha = 1/b$ is defined as the production efficiency. The production efficiency is the performance measure used for the agent, and the unit cost of input is the level of effort. Similar to the cost model, we use three different levels—α_0 (low), α_1 (medium), and α_2 (high)—with $\alpha_0 < \alpha_1 < \alpha_2$ (lower α implies better efficiency). Similar to the cost model, the effort has two levels: B_l (low effort) and B_h (high effort). A higher effort may involve, for example, more investment per unit of labor in training or per production line in precision machinery, with the intent to achieve better downstream efficiency. Thus, $B_h > B_l$. Note that there may be a fixed cost associated with effort that is not modeled here. Equations 15 and 16 relate performance to effort in a probabilistic framework as before, with $p_0^l > p_1^l > p_2^l$ and $p_0^h < p_1^h < p_2^h$.

$$\alpha(B_l) = \begin{cases} \alpha_0 & with\ probability\ p_0^l \\ \alpha_1 & with\ probability\ p_1^l\ , where\ \sum_{i=0}^{2} p_i^l = 1 \\ \alpha_2 & with\ probability\ p_2^l \end{cases} \tag{15}$$

$$\alpha(B_h) = \begin{cases} \alpha_0 & with\ probability\ p_0^h \\ \alpha_1 & with\ probability\ p_1^h\ , where\ \sum_{i=0}^{2} p_i^h = 1 \\ \alpha_2 & with\ probability\ p_2^h \end{cases} \tag{16}$$

If the agent chooses to enter into a fixed-price contract with the principal, where *Y* is the per-unit output price, the agent then must choose what level of effort to expend based on the expected gain *G*(*B*), which is a function of payment from the principal and costs associated with production and with effort.

$$E\left[G(B_j)\right] = NY - \sum_{i=0}^{2} p_i^j B_j N^{\alpha_i},\ \ for\ j = l, h \tag{17}$$

The agent selects the level of effort whereby $E\left[G(E_j)\right]$ is maximized. However, this formulation does not address two of the principal's concerns regarding the contract—the selection of an appropriate value of *Y* and the timely delivery of output units. The performance measure α is primarily of interest to the agent unless it can be translated into schedule performance. Two methods of doing this are using a discounted cash flow model for the payments and costs and applying penalties to the payments when the schedule is not met. These methods are the subject of current work.

Simulation Implementation

A simulation model using the preceding constructs has been implemented using an organizational simulation framework. This framework uses AnyLogic, a commercially available simulation software product, plus a set of customized classes to model organizational artifacts and behaviors (Bodner, 2009). This allows actors to be modeled using an agent-based approach and acquisition processes to be modeled using a discrete-event, process/transactional approach. The interaction of these two approaches is shown in Figure 3. Note that not all possible behavioral interactions or structural relationships are shown.

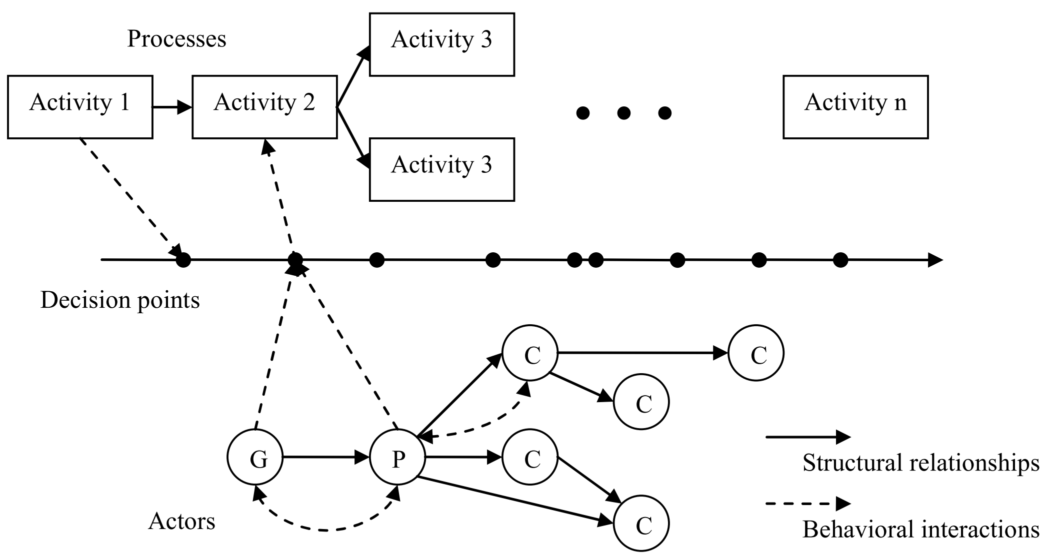

Figure 3. Process-Actor Interaction

This paper focuses on the implementation of a principal-agent model and an associated cost model within one acquisition phase. Each year within the phase, the following occur:

- The agent determines its level of effort.
- Based on the level of effort and the probabilities, a value for the performance level is computed.
- The principal's cost incurred is updated with the relevant cost from the year in question.
- Based on the cost incurred, cost growth is measured.

- The estimated time to completion is updated based on the performance for the year.
- The estimated cost for the acquisition phase is updated.
- Cost growth for the acquisition phase is estimated.
- The principal and agent interact, with new probabilities being generated.

At present, we assume that the contract structure and amount are not renegotiated.

Experimental Example

This section describes example simulation results from the cost-plus incentive model described in the Model Description section. The model features a principal and an agent that interact annually over a particular acquisition phase. At each interaction, the probabilities for agent performance change. Cost accrual is tracked, as is time taken to complete the phase by the agent.

Parameters

Tables 1–4 contain parameters used in the simulation example.

Table 1. Probability of Performance

Low Effort			High Effort		
Low	Medium	High	Low	Medium	High
0.6	0.3	0.1	0.1	0.3	0.6

Table 2. Principal's Cost Based on Performance

Low	Median	High
100	200	400

Table 3. Agent's Cost

Low effort	High Effort
50	150

Table 4. Other Parameters

Est. Phase Duration (Yrs.)	Interaction Frequency	Reserve Utility
10	Annually	100

Probabilistic Performance

To model changes in the probabilities (p_i^j) associated with achieving a certain performance level given a level of effort, we use two methods.

- Random assignment. Each p_i^j is assigned a new value from the Uniform (0, 1) distribution, subject to the earlier constraints ($p_0^l > p_1^l > p_2^l$ and $p_0^h < p_1^h < p_2^h$).
- Random addition. Each p_i^j is assigned a new value by adding a random amount to the previous value. The new value is $p_i^j(1 + rUnif(-1,1))$, where *r* = 0.1. This simulates a random walk process. The same constraints are observed, as well as the constraint that $p_i^j > 0 \, \forall \, i,j$.

Example Results

Using the random assignment of probabilities, the following results are obtained, as shown in Figure 4. The initial phase duration estimate of ten years was proven to be incorrect, since the phase lasted fifteen years. The estimated cost remained relatively constant, and the final cost ($3,800) was within a 95% confidence interval for the mean of the estimated total costs from each year ($3,727, $3,982).

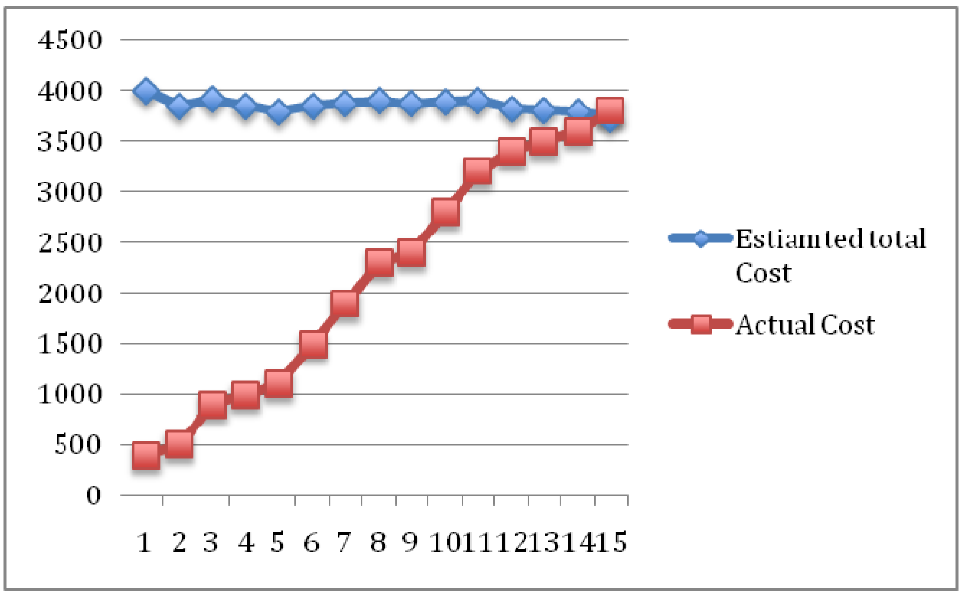

Figure 4. Cost Accrual Using Random Assignment

Under random addition, the following results are obtained, as shown in Figure 5. Similar to the previous example, the initial estimate for phase duration was incorrect, with the actual value being twelve years. The actual cost of $3,600 was likewise within a 95% confidence interval for the mean of the estimated total costs from each year ($3,425, $3,953).

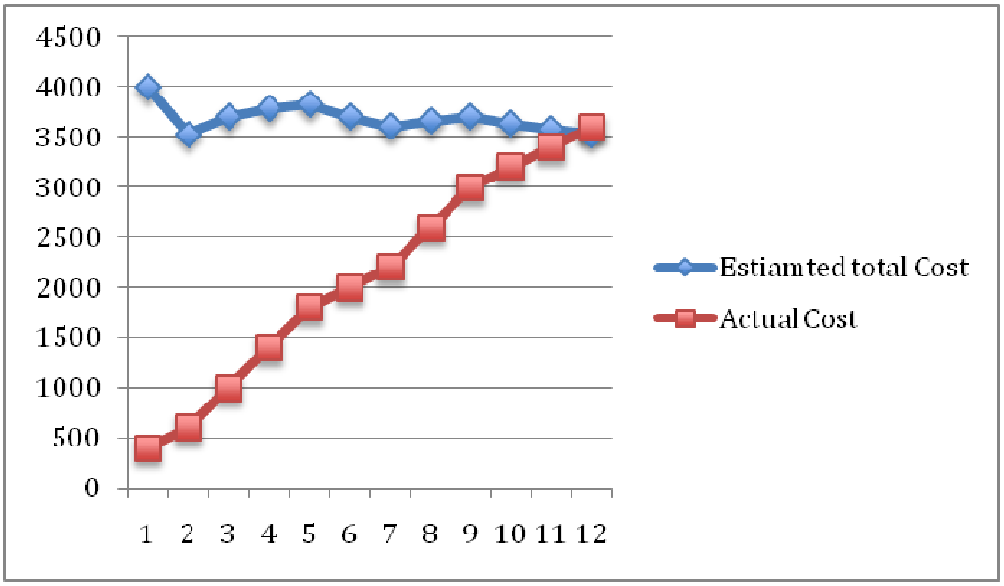

Figure 5. Cost Accrual Using Random Addition

In the second case, there is less variation in the probability values across time as compared to the first case. This is due to the probability update mechanism of the second (random addition), which changes the probabilities within a smaller range than the first. This is due to the relatively small value of *r*. Thus, in the first case, the agent can switch much more readily between low effort and high effort, while in the second case, the switch occurs less often. Thus, we see that this type of variability can drive longer phase durations.

In both examples, there is little to no cost growth. This occurs largely due to three reasons. First, the payment differential between high performance and low performance is relatively large. This motivates the agent to expend high effort. A smaller differential would likely cause increased expenditure of low effort (at relatively higher cost), resulting in cost growth. Second, the example does not use an initial cost estimate derived independently from the estimate used during program performance. Such independent estimates may be artificially low. Finally, technical issues are not modeled that would tend to drive cost growth (e.g., immature technologies, production quality issues). These issues have been demonstrated in previous work (Bodner et al., 2010).

Discussion and Future Research

This paper has presented a model for the acquisition enterprise that addresses its process-oriented aspects, as well as incentives for the actors involved. The incentive model is derived from the principal-agent model used in micro-economics. The acquisition model has been implemented using an organizational simulation framework. Sample results are presented to demonstrate the behavior of a government principal and a prime contractor agent.

Current work addresses the scale-up of the model to more realistic acquisition situations and the integration of more detailed process models (which cover the multi-phase acquisition life cycle and associated technical drivers of cost growth) with the actor models. Of primary interest are programs such as the F-35 Joint Strike Fighter. In this program, cost growth has been an issue, due to technical process issues and due to incentives. In addition, the F-35 employs a systems integrator paradigm of acquisition in which the prime contractor integrates complex subsystems designed and produced by a network of other contractors. This paradigm is relatively new, since it was preceded for many years by the manufacturer paradigm, in which most design and production were performed by the prime contractor, with relatively simple subsystems contracted out according to the prime's specifications. It is increasingly being used in acquisition of complex systems by the DoD and the industry (e.g., Boeing Dreamliner). The systems integrator paradigm implies the need for extensive research in incentives and contract structures. Due to the complexity of supply networks, simulation will be a valuable tool in this type of research.

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Acknowledgments

This material is based upon work supported by the Naval Postgraduate School under Award No. N00244-09-1-0015. Any opinions, findings, and conclusions or recommendations expressed in this publication are those of the authors and do not necessarily reflect the views of the Naval Postgraduate School.

The Failures and Promises of an Operational Service-Oriented Architecture: The ROI of Operational Effectiveness in Addition to Acquisition Efficiency at the Navy's Op Level of War

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Nicholas Potter

Abstract

This paper and presentation will share four years of research by the Naval War College into the operational requirements for a service-oriented architecture (SOA) for the Navy's operational level of war applied at the Navy's Maritime Operations Centers (MOCs). It will also argue that the cost-benefit analysis for SOA must be the improved operational effectiveness of the organization, not just the lower costs of data management and reduced redundancies of legacy systems. It will share a model for such an evaluation, and a model for proper protocols and data management for implementation. This paper argues that the proper cost-benefit analysis of service-oriented architecture is not possible without an operational integrated architecture that explicitly captures the role-based decision making protocols mapped to the core operational and enterprise-wide processes necessary to improve operational effectiveness. This paper and presentation will share this research and its direct application to the design and implementation of SOA for the Navy's Operational Level of War.

Report Summary

This paper and presentation will share four years of research by the Naval War College into the operational requirements for a service-oriented architecture (SOA) for the Navy's operational level of war applied at the Navy's Maritime Operations Centers (MOCs). It will also argue that the cost-benefit analysis for SOA must be the improved operational effectiveness of the organization, not just the lower costs of data management and reduced redundancies of legacy systems. It will share a model for such an evaluation, and a model for proper protocols and data management for implementation.

A primary goal of information technology (and related knowledge management acquisition) has been to optimize and obtain efficiencies related to coherence to legacy IT systems and protocols. Improving different IT characteristics such as speed and coherency are seen as the primary metrics of cost-benefit analysis and system's effectiveness. Some offer that a requirement to improved efficiency would be to better understand the tasks within the work breakdown structure and the functionality of the systems themselves. However, this depends on the Enterprise Architecture satisfactory reflecting the requirements for data exchange from the operational requirement. It often does not, and does not in the critical domain of the operational level of war, where importantly a properly designed SOA (such as Consolidated Afloat Networks and Enterprise Services, CANES) would have a profound impact on operational performance of warfighting decision making.

Research at the Naval War College has yielded a methodology which can establish an architecture that would be both accurate and dynamic, and well serve SOA design leading to a full benefit analysis.

The paper and presentation will share CBCA (Capabilities Based Competency Assessment) research conducted over the last four years by the Naval War College. CBCA has produced a data model which identifies and defines the critical nodes for the operational architecture across the Navy's Maritime Operations Centers MOCs, and places that work in a dynamic workforce environment which allows architects and IT designers to capture the necessary business (operations) context for correct rules and protocols for data management.

This paper argues that the proper cost-benefit analysis of service-oriented architecture is not possible without an operational integrated architecture which explicitly captures the role-based decision making protocols mapped to the core operational and enterprise-wide processes necessary to improve operational effectiveness.

Operational effectiveness is improved by synchronizing and enabling delivery of valid and reliable information (data + data context) with the right content (information + process context) to the right user (role + content).

MOCs are operational planning nodes within the Navy's numbered fleet commands. They are inherently joint, process driven, and globally connected.

CBCA research has developed a methodology that delivers the visibility, sequencing and coherency (data convergence) necessary for the performance of roles within and across the MOCs. The research and outcomes argue that any return on investment or cost-benefit analysis must use operational effectiveness as the primary measure, and demonstrates one method to do so.

This paper and presentation will share this research and its direct application to the design and implementation of SOA for the Navy's Operational Level of War.

The Theory and Feasibility of Implementing an Economic Input/Output Analysis of the Department of Defense to Support Acquisition Decision Analysis and Cost Estimation

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Abstract

Acquisition decisions drive resource requirements that are spread widely across the Department of Defense (DoD). DoD policy and Federal statute call for using the Fully Burdened Cost of Fuel (FBCF) in cost estimates in Analyses of Alternatives (AoAs) that support acquisition decision making so that decisions reflect all of the costs throughout the DoD organization that will be incurred (or saved) by a given acquisition decision. An Economic Input/Output (EIO) model of the DoD organization could be used to estimate the unit-specific FBCF, capturing all higher-order effects as demand is propagated through a complex and nonlinear supply chain. The model would produce unit-specific estimates of the cost and DoD-wide fuel requirements associated with a marginal change in fuel requirements in any unit of the organization. This paper describes the feasibility and potential benefits of an EIO model of DoD fuel supply.

Introduction

Acquisition decisions drive resource requirements that are spread widely across Department of Defense (DoD) organizational components. These decisions include Analyses of Alternatives (AoA) and Milestone decisions supported by Life Cycle Cost Estimates (LCCE). An important component of LCCE is energy usage (primarily fuel) during the Operating and Support phase. To provide more realistic cost estimates of fuel, the DoD has mandated use of "fully burdened cost of fuel" (FBCF). The purpose of this research effort is to evaluate the feasibility of developing an Economic Input/Output (EIO) model of the DoD organization to estimate the FBCF and thereby to support acquisition decisions.

DoD fuel usage creates risk by tethering deployed forces to a long and costly supply chain and by making the DoD strategically dependent on foreign oil sources. DoD policy and Federal statute call for using the Fully Burdened Cost of Fuel (FBCF) in cost estimates in Analyses of Alternatives (AoAs) that support acquisition decisions so that these decisions reflect all of the costs throughout the DoD organization that will be incurred (or saved) by a given acquisition decision. One of the challenges in estimating the FBCF is that a reduction (increase) in fuel requirement in one part of the organization has a cascading effect because it reduces (increases) demands on supporting organizations, multiplying the effect of a change in usage along the transportation supply chain getting the fuel to its point of use. Current FBCF models do not capture this multiplier effect, with the result that the true cost of fuel is underestimated.

Economic Input/Output (EIO) earned the Nobel Prize in economics for its creator, W. Leontief (Leontief, 1986), but it is a fairly simple model. Usually applied to a national economy, using industries and sub-industries as the unit of analysis, EIO produces a general equilibrium model, so that the impact of marginal changes in one sector can be propagated and measured through the rest of the economy. The research literature is rich with applications to Life Cycle Assessment, which is the estimation of the environmental impacts of the consumption of products and services traced back through a complex supply chain (Hendrickson, Lave, & Matthews, 2006). An EIO system for the DoD would have organizational units as sectors (which we call components), and marginal changes in output or input requirements in one component could be propagated through the entire system to estimate the net effects on the entire organization.

The primary benefits of EIO are its ability to capture all higher-order effects of a change in one part of the organization and the ability to trace resource-specific requirements throughout the system. For example, an EIO system could estimate not only the total costs of FBCF (specific to every organizational unit) but also the total DoD-wide reduction in fuel demand associated with a reduction of one gallon of fuel in a given unit. The EIO method can be used to capture the costs of force protection.

In the context of FBCF, an EIO system could be used to develop a more credible value for FBCF by producing an estimate of the DoD-wide effect of reducing (or increasing) fuel or power demand. The estimated FBCF would be specific to an organizational unit, as appropriate because the requirements involved in providing a gallon of fuel differ across organizational units, depending in particular on the supply chain that sustains the unit.

The section FBCF Using Unit Costs vs. EIO Estimate uses a simple example to show how the EIO approach can be adapted to model the DoD fuel supply chain and illustrate the multiplier effect. The Modeling the Supply Chain with EIO section provides a formal EIO model for DoD fuel supply and shows examples of the calculations. The section Feasibility Considerations discusses feasibility and challenges of the approach, and the final section concludes with a discussion of the potential advantages and disadvantages of EIO relative to scenario-based approaches to estimating the FBCF.

FBCF Using Unit Costs vs. EIO Estimate

Consider a very simple model of a supply chain that provides fuel to a single warfighting unit. We will call the warfighting unit a “component,” where a component is the organizational subunit that is directly modeled, equivalent to an industry or sector in classical EIO. The supply chain includes three logistical stages, each of which is a component as well as the end user component that uses the fuel in warfighting.

Fuel delivered is the total number of units (here, gallons) of fuel that each stage delivers to its customers. In this example, the supply chain is linear, so each stage has exactly one supplier (the prior stage, or, in the case of Stage 1, an external purchase) and exactly one customer (the next stage, or, in the case of Stage 3, the warfighting component).

Fuel operating costs exclude the cost of the delivered fuel. It includes the cost of the fuel consumed by this component in providing its services calculated at the official Defense Energy Support Center (DESC) standard price, which in this example is $2/gallon. The other (non-fuel) costs include operating and support (O&S) costs, depreciation, infrastructure and recapitalization, and infrastructure—everything attributable to the logistical component and capturing cost elements 2-5 in the FBCF methodology (Fully Burdened Cost of Fuel Calculator, version 7, Model Description & Assumptions, March 2010).[1]

The naive application of the FBCF calculation for the logistical support would attribute the unit cost of delivered fuel by each supply-chain component to a unit of fuel provided to the consuming component. Table 1 shows an example calculation; the FBCF estimated cost of the supply chain per gallon of fuel delivered to the warfighter component is $4.45, the sum of the unit operating costs of the three supply-chain components. Adding the $2/gallon DESC price, this comes to an estimate of $6.45 for the FBCF. This would be appropriate in a one-stage linear supply chain. However, it doesn't work in a multistage supply chain.

Table 1. Example Calculation of Delivery Cost in Three-Stage Supply Chain

	Fuel Delivered (gal)	Fuel Consumption (% of delivered)	Operating Costs Non-Fuel	Operating Costs Fuel	Operating Costs Total	Operating Costs/Unit Delivered
Stage 1	1560	15%	$ 1,532	$ 468	$ 2,000	$ 1.28
Stage 2	1200	30%	$ 1,280	$ 720	$ 2,000	$ 1.67
Stage 3	1000	20%	$ 1,100	$ 400	$ 1,500	$ 1.50
			$ 3,912	$ 1,588	$ 5,500	$ 4.45

Figure 1 shows the multiplier effect on the total quantity of fuel required at each stage (note that it does not show costs). Because Stage 3 requires 0.2 extra gallons of fuel for every gallon it delivers, then to deliver 1,000 gallons of fuel, it must receive 1,200 gallons from Stage 2. If the fuel demand from the warfighter were reduced by a gallon, then Stage 3 would have to receive 1.2 gallons less, not just 1 gallon less.

[1] The seven cost elements are:

1. Commodity Cost of Fuel.
2. Primary Fuel Delivery Asset O&S Cost.
3. Depreciation Cost of Primary Fuel Delivery Assets.
4. Direct Fuel Infrastructure O&S and Recapitalization Cost.
5. Indirect Fuel Infrastructure O&S Cost.
6. Environmental Cost.
7. Other Service & Platform Delivery Specific Costs (including force protection).

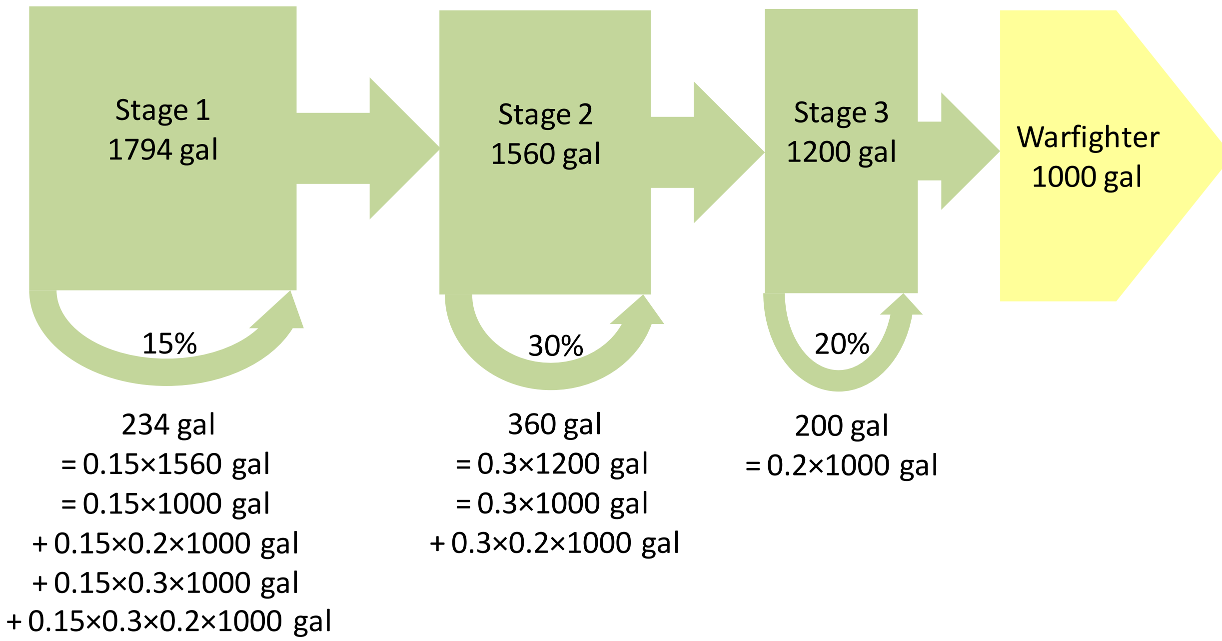

Figure 1. Multiplier Effect in Simple Supply Chain

In the example in Table 1, the appropriate fully burdened cost of a gallon of fuel (hereafter the EIOCF) is the total cost of operating all three supply-chain components including the costs of the extra fuel required by each supply-chain component to deliver the 1,000 gallons of fuel needed by the warfighter plus the fuel required to deliver the extra fuel required by the downstream components as detailed below:

$2000 = 1000 gal ×$2/gal for fuel used by the warfighter component
$300 = 0.15×1000 gal ×$2/gal for extra fuel used in Stage 1 to transport 1000 gal
$600 = 0.3×1000 gal ×$2/gal for extra fuel used in Stage 2 to transport 1000 gal
$90 = 0.15×300 ×$2/gal
= for extra fuel used in Stage 1 to transport extra 300 gal to Stage 2
$400 = 0.2×1000 gal ×$2/gal for extra fuel used in Stage 3 to transport 1000 gal
$120 = 0.3×200 ×$2/gal
= Stage 2 cost to transport the extra 200 gal needed at Stage 3
$60 = 0.15×200 ×$2/gal
=Stage 1 cost to transport the extra 200 gal needed at Stage 3
$18 = 0.15×60 ×$2/gal
= Stage 1 cost to transport the extra 60 gal required at Stage 2 to transport the extra 200 gal needed at Stage 3

$3,588= Total Fuel Cost, including $2,000 for fuel used by warfighter component and $1,588 for fuel used by supply chain

The total direct fuel cost to transport 1,000 gallons: $1,300 = 1,000 gallons × (0.15 + 0.2 + 0.3) × $2/gallon. This is the only fuel cost that would be captured by a naive FBCF estimate. In this example, the total non-fuel cost of the supply chain is $3,912, so the total cost of supply chain plus direct cost of 1,000 gallons of fuel is $7,500, and the total cost of the supply chain per unit of fuel consumed by the warfighter is $7.50, which we will call the EIO cost of fuel (EIOCF).

EIOCF = \$7.50/gallon.

The EIOCF of \$7.50/gallon contrasts with the FBCF of \$6.45 calculated above if the multiplier effects are not captured. In this simple example, that is a difference of \$1.05/gallon, which is 16% of the total cost of the delivered fuel (including non-fuel costs to the supply chain) and 29% of the fuel costs of the delivered fuel.

If we assume that, like fuel costs, the non-fuel costs of the supply chain components are proportional to the quantity of fuel that each component delivers, then the EIOCF is the marginal cost of a gallon of fuel delivered to the warfighter. In the example in Table 1, increasing the quantity demanded by the warfighter to 1,001 gallons would increase the total cost of the supply chain to \$7,507.50. Therefore, the EIOCF is the appropriate cost to use in decisions—acquisition decisions, operational decisions, even force planning decisions—that can affect warfighter fuel requirements. The naive FBCF underestimates the marginal cost of a gallon of fuel consumption.

While it is certainly possible for an analyst to estimate the multiplier effects when conducting a FBCF analysis, it would be difficult as it requires estimating the amount of fuel that a unit transports that is destined for the end user rather than other elements of the supply chain, and in general at most second-order effects are captured.

Modeling the Supply Chain with EIO

Modeling a system using EIO requires first, defining the components or unit of analysis, which determines the level of data that will be required to populate the model. Second, the model requires a populated matrix of the type shown in Table 2. An EIO model is a static snapshot representing the flows of resources among components of the modeled system. For national accounts, the snapshot is usually an annual total. For the DoD, an annual average or total representation of the supply chain would likely be used and results would reflect averages over the period. This section formalizes the model.

Linear Supply Chain

Components are indexed $i = 1,\ldots,n$, where n is the warfighter component, and $1,\ldots, n-1$ are links in the supply chain transporting fuel to component n. Think of component $i=1$ as DESC (DLAE), and each component $i<n$ directly supplies only component $i+1$. Each supply component has precisely one output: delivered fuel. The amount of fuel delivered by each component is denoted x_i.

Using the convention of EIO analysis, let a_{ij} = the number of units of output from component i required to produce each unit of output from component j. Often, both a_{ij} and x_i are normalized in terms of dollars. We will instead assume a_{ij} and x_i are in units of fuel, with all fuel treated identically. The exception is x_n, the output of the warfighter component, which might be steaming hours, patrols performed, or other output measures.

We will also introduce an external component, indexed X, which represents any supplier outside the organization. In our example, this captures purchases of fuel from the private sector. In classical EIO, the entire economy is modeled. In some cases, such as national accounting, imports are purchases external to the organization.

The total fuel requirement for the organization is $\sum_{j=1}^{n} x_j a_{Xj}$. The input-coefficient matrix is shown in Table 2.

Table 2. General Input-Coefficient Matrix

			destination			
			component			
			1	2	3	n
source	component	1	a_{11}	a_{11}	…	a_{1n}
		2	a_{21}	a_{22}	…	a_{2n}
		…	…	…	…	…
		n	a_{n1}	a_{n2}	…	a_{nn}
		external	a_{X1}	a_{X2}	…	a_{Xn}

The values of a_{ij} and x_i satisfy the n equalities:

$$x_i = \sum_{j=1}^{n} a_{ij} x_j , \forall i = 1,...,n ,$$

which means that each component i produces exactly enough of its output, x_i , to satisfy the input demands of all components for its output. The above can be rearranged as follows:

$$x_i = \frac{\sum_{\substack{j=1 \\ j \neq i}}^{n} a_{ij} x_j}{1 - a_{ii}} . \qquad (1)$$

Since we are assuming a very simple supply chain in which component 1 supplies component 2 (and no one else) and so on, and the model accounts for exactly one input type (fuel), the input coefficient matrix has a special structure:

$$\forall i = 2,...,n-1 \; a_{i-1,i} = 1 + \alpha_i \text{, and } a_{ij} = 0 \text{, } \forall j \neq i+1 \text{,}[2]$$

where the value α_i is the amount of fuel consumed by component i in delivering one unit of fuel. It is assumed that the fuel any component consumes is not its own delivered (output) fuel, but rather the fuel delivered by the component that supplies it.[3] The input-coefficient matrix is given in Table 3.

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[2] We will further assume that the units of output from component n are defined in such a way that $a_{n-1,n} = 1$, although this is for simplicity and is not otherwise required because the output from component n is of a different type than components $i < n$.

[3] A fuel-supplying component's efficiency is therefore $1/(1+\alpha_i)$.

Table 3. Coefficient Matrix for Linear Supply Chain

			Destination				
			Component				
			1	2	…	$n-1$	n
Source	component	1	0	$1+\alpha_2$	…	0	0
		2	0	0	…	0	0
		…	…	…	…	…	…
		$n-2$	0	0	…	$1+\alpha_{n-1}$	0
		$n-1$	0	0	…	0	$a_{n-1,n}$
		n	0	0	…	0	0
		External	$a_{X1}=1+\alpha_1$	0	…	0	0

For components $i<n$, each component's output (gallons of fuel) is: $x_i = a_{i,i+1}x_{i+1} = \left(1+\alpha_{i+1}\right)x_{i+1}$, and the total organizational fuel requirement is

$$x_X = \prod_{i=1}^{n-1}\left(1+\alpha_i\right)a_{n-1,n}x_n \quad (2)$$

$x_X = x_1 a_{X1} = \prod_{i=1}^{n-1}\left(1+\alpha_i\right)a_{n-1,n}x_n$, as shown in the example below, with three supply chain links (components 1-3) and one warfighter component (4). The warfighter component's output is exogenous, and it is arbitrarily set to 100. The total fuel required by the organization is 1.15 × 1.3 × 1.2 × 1,000 = 1,794.

Table 4. Input Coefficient Matrix for Simple Supply Chain Example

input coefficient matrix					
	destination	component			
	source	1	2	3	4
component	1	0	1.3	0	0
	2	0	0	1.2	0
	3	0	0	0	1
	4	0	0	0	0
	external	1.15	0	0	0
	output by component	1560	1200	1000	1000
	total external requirement	**1794**			

For a given component, we will define its fuel multiplier (denoted β_i) as the factor by which the organization's total fuel requirement from the external source would increase (decrease) with a change in the component's fuel output (either as a result of decreased demand from the next stage in the supply chain, or as a result of an increased efficiency) or decrease in demand for its product. The EIO approach assumes that changes in input requirements are proportional to changes in output (constant returns to scale). Hence,

$\beta_i = {x_X}/{x_i}$. We can rewrite Equation 2 as $x_X = \prod_{j=1}^{i}\left(1-\alpha_j\right)x_i$, for any $i = 1,...,n-1$ implying that $\beta_i = {x_X}/{x_i} = \prod_{j=1}^{i}\left(1-\alpha_j\right)$.

More Complex Supply Chain

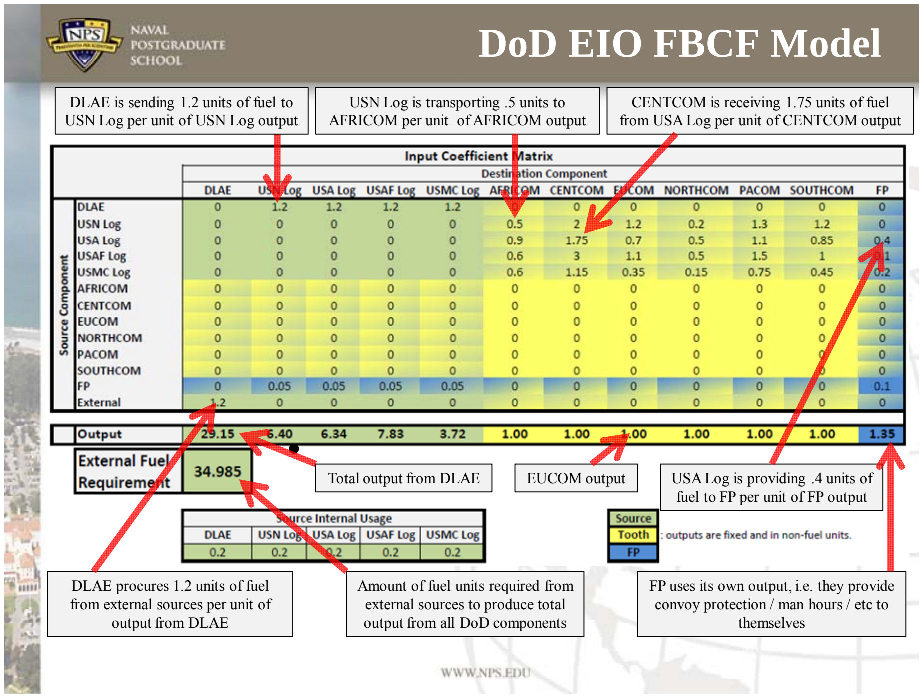
Within the DoD it is more realistic for a supply chain to include complexities such as:

- multiple warfighter components;
- force protection components distinct from warfighting components, which produce an output (protection) that warfighting and logistics components may use;
- each component may receive fuel directly from more than one fuel-supply component; and
- nonlinearities (e.g., one component may both supply and be supplied by another component).

In this case, the general matrix in Table 2 is applicable, together with a vector of outputs, x_i for all i . The consistency constraints in Equation 1 still apply. An example is shown in Figure 2.

As before, a_{ij} = the number of units of output from component i required to produce each unit of output from component j , and the units are the units of i 's output over then units of j 's output. This means that $a_{ij}x_j$ is the amount of output of component i consumed by component j in the same units that component i 's output is measured. The output of force-protection components is also not in units of fuel but rather in units of force protection.

Additional constraints are required to ensure that each component receives the required amount of input of a given type. In particular, if component j supplies fuel, then the total input it receives from all fuel-supplying components must equal $1+\alpha_j$.



Source Component	DLAE	USN Log	USA Log	USAF Log	USMC Log	AFRICOM	CENTCOM	EUCOM	NORTHCOM	PACOM	SOUTHCOM	FP
DLAE	0	1.2	1.2	1.2	1.2	0	0	0	0	0	0	0
USN Log	0	0	0	0	0	0.5	2	1.2	0.2	1.3	1.2	0
USA Log	0	0	0	0	0	0.9	1.75	0.7	0.5	1.1	0.85	0.4
USAF Log	0	0	0	0	0	0.6	3	1.1	0.5	1.5	1	[illegible]
USMC Log	0	0	0	0	0	0.6	1.15	0.35	0.15	0.75	0.45	0.2
AFRICOM	0	0	0	0	0	0	0	0	0	0	0	0
CENTCOM	0	0	0	0	0	0	0	0	0	0	0	0
EUCOM	0	0	0	0	0	0	0	0	0	0	0	0
NORTHCOM	0	0	0	0	0	0	0	0	0	0	0	0
PACOM	0	0	0	0	0	0	0	0	0	0	0	0
SOUTHCOM	0	0	0	0	0	0	0	0	0	0	0	0
FP	0	0.05	0.05	0.05	0.05	0	0	0	0	0	0	0.1
External	1.2	0	0	0	0	0	0	0	0	0	0	0
Output	29.15	6.40	6.34	7.83	3.72	1.00	1.00	1.00	1.00	1.00	1.00	1.35

Source Internal Usage				
DLAE	USN Log	USA Log	USAF Log	USMC Log
0.2	0.2	0.2	0.2	0.2

Figure 2. An Example Implementation of a DoD EIO Model that Includes Multiple Warfighter Components (the COCOMS) and Force Protection (FP)
(Dubbs & Hills, 2011)

Feasibility Considerations

The first challenge in this effort is identifying the unit of organization that can serve as the element of analysis (which we call component) for a DoD EIO Defense Accounts system. This modeling choice represents a tradeoff among data availability, data quality, and homogeneity of activities within the selected unit. The components should be defined such that the necessary coefficients can be estimated, but that the output of each component is homogenous enough that each unit of output can be treated identically.

EIO cannot be done piecemeal—it requires a fully populated matrix of the type shown in Table 2. Therefore, to calculate the EIOCF for any unit, it would be necessary to implement a DoD-wide EIO system of defense accounts. This is analogous to national accounts in the usual applications of EIO to analyze regional and sector economies (see Dietzenbacher & Lahr, 2004 for a history of the development of EIO theory and practice and for examples of EIO in national accounting), and therefore can be used in many cost estimation applications. A DoD EIO system should be DoD-wide because of the Joint nature of supply and logistics. Once such a system is implemented, it could be used to assess the impact of marginal changes within any unit in the organization. The computational effort required to estimate the impacts of additional marginal changes is negligible.

All modeling techniques have their limitations. The most relevant in this application of EIO are the following:

1. Data availability is, as always, important. We believe that the data required for this effort are available, but they do reside in several organizations across the DoD enterprise. To capture the net DoD fuel requirement associated with fuel consumption in each component, fuel flows across components within the DoD need to be estimated. In addition, to provide a dollar estimate of

EIOCF, each component's total costs associated with fuel logistics must be estimated. If force protection, a significant part of the burden of fuel supply in some operations, is to be included, then the costs associated with each component that supplies force protection to the supply chain, as well as the component's fuel requirements and suppliers and the amount of force protection output provided to each component, must be estimated.

2. EIO has assumptions—as do all models—that can limit its applicability. Principal among these for EIO is the proportionality assumption. Therefore, defining the unit of analysis (the components) such that proportionality is a reasonable assumption will be an important consideration.
3. EIO is a static snapshot of the modeled system. Especially in active operational contexts, the DoD supply chain may be changing frequently, sometimes over a matter of days or weeks. EIO allows for a given component to receive fuel (or other resources) from multiple supplying components with the resulting EIOCF estimates reflecting averages over all paths that fuel takes to reach each component. However, if the proportions of fuel change significantly, permanently, and frequently, then the static EIO matrix will be an inadequate model and provide inaccurate FBCF estimates.

The EIOCF may provide less precision for a given scenario than an approach that requires a detailed study of the particulars of the scenario. However, by definition, any detailed scenario is quickly outdated. An EIOCF might be a better estimate than an outdated detailed scenario, and may prove a better estimate of the marginal cost of fuel in a fast-changing or complex supply chain.

Conclusions

The up-front costs of populating a DoD-wide model with good data are higher than a few single-scenario FBCF studies. However, once the model is developed, it can answer questions about the marginal impacts of changes in any component with much less work per query. The EIO framework and, if implemented, a populated EIO model of the DoD supply chain could also be used to estimate the cost and resource requirements associated with any marginal change in output requirements or input mix in any unit of the organization, thus becoming a valuable tool to support many acquisition-related decisions. It is worth exploring the feasibility of constructing a EIO model of the DoD supply chain because the potential benefits for decision support are so great.

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Panel 16 – Contributions of Systems Engineering to Effective Acquisition

Thursday, May 12, 2011	
9:30 a.m. – 11:00 a.m.	**Chair: Rear Admiral John Clarke Orzalli,** USN, Vice Commander, Naval Sea Systems Command ***Control of Total Ownership Costs of DoD Acquisition Development Programs Through Integrated Systems Engineering Processes and Metrics*** Paul Montgomery and Ron Carlson, NPS ***Applying an Influencer Approach to Ingrain Systems Engineering into Pre-Milestone B Defense Programs*** Bob Keane, Ship Design USA, Inc. ***Factors Influencing the Effectiveness of Systems Engineering Training and Education in the Department of Defense*** William Fast, NPS

Rear Admiral Orzalli—Vice Commander, Naval Sea Systems Command (NAVSEA). Rear Admiral Orzalli is the son of a retired Navy captain. He graduated with distinction from the U.S. Naval Academy in 1978.

At sea, he served aboard USS *Snook* (SSN 592) as an engineering division and weapons officer; and as USS *Helena's* (SSN 725) engineering officer. Ashore, Orzalli has served at the U.S. Naval Academy, as well as tours at naval shipyards in Mare Island, Puget Sound, and Portsmouth.

Orzalli was the 45th shipyard commander at Puget Sound Naval Shipyard from 2002–2005. During his command tour, he assumed additional duties in establishing the Northwest Regional Maintenance Center. Following selection to flag rank, Orzalli was the deputy director, Fleet Readiness Division, OPNAV (N43B); commanding officer, Mid-Atlantic Regional Maintenance Center, then established commander, Regional Maintenance Centers.

Most recently, Orazalli was the director, Fleet Maintenance on the staff of commander, U.S. Fleet Forces Command. His service decorations include the Legion of Merit (with four stars), the Meritorious Service Medal (with two stars), Navy Commendation Medal (with star), Navy and Marine Corps Achievement Medal (with three stars) and various other unit and operational awards.

Orzalli holds a Bachelor of Science in Marine Engineering from the U.S. Naval Academy, Naval Engineer, a Master of Materials Science and Engineering from Massachusetts Institute of Technology, and a Master of Science in Systems Management from Golden Gate University.

Control of Total Ownership Costs of DoD Acquisition Development Programs Through Integrated Systems Engineering Processes and Metrics

Paul Montgomery—After retiring in 1990 from a 20-year career in the Navy, Dr. Montgomery served as a Senior Systems Engineer with Raytheon and Northrop Grumman corporations and developed communications, surveillance, and sensor systems for commercial, military (USN, USA, USAF), and intelligence communities (NSA, NRO). He earned his doctorate in Systems Engineering from George Washington University (D.Sc. 07) performing research related to cognitive/adaptive sensors, MSEE (1987) from Naval Postgraduate School, and BSEE (1978) from Auburn University. The International Council on System Engineering (INCOSE) certifies him as an Expert Systems Engineering Professional (ESEP). Dr. Montgomery is an SE Department–embedded faculty member providing onsite research and instruction support to NAVAIR (Patuxent River, MD), NAVSEA (Dahlgren, VA, Carderock, MD), and NPS SE students in the Nation Capital Region. [prmontgo@nps.edu]

Ron Carlson—Mr. Carlson served 26 years in Naval Aviation as a pilot, seven years of which were at NAVAIR, where he led NAVAIR Systems Engineers through several years of systems engineering revitalization to the NPS SE Department. He is currently in the Systems Engineering doctoral program at Stevens Institute of Technology. He earned master's degrees in Strategic Studies and National Policy from the Naval War College and Business Administration-Aviation from Embry Riddle Aeronautical University and his Bachelor of Science in Nuclear Engineering from the University of Michigan. Mr. Carlson is an SE Department–embedded faculty member providing onsite research and instruction support to NAVAIR (Patuxent River, MD), NAVSEA (Dahlgren, VA, Carderock, MD), and NPS SE students in the Nation Capital Region. [rrcarlso@nps.edu]

Abstract

Many DoD weapon systems acquisition programs are exceeding their original estimates for total ownership costs. There are probably many contributing factors to this cost growth, but is Systems Engineering (SE) one of them? How can systems engineering processes, methods, and practices be improved to better control total ownership cost growth in DoD acquisition programs? This paper discusses research in developing an understanding of how SE can be optimized for developing high confidence estimates and better control of acquisition program total ownership costs (TOC). Although this research is in the very early stages, we discuss the technical approach to investigating systems engineering methods and practices related to TOC as executed at one of the Navy's major system acquisition commends (Naval Air Systems Command-NAVAIR). We discuss very preliminary findings and set the stage for further research results.

Background

Total Ownership Cost (TOC) Definitions

Many DoD weapon systems acquisition programs are exceeding their original estimates for total ownership costs. There are probably many contributing factors to this cost growth, but is Systems Engineering (SE) one of them? How can systems engineering processes, methods, and practices be improved to better control total ownership cost growth in DoD acquisition programs? This paper discusses research in developing an understanding of how SE can be optimized for developing high confidence estimates and better control of acquisition program total ownership costs (TOC). Although this research is in the very early stages, we discuss the technical approach to investigating systems engineering methods and practices related to TOC as executed at one of the Navy's major system acquisition commends (Naval Air Systems Command; NAVAIR). We discuss very preliminary findings and set the stage for further research results.

Before proceeding further, it would be useful to establish definitions for TOC. In general, TOC is made up of four categories of cost that are incurred during the system acquisition lifecycle. These are not completely independent but overlap and are associated with four major phases of the system lifecycle. TOC is comprised of the following:

- Research and development cost that extend from the concept phase to the technology development phase and through to development and demonstration,
- Costs associated with system production,
- Operations and support cost during sustainment phase, and
- Disposal and retirement costs.

Another broad definition of TOC is that "TOC is comprised of costs to research, develop, acquire, own, operate, and dispose of weapon and support systems, other equipment and real property, the costs to recruit, train, retain, separate and otherwise support military and civilian personnel, and all other costs of business operations of the DoD" (Gansler, 1998).

A more specific example of how TOC elements can be decomposed can be found in Figure 1. This figure is derived from NAVAIR discussions and their perspective of aviation weapons systems acquisitions. TOC, therefore, includes many components of cost that go well beyond simply the initial acquisition of the system.

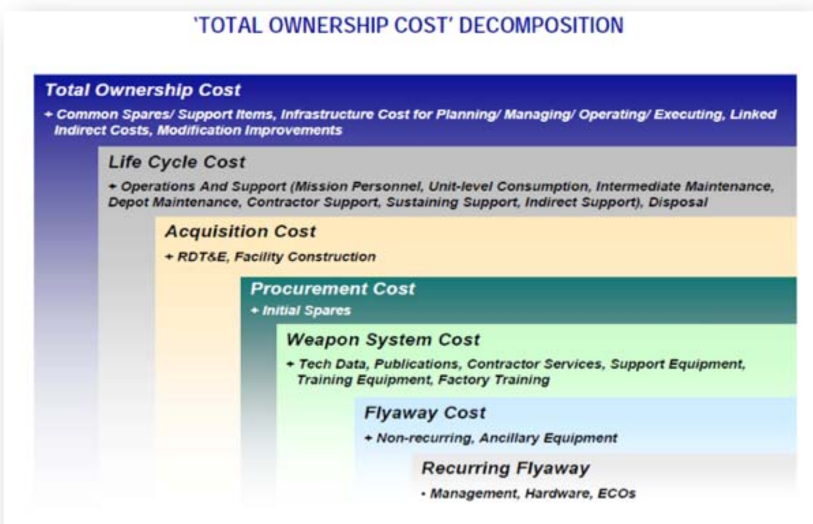

Figure 1. Total Ownership Cost Components at NAVAIR

DoD Acquisition Total Ownership Cost Concerns

DoD systems are often acquired with operational performance in mind during the engineering phase. For warfare systems, this is entirely appropriate as the systems are usually employing leading technology, operate in challenging environments, and their failure can result in potentially cataclysmic national impact. The acquisition of warfare systems has, however, manifested a higher total ownership cost over the lifetime of the system then was either predicted or anticipated when the program was originally made a program of record. Considerations for how a system would operate beyond the acquisition cycle has often fallen to the logisticians, maintainers, supply chain analysts, and communities involved with operations and maintenance. The total cost of operating the systems, however, during these phases can easily exceed 50% of the total cost of the system from birth until retirement.

While design for performance remains the key objective for systems acquisition, designing for affordability is emerging as a key companion objective which may require new system engineering practices, trade-off analyses, optimization and value assessment, and other modifications to the system engineering methodologies currently employed in a performance-first focus. Additionally, system engineering, logistics, and program organizational realignments also may be necessary to influence the entire enterprise to ensure that design for affordability is increased in stature as compared to design for performance. New methods of engineering emphasis on governance and analysis appear to be needed as major military acquisitions continue to exceed total ownership cost objectives and estimates.

Senior leaders in the DoD and the Navy have started to apply new emphasis to the reduction of total ownership cost (R TOC) of systems. This emphasis and reduction in total ownership costs has resulted in pilot programs that examine logistics, maintainability, and supply chain management issues that are intended to discover ways to improve readiness and reduce logistics footprint (Wynne, 2003). This has spawned research dedicated solely to reduction of TOC but often from a management (vice engineering) perspective (Boudreau, 2003). Recently, the Chief of Naval Operations stated that total ownership costs will become a priority at beginning of program start: “I tell my leaders if we’re going to talk about a program or policy we’re going to start with the discussion of total ownership costs before we get on to anything else. That’s absolutely key” (Roughead, 2010).

Additionally, to increase the visibility and measurability of affordability of a program, the Under Secretary of Defense has recently recommended that affordability be mandated as a requirement in any program (Carter, 2010).

It is well understood that the determining factors of total ownership cost are established early in the development of the system. The design decisions, architectures, logistics strategies, and operational concepts all are established early and, in effect, “set in concrete” the destiny of the overall lifecycle cost of the system. As shown in Figure 2, some chronic TOC problems are starting to show up where early estimates of total ownership cost have proven to be inaccurate, which brings unpleasant surprises later in the lifecycle of systems that have been deployed. This error in estimation or the inability to control ownership cost is causing significant perturbations to the operational and sustainment (O&S) budgets within the DoD.

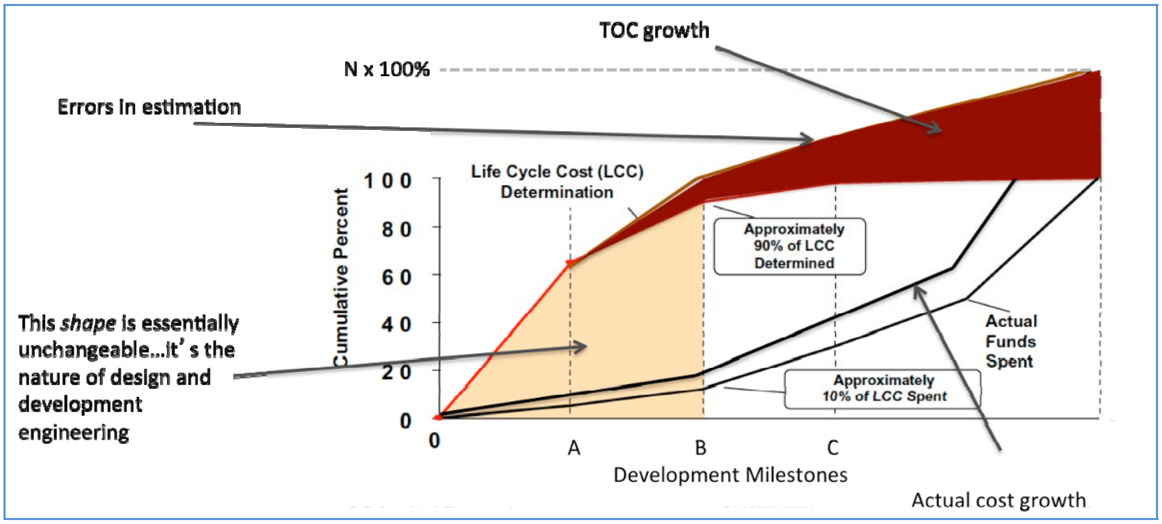

Figure 2. Dimensions of Total Ownership Cost Growth in the Acquisition Cycle
Note. This figure was derived from Eggenberger (2010).

As shown in Figure 3, these O&S costs can represent 70–80% of the total program cost. The question remains, if the trajectory of total ownership costs is set early in the design phase of a program acquisition, what can be done during those early phases to improve the accuracy of the estimates and ultimately the control of the cost later in the lifecycle?

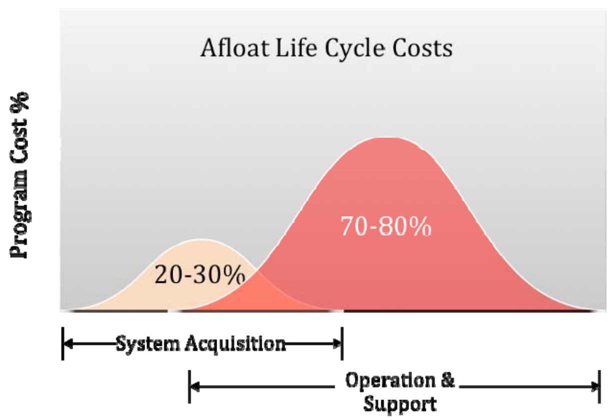

Figure 3. Distribution of Key TOC Components
(Eggenberger, 2010)

NAVAIR TOC Research

Problem Definition

The Naval Air Systems Command (NAVAIR) is a highly experienced and technical system acquisition organization that acquires U.S. Navy's aircraft and supporting systems. They have robust engineering and logistic processes that shepherd the acquisition of new systems into the Naval aviation enterprise. NAVAIR realizes, as with the other systems commands, that the estimation and control of TOC remains a challenge, especially in this era of high-tempo combat operations. An investigation is underway to examine whether or not specific processes can be improved to increase TOC estimation accuracy and control.

The System Engineering Development and Implementation Center (SEDIC) at NAVAIR has been investigating how the earliest system engineering activities influence TOC estimation accuracy and control and whether or not the system engineering activities can be improved upon. The authors have participated with the SEDIC to assist in the development of improved system engineering solutions and also to examine the opportunity to develop new SE metrics and tools to the larger system engineering community. Specific problems and research questions that we've established are listed as follows:

- **Problem:** Systems engineering (SE) is optimized for designing for best system performance but may not be aligned, prioritized, or defined well to designing for affordability and TOC objectives.
  - **Research Question 1:** How does SE contribute to TOC estimation, reduction, and control objectives and activities?
  - **Research Question 2:** Can SE activities be improved, better defined, or integrated into other TOC reduction activities to improve TOC estimation and control?
  - **Research Question 3:** Can TOC metrics be developed and integrated into SE and program activities and toolsets to quantitatively develop TOC KPPs, KSAs, MOEs, etc., and quantitatively assess program performance against those metrics?

This research positions itself between the system engineering activities that are typically associated with designing for performance and the system engineering activities and logistics activities which are often considered to be designing for affordability (see Figure 4). The research is attempting to find best practices that are successful in developing accurate TOC strategies as well as assisting in identifying improvements and linkages among these methodologies.

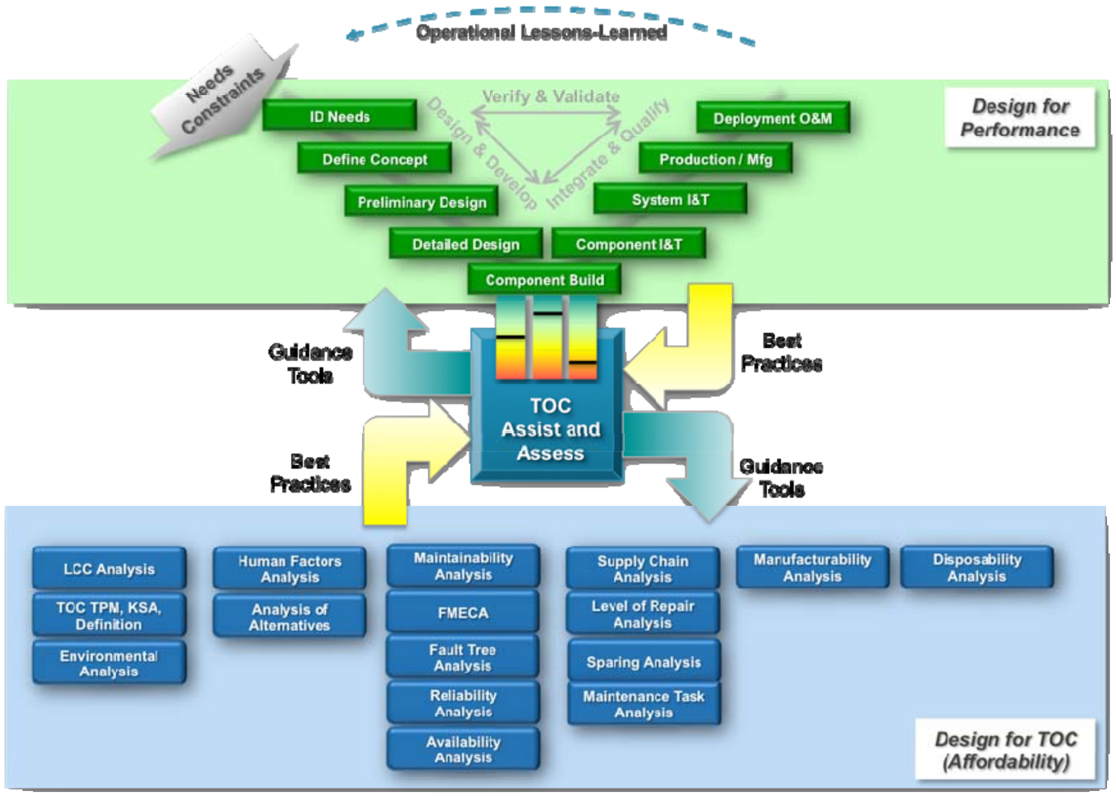

Figure 4. This Research Focuses at the Intersection of Design for Performance and Design for Affordability Methods and Practices

Previous and Related Methodologies

The estimation, measurement, and control of acquisition costs is not a new topic, nor is there a lack of techniques that are intended to control such costs. This research is highly focused on the early system engineering activities and how they can directly impact TOC estimation and control. We acknowledge proven bodies of knowledge and methodologies and will not reinvestigate or replicate but, rather, will attempt to integrate the most applicable facets of those methodologies into any SE methodology we may be able to discover. In particular, methodologies associated with (1) value methodology, (2) O&S cost engineering, (3) design to cost, and (4) cost as an independent variable form a substantial foundation upon which to build. Each of these disciplines, however, brings their own perspective to cost estimation and control and may be enriched by enhancing with system engineering activities that are also focused and similar areas. Following discussions highlight how these different existing disciplines are focused.

Value Methodology

Value methodology (VM; also Value Engineering, VE), is a structured approach used to analyze manufacturing products and processes, design and construction projects, and business and administrative processes. VM helps achieve balance between required functions, performance, quality, safety, and scope with system cost. The proper balance results in the maximum value for the project where value is often the ratio of cost-to-functionality (SAVE, 2011).

Value methodology is often implemented through a process consisting of a series of activities, including:

- Mission and requirements definition,
- Functional analysis,
- Alternative synthesis, and
- Evaluation, trade-off, and selection.

This methodology is mature and SE has inherited and incorporated many of the VM tenants in Functional Analysis and Allocation, Requirements Engineering, and System Analysis processes. Applicability to this research is the proposition of “value” and how that assessment relates to the “value” metrics of TOC.

Cost Engineering

The Operating and Support (O&S) Cost element structure is often divided into six major categories: (1) personnel, (2) operations, (3) maintenance, (4) sustainment support, (5) system improvements, and (6) indirect support (OSD, 2011). At NAVAIR, the cost process includes the following activities:

- Break-Even Analysis,
- Present Value Analysis,
- Regression Analysis,
- Forecasting,
- Sensitivity Analysis,
- Should Cost Analysis,
- Cost Modeling,
- Financial Analysis,
- Cost Data Analysis,
- Proposal Analysis,
- Overhead Analysis,
- Rate Analysis,
- Engineering Cost Analysis, and
- Learning Curve Application. (NAVAIR, 2011)

The varied analysis and modeling activities mentioned previously are highly dependent on accurate, high-fidelity engineering inputs in order to produce high-confidence cost estimates. The focus of this research is not to explore different cost engineering methodologies, but rather to discover better ways of performing systems engineering to produce more meaningful, relevant, accurate, high-confidence information that serve as inputs to the models and estimate analyses of cost engineering; all with a focus on TOC.

Design-to-Cost (DTC) and Cost-as-an-Independent-Variable (CAIV)

The Design-to-Cost (DTC) methodology focuses upon projected average unit production costs (with O&S as a second-order factor). We feel the DTC process and metrics may often work against control of TOC. With the emphasis on production costs, the program management team may obscure the long-term TOC issues during development in order to satisfy DTC objectives.

Cost-as-an-Independent-Variable (CAIV) is another methodology (like DTC) that uses cost as an end goal. In CAIV, cost is treated as an independent variable among the three variables traditionally associated with a defense acquisition program: cost, schedule, and performance. Cost is “fixed” and other variables traded off against the fixed constraint of cost. Most often, the “cost” associated with CAIV are, indeed, total program and life cycle costs (i.e., TOC). The control or reduction of estimated future life-cycle costs are considered as important as trade-offs to meet the schedule and performance thresholds (Land, 1997).

We anticipate that CAIV methodologies are very closely related to the end goals of this research. Our thesis is that CAIV methods are only as good as the inputs received to perform meaningful cost trade-offs. The goal is to improve those inputs and processes related to SE to improve upon CAIV, where used. Additionally, we are searching to find opportunities to decompose CAIV into other components such as RMA (reliability, maintainability, and availability) as an independent Variable (MAIV), or TOC as an independent variable (TAIV), etc.

NAVAIR Technical Approach

The technical approach for this research is shown in Figure 5. The desired outcomes are to publish best practices to the system engineering (primarily), competency engineering (e.g., aero engineering, mechanical engineering, etc.), logistics, and program management communities at NAVAIR. We also seek to improve existing review processes (i.e., SE Technical Reviews, SETR). Finally, we want to identify and be able to assess metrics that emerge from system engineering that can provide program and engineering managers an assessment of the confidence of their program’s TOC posture.

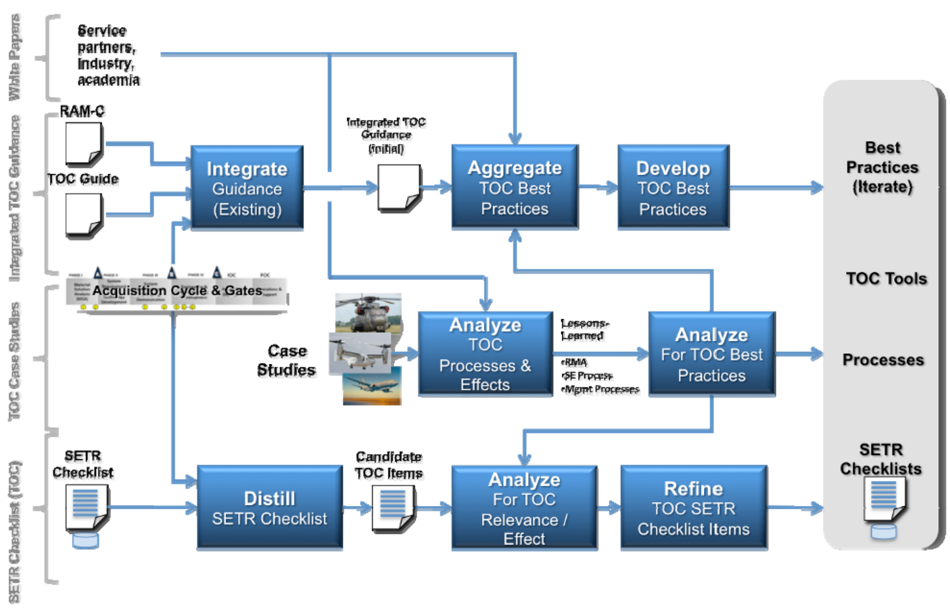

Figure 5. Technical Approach to TOC Research at NAVAIR

As stated in the previous section, we are leveraging well-established methods within the DoD and in industry that are supported by recent academic research (e.g., CAIV, cost engineering, etc.). Using that as a baseline, we are integrating emerging standards related to TOC or reliability, availability, and maintainability into a first-order guidance that is aligned to the acquisition cycle milestones and gate reviews. Currently, NAVAR uses a checklist tool that aids the program and engineering managers to navigate the technical review process (SETR), and we are evaluating how design considerations related to TOC are included in those lists in a relevant and clear manner, as well as considered early and continually throughout the acquisition process. Finally, we are examining various acquisition program case studies to understand where they encountered problems in TOC estimation or control to understand best practices or common themes that could reveal necessary remediation in the system engineering methods.

Current Findings

Case study analysis, interviews, documentation integration, and process improvement activities are in early phases and have yet to generate major discoveries. This paper, however, lays out the technical approach and strategy with some early findings that will set the stage for continuing dialogue and discussion as this research proceeds.

Throughout many interviews with engineers experienced with system development at NAVAIR, certain themes are emerging. The impacts to TOC growth, in many cases, could be categorized as caused by operational, process, and/or design issues (see Figure 6). Unanticipated operational tempo or harsh real-world environments caused TOC growth from the exigencies of combat operations that were not anticipated, and these operations were conducted in particularly harsh environments (e.g., heat, sand, etc.). Some of the aircraft systems were of unusually high complexity and introduced new technologies unlike previous aircraft. This dissimilarity made early TOC estimates difficult with high degrees of uncertainty. Finally, processes and analyses associated with reliability, maintainability, and availability (RMA) and integrated logistics support (ILS) analyses were challenged at early design phases; that also resulted in high variance in final TOC. These three dimensions appear to have strong mutual coupling of their dependencies and each have impacts on TOC. The intent is to discover these independencies and correlated effects through case study analysis.

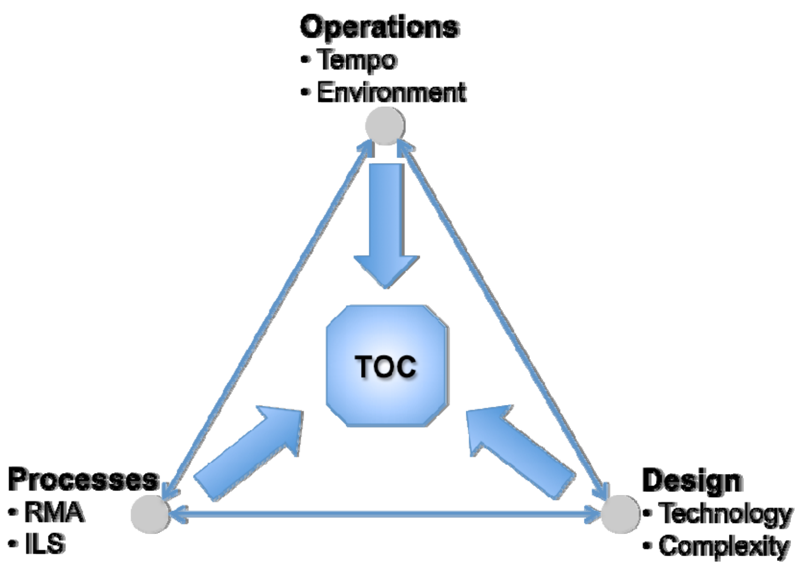

Figure 6. Key Contributors to TOC Derived From Case Studies

Documentation and Guidance

As we examine the emerging guidelines for TOC and reliability, maintainability and availability, we found through interviews and user interaction that the documentation had not been placed into common usage. It became apparent that many documents brought different perspectives that were difficult for the engineering teams to reconcile. In other cases, the documentation did not translate well into the design phase or acquisition process of the program. Additionally there was little quantitative help in either of the documents.

We were able to parse and aggregate the emerging standards and documentation where appropriate to align the relevant portions of each to the proper technical reviews, major milestones, and associated gate reviews. Currently, we have integrated that information into a tool that is web-based and are now exposing the engineering community to the tool to get feedback as to its effectiveness.

Figure 7 depicts an example of how portions of documentation are being aggregated to align with the major milestones, and Figure 8 indicates a similar alignment of the documentation to the gate reviews. The web-based tool allows the user to investigate which TOC issues need to be addressed prior to the reviews or the milestones as they progress in the development cycle.

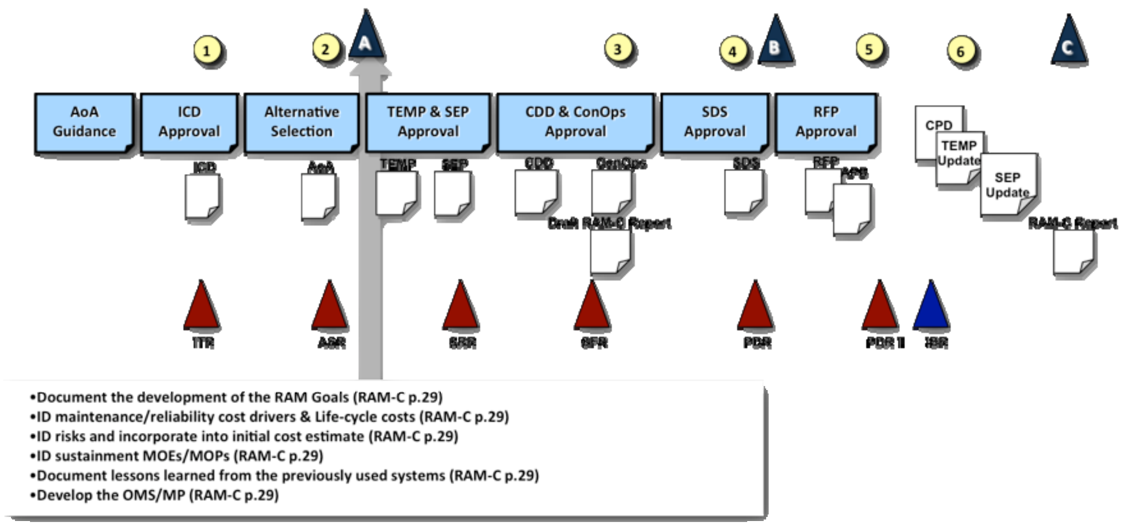

Figure 7. Integrating Standards and Aligning to Major Acquisition Milestones

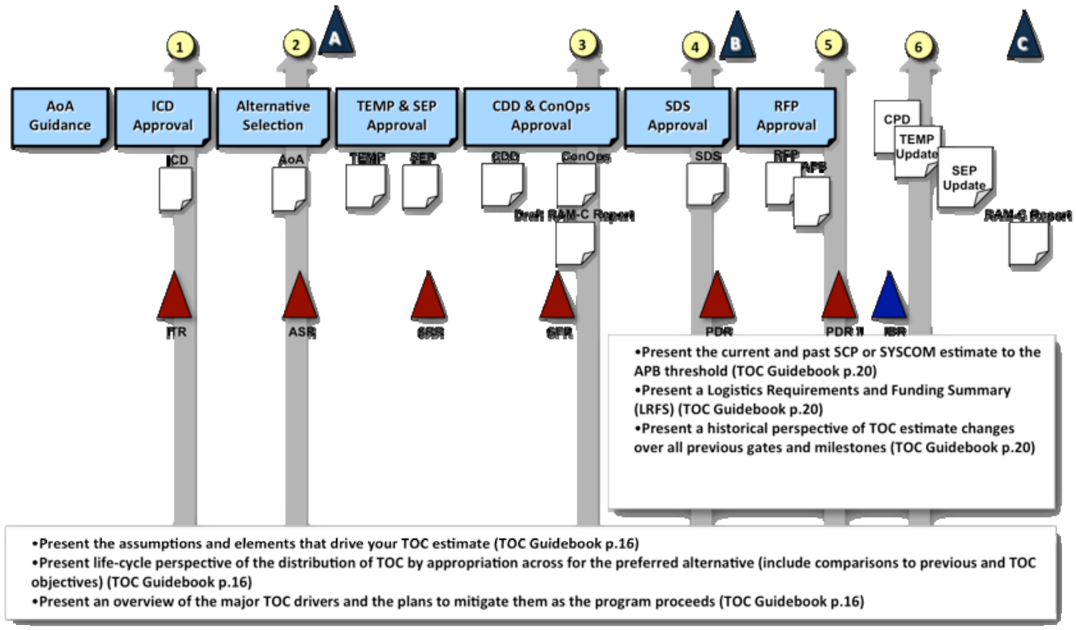

Figure 8. Integrating Standards and Aligning to Gate Reviews

Technical Review Checklist

We are carefully reviewing the large body of SE technical review items that are currently used in the NAVAIR SETR checklists for applicability to TOC. We are exploring specific checklist items that pertain to TOC, how the language of the checklist item can be strengthened relative to TOC objectives, timing of the items, and whether they expose or stimulate necessary engineering activity to help increase TOC estimation accuracy at the correct phase of an acquisition. Figure 9 indicates an early assessment of how many TOC related checklist items are addressed at each design review as prescribed by current checklist policy. Although this data is very preliminary, it does support how design decisions related to TOC are most appropriately applied early in the program. The results of this activity will be to produce a set of refined and more directed checklist items (relative to TOC) they can be reintegrated into the existing web-based checklist tool.

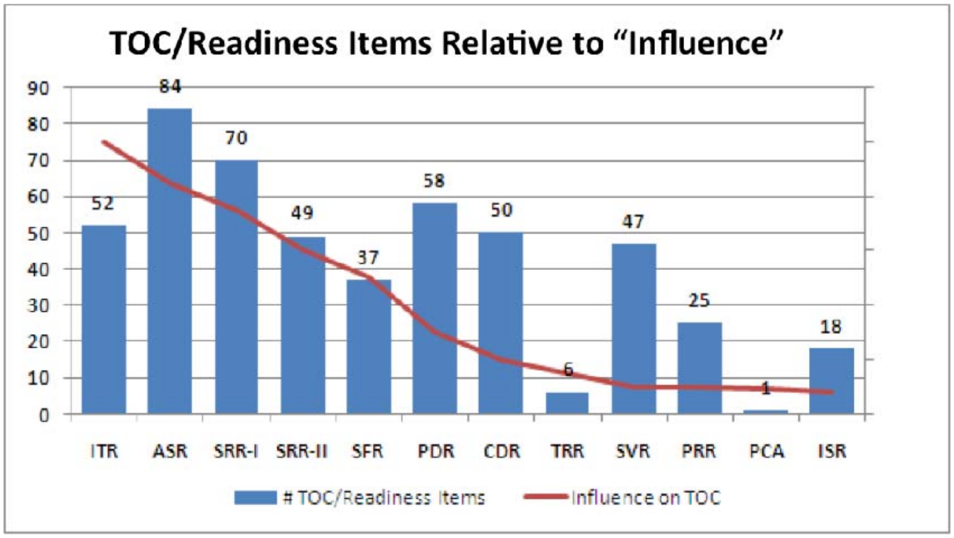

Figure 9. TOC-Related SETR Checklist Items Appear Appropriately Front-Loaded During Acquisition

Reliability Analysis

Initial case study interviews indicate there is a strong correlation between the early reliability and maintainability analysis performed on the program and the quality of assessing the TOC of the program. It's generally accepted at the working level that reliability analyses that are performed during the early design phases have a high degree of uncertainty because of the many undefined features of the system that is being designed. As the design proceeds, reliability analyses become more accurate as they reflect more and more actual components that will comprise the system. Unfortunately, early program TOC estimates must be based on these early reliability analyses which, when published, can overly bias the later TOC estimates that use the refined RMA data, thus creating high variance in total program TOC control. We will continue to investigate process improvements, additional metrics, and the strength of correlation between TOC growth and early reliability estimations.

Cost Modeling

Early coordination with cost estimation organizations confirms that while those organizations have high confidence in the cost models, the models themselves and the resulting outputs are, of course, dependent on the quality of input. Currently we are investigating inputs to the cost model related to the technical baseline of the system, spare parts, depot level repair strategy, and related supply chain issues, as these are indicating a strong impact on model performance.

SE Process Alignment

Together with aggregation of emerging standards into a guidance document, we are also investigating how to align SE processes to the TOC objective and also maintain alignment with technical reviews and gate reviews. As shown in Figure 10, we are starting to model and posit alignment of SE activities that will be explored further and validated within the NAVAIR community.

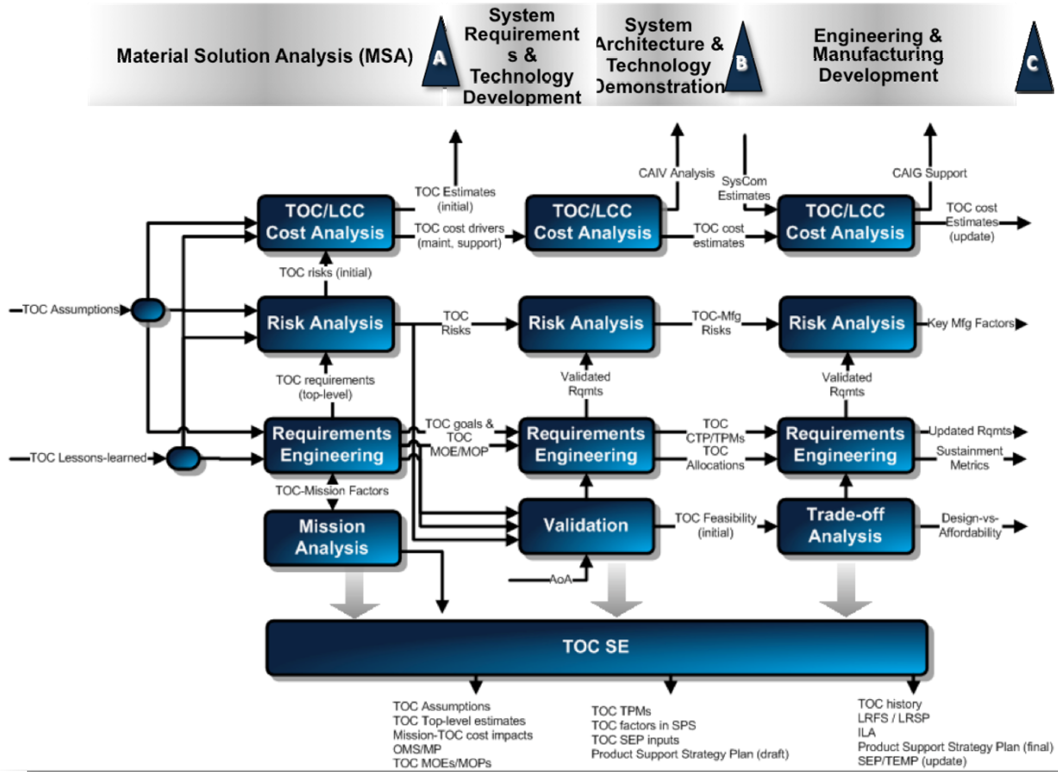

Figure 10. Initial SE TOC-Related Process Alignment to Acquisition Cycle

Summary and Future Research

This research investigates how SE processes and methods can be improved to increase the fidelity of TOC estimation and, ultimately, TOC control at NAVAIR. Early findings are beginning to point to the conclusion that there are opportunities for improvement both in SE processes but also the tools and documentation and guidance which is distributed throughout the organization.

We are investigating existing documentation and integrating that documentation into guidelines that are meaningful to TOC. We are trying to enrich existing tools (with TOC relevance) that guide engineering and acquisition teams through the technical development and review process. We are investigating historical and ongoing aircraft acquisition programs to discover best practices and to reveal opportunities for processes to improve TOC. Finally, we are in the early phases of uncovering SE metrics that may aid in the development of tools for the program management and engineering management teams to assess the TOC posture of their program. Further research will continue along the activities outlined in this paper and will be shared in subsequent papers and forms.

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Acknowledgments

The authors have been working in close collaboration with the members of the NAVAIR SEDIC team at NAS, Patuxent River, MD, in the conduct of the subject research. Much of the foundational work referred to in this paper is a result of their efforts. The team includes John Quartuccio and Paul Hood of NAVAIR and Johnathan Gilliard and Tina Denq from Booz Allen Hamilton.

Disclaimer

The opinions in this paper are the authors' and do not necessarily reflect the opinion of NAVAIR or the SEDIC team members.

Applying an Influencer Approach to Ingrain Systems Engineering into Pre-Milestone B Defense Programs

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Mr. Keane is widely recognized as an expert in naval ship design, is a plank holder in the Navy's Center for Innovation in Ship Design at NSWCCD, and has fostered the professional development of engineers and scientists in government and industry. He received his Bachelor of Engineering Science in Mechanical Engineering from Johns Hopkins University, Master of Science in Engineering in Ship Hydrodynamics from Stevens Institute of Technology, and Master of Science in Engineering in Naval Architecture and Marine Engineering from the University of Michigan.

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Mr. Keane has received many honorary awards including the Secretary of the Navy Distinguished Civilian Service Award, Department of the Navy Superior and Meritorious Civilian Service Awards, SNAME David W. Taylor Medal, ASE Silver Medal, ASE Professional Achievement Award, SNAME Distinguished Service Award, two SNAME Elmer Hann Awards for Best Paper, ASE John Niedermair Award for Best Paper, and election as a Fellow of SNAME. Mr. Keane and his wife Judy have three sons and four grandchildren. [keanerg@comcast.net]

Factors Influencing the Effectiveness of Systems Engineering Training and Education in the Department of Defense

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Abstract

While current systems engineering certification courses within the Department of Defense appear to do a pretty good job of training and educating the workforce, improvements can be made. The use of more problem-based methods of learning would equip the students with better problem identification and reasoning skills needed to solve the complex problems they encounter on the job. Learning outcomes in some of these courses could be rewritten to target the *analyze, evaluate,* and *create* levels of Bloom's Taxonomy, thereby improving student critical thinking skills and ultimately improving far-transfer of learning to the job. Also, learning assessment methods in a few of the courses could be changed to focus more on the assessment of conceptual understanding, vice rote memorization, in order to promote deep learning. Recommendations are also presented for additional research into a more effective systems engineering andragogy.

Purpose

Competency-based training for defense acquisition workers in the systems engineering discipline is accomplished through a continuum of four courses developed and delivered by the Defense Acquisition University (DAU):

- SYS 101 Fundamentals of Systems Engineering; computer-based distanced learning; 35 hours.
- SYS 202 Intermediate Systems Planning, Research, Development and Engineering, Part 1; computer-based distance learning; 30 hours.
- SYS 203 Intermediate Systems Planning, Research, Development and Engineering, Part 2; resident course; 36 hours.
- SYS 302 Technical Leadership in Systems Engineering; a resident course; 68 hours.

The primary purpose of this research was to determine if the methods and objectives of these systems engineering certification courses encourage a deep approach to learning and far-transfer of that learning (i.e., the students are able to apply what they have learned on the job). Ultimately, the effectiveness of systems engineering training within the Department of Defense does affect the outcome of systems acquisition programs.

Method

A literature search revealed that a problem-based approach to teaching systems engineering, with the primary objective of developing the student's ability to reason and solve complex problems (i.e., develop critical thinking skills), would result in deep learning and promote skill transfer to the job. Therefore, I decided to study the current design of systems engineering courses to determine how much problem-based instruction was actually used. To gauge the stimulation of student critical thinking skills in these courses, I examined student learning outcomes for each of the systems engineering courses discussed above. I also examined the learning assessments for each course to determine if they had been designed to promote deep or surface learning by the students.

Student course materials and learning objectives from the four systems engineering certification courses discussed previously were analyzed in three ways. First, student materials were inspected to determine the time allocated to computer-based training (CBT), lectures, and problem-based exercises in each of the courses. These student course materials are available to the public on the DAU *iCatalog* website (DAU, 2011).

Second, the lesson objectives (expected student outcomes) for each of the four systems engineering certification courses were categorized according to their required levels of functional thought, using Bloom's Taxonomy (Bloom, 1956, updated in accordance with Figure 1). Specifically, the measureable action verb from each learning objective was placed into one of the six Bloom categories representing the cognitive activity required by the student to successfully demonstrate that objective. The lesson objectives are available to the public on the DAU *iCatalog* website (DAU, 2011).

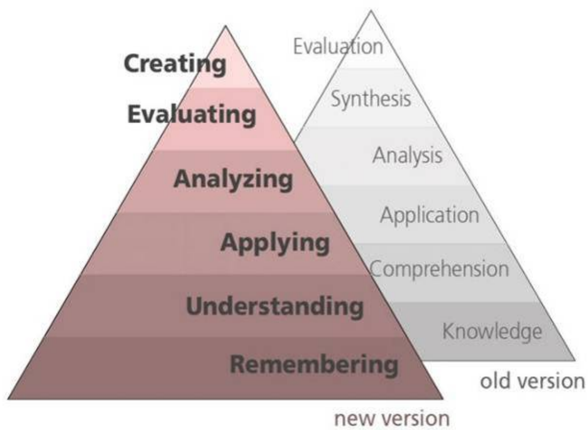

Figure 1. Bloom's Taxonomy
(Rodgers, 2011)
Note. This figure contrasts the original (old) version with an updated (new) version; note changes in top two levels.

Third, the course learning objectives (expected student outcomes) from three selected systems engineering courses developed and delivered by the Naval Postgraduate School (NPS) were categorized according to their required levels of functional thought, using Bloom's Taxonomy. The three courses were as follows:

- SE3100 Fundamentals of Systems Engineering; resident and distance learning; 5 quarter hours (3 lecture/2 lab); equivalent to DAU SYS 101, SYS 202, and SYS 203.
- SI3400 Fundamentals of Engineering Project Management; distance learning; 5 quarter hours (3 lecture/2 lab); equivalent to DAU SYS 302.
- SE4012 Management of Advanced Systems Engineering; distance learning; 4 quarter hours (4 lecture/0 lab); equivalent to DAU SYS 302.

The course learning objectives were obtained from Professor Gary Langford of the Systems Engineering Department, Graduate School of Engineering and Applied Sciences, NPS.

Finally, student learning assessments were examined in the four DAU and the three NPS systems engineering course to determine if the current assessments promoted deep or surface learning. Surface learning is promoted by assessments that emphasize recall based upon rote memorization. Deep learning is promoted by assessing the student's understanding of topics (Felder & Brent, 2005, p. 64).

Results

Time allocated to computer-based training (CBT), lectures, and problem-based instruction in each of the four systems engineering certification courses developed and delivered by DAU are found in Table 1.

Table 1. DAU Systems Engineering Course Hours Categorized by Method of Instruction
(DAU, 2011)

Course	CBT Hours	Lecture Hours	Problem-Based Hours	Total Hours
SYS 101	35			35
SYS 202	30			30
SYS 203		9	27	36
SYS 302		21	47	68
Totals	65	30	74	169
Percentage	**38.46%**	**17.75%**	**43.79%**	**100%**

Lesson learning objectives (expected student outcomes), categorized by Bloom's level, for each of the four systems engineering certification courses developed and delivered by DAU are found in Table 2.

Table 2. DAU Systems Engineering Course Objectives Categorized by Bloom's Level
(DAU, 2011)

Course	Remember	Understand	Apply	Analyze	Evaluate	Create	Total Objectives
SYS 101	14	138	1	1			154
SYS 202	1	29					30
SYS 203	3	9	5	6	12	1	36
SYS 302	2	49	14	8	24	28	125
Totals	20	225	20	15	36	29	345
Percentage	**5.80%**	**65.22%**	**5.80%**	**4.45%**	**10.43%**	**8.41%**	**100%**

Course learning objectives (expected student outcomes), categorized by Bloom's level, for three selected systems engineering courses developed and delivered by NPS are found in Table 3.

Table 3. NPS System Engineering Course Objectives Categorized by Bloom's Level
(NPS, 2011)

Course	Remember	Understand	Apply	Analyze	Evaluate	Create	Total Objectives
SE 3100	2	1	2	2	1	2	10
SI 3400	1	1	6	1		1	10
SE 4012	2	2	1	1		1	7
Totals	5	4	9	4	1	4	27
Percentage	**18.52%**	**14.81%**	**33.33%**	**14.81%**	**3.70%**	**14.81%**	**100%**

The types of assessments used in the four DAU systems engineering certification courses and the three NPS systems engineering courses are found in Table 4.

Table 4. Types of Learning Assessments Used in DAU and NPS Systems Engineering Courses
(DAU, 2011; NPS, 2011)

Assessment	SYS 101	SYS 202	SYS 203	SYS 302	SE 3100	SI 3400	SE 4012
Objective Exam/Quiz	X	X	X	X	X	X	X
Subjective Exam/Quiz					X	X	X
Homework					X	X	X
Discussion Participation			X		X	X	X
Reflective Writing						X	
Individual Briefing			X	X	X	X	X
Individual Project					X	X	X
Team Project			**X**	**X**	**X**	**X**	**X**

Discussion

The results of this research, as presented in Table 1, reveal that DAU systems engineering certification courses use a mix of computer-based training, lecture, and problem-based instruction. The SYS 101 and SYS 202 courses are designed as computer-based training for individuals and have no student-led problem-solving exercises. However, SYS 202 does use an integrated case study to help the student understand systems engineering in the context of a notional defense weapon system. The SYS 203 course was designed as the exercise extension of SYS 202, so students in SYS 203 spend about 75% of the class time in problem-solving exercises. Problem-solving exercises also account for 69% of the class hours in the SYS 302 course. Thus, two of the four DAU systems engineering certification courses do provide students with significant amounts of problem-based instruction.

With respect to student learning objectives, the DAU SYS 203 and SYS 302 courses grade out at higher Bloom's levels (*analyze, evaluate,* and *create*) in about half of their learning objectives (see Table 2). These top three Bloom's levels are usually associated with critical thinking. Bloom's *understand* level predominates in the other two DAU systems engineering courses.

Half of the student learning objectives for the NPS SE3100 course grade out at the critical thinking level (e.g., *analyze, evaluate,* and *create*; see Table 3). Bloom's *apply* level predominates in the NPS SI3400 course and the *remember* and *understand* levels are the focus of the NPS SE4012 course.

It should be noted that Tables 2 and 3 are not directly comparable. The assessment in Table 2 is based upon *lesson objectives* in the four DAU systems engineering certification courses, of which there are a great number. The assessment in Table 3 is based upon *course objectives* from the three NPS systems engineering courses, of which there are but a few. Also, the number of hours of CBT, lecture, and problem-based instruction in the NPS courses was not clearly identified on the syllabi examined. Therefore, no categorization of instructional methods for the NPS courses was possible (and methods can be expected to vary by instructor).

With respect to course assessments, further research into the types of objective and subjective questions is needed to conclusively determine if the questions really assess the depth of student learning (see Table 4). However, deep learning by the students taking the SYS 101 and SYS 201 courses might be encouraged through the use of other assessment methods besides online multiple choice exams. While this might seem difficult for computer-based training, it is certainly not impossible. For example, computer simulations, scored games, and intelligent essay assessors might be used. The other DAU certification courses and the three NPS courses appear to have a good mix of both objective and subjective assessments that encourage a deep approach to learning.

Based upon this research, deep learning, which promotes the development of critical thinking skills, can occur in the SYS 203 and SYS 302 courses when students are involved in problem-based exercises. However, both SYS 101 and SYS 201 could be improved by adding problem-solving scenarios to stimulate the mind and help students build more sophisticated mental models of the systems engineering discipline earlier in their training. Also, more of the lesson objectives within all of the DAU systems engineering courses could be written with verbs that target the *analyze, evaluate,* and *create* levels of Bloom's Taxonomy.

Some might argue that the systems engineering fundamentals course (SYS 101) and intermediate course (SYS 201) have to first target the *remember* and *understand* Bloom's levels before students are able to move on to the *analyze, evaluate,* and *create* levels that develop student critical thinking skills. I would disagree. Research has shown that that even novice adult students benefit from learning approaches that build on past experiences. From a constructivist point of view, the goal of training and education is to develop within the student increasingly sophisticated ways of reasoning and problem solving. In effect, exposure to problem solving, even in these initial courses, would help students build bridges from their current ways of thinking to more correct contextual ways of thinking about systems engineering. Rather than filling their brains with lists of terms and acronyms that they may not even be able to apply, the goal should be to correct any pre-existing mental models and mature the right mental models that students need in order to succeed in the complex world of defense systems engineering (Pratt, n.d., p. 4).

Similar observations can be made regarding the three NPS systems engineering courses. Since the three courses provide equivalent credit to the DAU systems engineering certification courses, far-transfer of learning to the job is essential. Course learning objectives requiring students to *remember, understand,* and *apply* could be rewritten to challenge students to think critically (i.e., *analyze, evaluate,* and *create*). Of course, this would also require that the context for these objectives be stepped up from lecture to problem-based instruction and that students be assessed to the higher Bloom's levels of functional thought.

In the balance of this paper, I summarize my literature search that led me to conclude that deep learning and far-transfer of learning to the job are best achieved using problem-based instruction that challenges students to think critically. I also suggest areas for further research.

Learning—What Really Works?

Since 1986, Ken Bain, Director of the Center for Teaching Excellence at New York University, has conducted ongoing research to identify and examine highly effective university and college teachers. In his book, *What the Best College Teachers Do*, one of the questions that Bain asked was the following: What do the best teachers know about how students learn? Here are the top four answers:

- Knowledge is constructed, not received, and students bring pre-existing paradigms to the class that shape how they construct meaning.
- Mental models change slowly and only by challenging students intellectually (i.e., engaging them in deep thinking).
- Questions are crucial because they help students construct knowledge.
- Caring is crucial; if students don't ask important questions and care about the answers, they will not try to reconcile or integrate new information and replace old mental models. (Bain, 1986, pp. 26–32)

The implications for how we should teach systems engineering are significant. Bain reports that the best teachers create a natural critical learning environment in which knowledge and skills are incorporated into real-world (i.e., authentic) tasks that engage the student, arouse their curiosity, and challenge their assumptions (i.e., mental models). He also saw the best teachers create safe learning environments, where students were free to fail, receive feedback, and try again before being assessed. And finally, Bain found that the students understood and retained what they had learned because they had exercised their reasoning abilities to solve problems that concerned them (Bain, 1986, pp. 46–47). In other words, deep learning rather than surface learning had occurred.

Bain (1986) concludes the following:

> The most effective teachers use class time to help their students think about information and ideas the way scholars in the discipline do. They think about their own thinking and make students explicitly aware of that process, constantly prodding them to do the same. They do not think only in terms of teaching their discipline; they think about teaching students to understand, apply, analyze, synthesize, and evaluate evidence and conclusions. (pp. 114–155)

As discussed earlier, teaching to *analyze, evaluate,* and *create* challenges students to think critically.

Learning Style Preferences

One of the potential traps with systems engineering instruction is falling back into traditional methods of engineering instruction. I experienced traditional instruction in my undergraduate years as I pursed a Bachelor of Science degree in the engineering sciences. Most of my chemical, electrical, mechanical, and materials science classes were taught as lectures. The problem is that I'm a *visual* learner. I understand concepts and information most readily when they are presented in pictures and flow charts or by demonstrations.

Richard Felder, a professor emeritus of chemical engineering at North Carolina State University has studied the learning style preferences of over 2,500 engineering undergraduate students at 12 universities. He and his colleagues have found the following:

- 82% of these students are *visual* vice verbal learners, preferring pictures, diagrams, flow charts, and demonstrations;

- 64% of these students are *active* vice reflective learners, processing information through engagement in physical activity;
- 63% of these students use their *senses* vice intuitions, perceiving sights, sounds, and physical sensations; and
- 60% of these students are *sequential* versus global learners, preferring a logical progression of incremental steps.

Yet, engineering instruction at the schools they attend is primarily verbal, reflective, and often intuitive, emphasizing theory and mathematical modeling over demonstration or the use of visual aids (Felder & Brent, 2005, p. 61). Could this mismatch of learning style preference and methods of instruction be a problem in systems engineering training and education within the Department of Defense? Perhaps future research could sample the learning style preferences of systems engineering students taking the four DAU certification courses (and equivalent courses) and compare those student preferences with the teaching styles of the instructors.

We have intuitively known that a picture is worth a thousand words. When compared with written words or verbal communications, people actually do communicate more simply and efficiently with pictures or visual images. This is due to our natural ability to process and retain visual images in our minds. Pictures are *information-rich* and can convey more precise meanings and more clearly depict ideas (Gerard & Goldstein, 2005, pp. 18, 45). Learning transfer can also be improved with images. With images, patterns emerge, revealing relationship. These patterns also help in understanding how processes work. Communicating ideas with a visual image can result in clearer understanding of complex processes (see also Mintzberg & Westley, 2001, pp. 92–93).

Kevin Forsberg, Hal Mooz, and Howard Cotterman (2005) from the Center for Systems Management have dedicated the third edition of *Visualizing Project Management* to "mastering complexity" (p. xxi). They say that logical and systematic project management and systems engineering processes are left-brain activities. To stimulate creativity, the visually oriented right-brain needs to be engaged. Therefore, their book is full of visual models that simplify these complex process and help the student understand how things really work (Forsberg, Mooz, & Cotterman, 2005, pp. xxiv–xxv). In particular, they use the "V" model to depict the systems engineering process of top down requirements decomposition and design definition and bottom-up system integration and validation. It should be noted that the DAU and NPS systems engineering courses studied in this research all make good use of visual models.

Far-Transfer of Learning to the Job

In her book, *Building Expertise: Cognitive Methods for Training and Performance Improvement*, Ruth Colvin Clark (2008) discusses the psychology of learning transfer and practical ways to teach for transfer. She posits that far-transfer of learning, the ability to solve ill-defined or ambiguous problems on the job, comes from creative and critical thinking (Clark, 2008, pp. 234, 245). Yet, far-transfer of learning does not result from a single training event. In addition to training, far-transfer requires an innovative culture, collaborative projects, diverse work experiences, and the ability to reason within unfamiliar contexts or on novel tasks (i.e., fluid intelligence; Clark, 2008, p. 249).

To promote far-transfer of learning, Clark recommends the inductive training technique. Inductive training can be described by comparing it with traditional training. During traditional training, the *instructor* presents the content, the *instructor* provides examples, and the *students* apply the content. Inductive training changes the sequence and puts more emphasis on active engagement of the students: the *instructor* provides examples, the *students* derive the content, and the *students* apply the content. Traditional training actively engages the students only one third of the time; inductive training actively engages the students two thirds of the time (Clark, 2008, p. 270).

According to Clark (2008), the reason that inductive learning enables far-transfer of learning is because the students are engaged in building a personal mental model based on their own experience and collaboration with other students. Clark also recommends the use of simulations (used in a guided discovery mode) and problem-centered instruction. Both methods promote far-transfer of thinking skills by engaging the students to build their own knowledge and skill base in long-term memory (i.e., mental models) within a real-world context (Clark, 2008, pp. 273, 283–285).

Many others agree with Clark. Nobel laureate Herbert A. Simon, a professor of psychology and computer science at Carnegie Mellon University who studies human decision making has concluded that experience (e.g., from a problem-solving exercise) enables us to "chunk" information so that we can store and retrieve it more easily (as reported by Hayashi, 2001, p. 7). Felder and Brent (2005) say that inductive teaching methods such as problem-based and project-based learning can motivate students by making subject matter relevant to prior and future experiences, emphasizing conceptualization, versus rote memorization (p. 64).

Learning for Rapid Cognition

In his book *Blink: The Power of Thinking without Thinking*, Malcolm Gladwell (2005) explains how rapid cognition that happens in a blink of an eye can be used to make fairly good decisions in otherwise complex situations. Psychologists call the critical part of rapid cognition *thin-slicing,* which refers to the ability of our subconscious mind to recognize *patterns* in everyday life situations based upon narrow slices or samples of experience (Gladwell, 2005, p. 23). For example, I can tell by my wife's voice, within the blink of an eye, if she is happy, sad, or mad. Even on the telephone, the patterns of her voice—just her first few words—give me all the clues I need to correctly determine her mood. This is based upon my experience in listening to her and the fact that I love her dearly. I have created in my mind an array of mental models of her different voice patterns. Can rapid cognition be useful in training systems engineers to recognize and act on problems even in the complex environment of defense systems engineering? Perhaps it can.

Gladwell (2005) tells the story of Cook County Hospital (Chicago, IL) that has a trauma center that inspired the television series *ER.* Faced with overwhelming costs and a shoe-sting budget Brendan Reilly, chairman of the hospital's Department of Medicine, turned to cardiologist Lee Goldman who, based upon his years of experience with heart attacks, came up with an equation for predicting if chest pains really meant that a heart attack was about to happen. In the past, doctors would ask lots of questions of the patient, ask for expensive tests, and as a precaution, admit the patient. When Goldman's decision tree (i.e., pattern analysis) was implemented in the hospital emergency room over a two-year period, diagnoses were 70% better than the old method. The point, according to Gladwell, is that too much information confuses the issue and makes it harder to pick up the basic signature of the problem (i.e., the pattern; Gladwell, 2005, pp. 125–136, 142).

Nobel laureate Herbert Simon has concluded that "experts see patterns that elicit from memory the things they know about such situations [and]…what distinguishes experts is that they have very good encyclopedias that are indexed and pattern recognition that is that index" (as quoted in Hayashi, 2001, p. 63). So, what patterns should we be teaching our systems engineering students? For example, are there patterns in technical reviews, earned value analysis, or risk assessments that could instantaneously (in the blink of an eye) let them know whether a problem exists? Moreover, if every systems engineer working for or with the Department of Defense used decision trees prepared by systems engineering experts, would our system acquisition programs have better outcomes? Twenty years ago when I attended the Defense Systems Management College Program Management Course, I recall the recommendation to use the Willoughby templates to identify risk areas when transferring systems from development into production. Today these templates have been incorporated into the Best Manufacturing Practices Center of Excellence (BMPCOE) Technology Risk Identification and Management Systems (TRIMS). Would more emphasis on the use of such expert templates simplify issue and risk identification for earlier responses and ultimately help our acquisition programs succeed?

Learning Patterns of Response

According to UCLA Professor Moshe Rubinstein, an internationally renowned authority on problem solving and creativity in organizations, "We must learn to live harmoniously with change, chaos, and uncertainty. It is now the age of the brain. It is the age of finding ways to tap more of the human potential for creativity and innovation, to learn to adapt to chaos and uncertainty, and to use our minds to establish a sense of purpose and meaning in our personal and professional lives" (Rubinstein & Firstenberg, 1999, p. 20). In an age of growing connectivity and complexity, to include more complex defense systems, we must be able to embrace uncertainty, change, and chaos. According to Rubinstein, the human brain has the capacity to do just that.

During a recent weekend getaway to Marin County, CA, my bride and I took some time to visit the national office and kennels of Guide Dogs for the Blind in San Rafael. While touring the kennels, we were told that the young Labrador Retrievers are actually trained to respond in patterns of behavior. Clearly, the training course can never simulate all of the possible obstacles (to include change, chaos and uncertainty) in a city, home, work, or recreational environment that these young Labs will encounter. So, the Labs are taught "patterns of response" in order to lead the blind person around obstacles in their path. Can systems engineering training and education take a lesson from how guide dogs are trained?

Robert C. Collins, MD, a professor and the chair of the Department of Neurology at the UCLA School of Medicine, has discovered that brain wave patterns for hand movements are unique, but there is about a 50% overlap across various patterns. This means that hand movements start out planned, but end up as unplanned responses to the environment (Rubinstein & Firstenberg, 1999, p. 49). For example, I play the slide trombone. Let's assume that I'm going to try to play a solo and have never seen the music before (I'm sight reading). Based on past experience, my brain knows how far to extend my arm and wrist to reach the slide to the 4th position G to start my solo (i.e., the planned brain waves). But, the next note is B-flat. Do I play that note in the first position or the fifth position? Either position will work. And, if I encounter eighth or sixteenth notes, the next series of notes up or down the slide could happen in a blink of the eye. How then does my brain know what to do next (i.e., handle the unplanned)? Answer: spontaneous improvisation from previous experience (patterns of response). Even though I've never seen the music before, I've stored patterns of *rules* in my brain for getting to the next note(s) quickly and efficiently. In the case of the G to B-flat, I'll look to the note(s) after the B-flat to decide if it is easier to use the first or fifth position, thereby being better prepared to play the subsequent notes.

Rubinstein says, “We can safely conclude that human experience almost always involves both the earlier stored part, which is reproduced, and the newly created part, which is produced” (Rubinstein & Firstenberg, 1999, p. 49). How might this knowledge of our how the brain works and stored rule/response patterns change the way in we teach systems engineering? Might we teach patterns of response that could ultimately be applied to solve complex systems engineering issues and mitigate risks?

Rubinstein also has an interesting perspective on creative thinking. “Creative thinking requires a process that is quite different from that of rational thinking. Whereas rational thinking depends on categories and labels that have been set up in advance, creative thinking demands that we form new categories and labels. Rational thought leads us to find the similarities between a new experience and previous experiences so that we can treat them the same way. Creative thought looks for the differences among experiences, seeking unique ways of both interpreting situations and acting upon them. Rational thinking seeks to confirm; creative thinking seeks to invent.” (Rubinstein & Firstenberg, 1999, p. 22). Perhaps this definition of creative thinking should also be used to guide and assess the success of our systems engineering problem-based exercises.

Conclusions

Knowledge, skills, and abilities within the discipline of systems engineering are best learned experientially through problem-based instruction. Opportunities to role play, simulate, or actually perform system engineering tasks really help the students transfer learning from the classroom to their work. Over the years, the most successful training and education programs I’ve participated in as a member of the defense acquisition workforce have been case studies and simulations that combine the technical aspects of the systems engineering discipline with activities that require the application of interpersonal skills and leadership. Having been an instructor in both systems engineering training and education environments, I know that students do their best when challenged with authentic problems that have meaning to them in the real-world. As adult students, they appreciate a learning environment in which they can “do it until they get it right.” Knowingly or unknowingly, they can learn much from their peers. Also, they excel when invited to display their knowledge in front of their peers. All of the experience I’ve had in learning and teaching within this discipline point to the absolute necessity for active learning activities that are relevant to the real-world of the systems engineer.

The purpose of instruction in the defense systems engineering discipline is to equip adult students to succeed in what can be a very complex and often ambiguous public policy environment. These students want to understand the “why” behind the concepts and principles of their profession. Only with that knowledge can they know what is important and what to ignore when overloaded with information. Also, they need to have had opportunities in a nonthreatening academic environment to experience what happens when they ignore that which is important (i.e., learn from their mistakes). Moreover, they need to think deeply within the discipline to understand what to accept and what to challenge. In other words they need to be humble critics of their profession who can rationally argue for change when change is needed. As an instructor, I need to come alongside my students (current and future systems engineers) to awaken and develop their intellects in the following key areas:

- Intellectual Humility—the systems engineering discipline is so big and dynamic that no one person can ever know everything.

- Intellectual Empathy—the systems engineer must be able to understand the perspectives and objectives of all acquisition stakeholders (e.g., warfighters/users, Congress, Executive branch, and defense industry).
- Intellectual Autonomy—in defending the program's systems engineering approach, the systems engineer has to be able to justify why he/she tailored a systems engineering process model, technical reviews, audits, verifications, etc.
- Intellectual Integrity—responsibility and accountability for program goals, to include credible cost, schedule, and performance reporting, are required from the systems engineer.
- Confidence in Reason—the systems engineer must develop sound rationale for the development approach, testing strategies, and logistical support for the system.
- Fair-mindedness—the systems engineer is a public servant, expected to give due consideration to all viewpoints and avoid even the appearance of any conflict with his/her personal interests or ambitions.

These intellectual traits ("Foundation for Critical Thinking," 1996) can only be awakened and developed through a *deep approach* to learning. My students need to be challenged to think beyond the course and look to the expert application of the knowledge they are learning as it affects their real-world jobs. To do this, I need to provide learning activities that target Bloom's *evaluate* level and frequently go above that to the *create* level. I have to prepare learning objectives and assessments that go beyond simply remembering facts and applying procedures. I need to create a *critical natural learning environment* that invites students to test the boundaries of the discipline (Bain, 2004, p. 99). A learning environment that invites my students to argue, compare, rate and ultimately judge for themselves what works and what doesn't work is what I'm seeking. After learning activities, I need to give the students time to *reflect deeply* on what they have experienced. In so doing, I want them to see the patterns of thought that led them to their conclusions. By recognizing these patterns, they can begin to experience the power of *thinking without thinking* -- like the experts do (i.e., *rapid cognition* based on *thin-slicing*, per Gladwell, 2005).

Critical natural learning environments can be cultivated and observed through classroom and online discussions of real-world case studies. Such environments can also be achieved through an integrated course exercise where student-led teams develop and brief a technical systems engineering strategy pertaining to a real-world need. Role playing during classroom discussions of dilemmas faced in real-world case studies would also work nicely. However, the one intangible in all of these learning activities is my passion and motivation for learning the systems engineering discipline. It is the creativity and drive that I bring to the course and into the classroom that truly motivates my students. To keep the energy and motivation flowing, I must constantly improve the learning activities and keep them relevant, gain a better understanding of where my students are coming from experientially and professionally, and be responsive to the constructive feedback my students give me.

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Panel 17 – The People Problem: Research in Acquisition Human Capital

Thursday, May 12, 2011	
11:15 a.m. – 12:45 p.m.	**Chair: Jeffrey P. Parsons,** Executive Director, Army Contracting Command, U.S. Army Material Command ***Determining the Appropriate Size of the Contracting Workforce: Yes We Can!*** Tim Reed, NPS ***How Can Civilian Retention in the Army Contracting Command Contracting Professional Community Be Affected?*** Charles Farrior, DAU ***Outsourcing the Procurement/Acquisition Function of an Operation: Is It a Good Thing or Not?*** Debbie Nicholson, J. M. Waller Associates, Inc.

Jeffrey P. Parsons—Executive Director of the U.S. Army Contracting Command (a new major subordinate command of the U.S. Army Materiel Command, AMC). The Army Contracting Command provides global contracting support to the operational Army across the full spectrum of military operations and in garrison. Mr. Parsons commands over 5,500 military and civilian personnel worldwide, who award and manage over 270,000 contractual actions valued at more than $80 billion per fiscal year. He exercises command and procurement authority over two subordinate commands, the Installation Contracting Command and the Expeditionary Contracting Command, and also leads the AMC Acquisition Centers, which support AMC's other major subordinate commands and Life Cycle Management Commands. Mr. Parsons was appointed to the Senior Executive Service on December 15, 2003.

Prior to assuming his current position, Mr. Parsons served as the Director of Contracting, Office of Command Contracting, Headquarters, AMC, Fort Belvoir, VA. Responsibilities from the Office of Command Contracting transitioned into the Army Contracting Command. Mr. Parsons continues to serve as the Principal Advisor to the Commanding General of AMC and his staff on all contracting matters and as the AMC Career Program Manager for the Contracting and Acquisition Career Program, with responsibility for the recruitment, training, education, and professional development of the civilian and military contracting professionals who are part of the acquisition workforce.

Prior to his appointment to the Senior Executive Service, Mr. Parsons was the Director of Contracting, Headquarters, U.S. Air Force Materiel Command, Wright-Patterson Air Force Base, OH, where he retired from active duty as an Air Force Colonel after 26 years of service. He was responsible for developing and implementing contracting policies and processes to annually acquire $34 billion in research and development, production, test, and logistics support for Air Force weapon systems. He was directly responsible for the training, organizing, and equipping of more than 3,000 contracting professionals.

Mr. Parsons' contracting career began in 1977 as a base procurement officer supporting the 90th Strategic Missile Wing at F. E. Warren Air Force Base, WY. He held a variety of positions as a contracting officer with a wide range of experience touching on all aspects of systems, logistics, and operational contracting. He was the Director of Contracting for a multi-billion dollar classified satellite program operated by the National Reconnaissance Office and served twice as a plant commander in the Defense Contract Management Agency. Mr. Parsons also held several key staff positions at

Headquarters, U.S. Air Force, the Air Force Secretariat, and with the Office of the Secretary of Defense, in which he was responsible for the development, implementation, and management of integrated, coordinated, and uniform policies and programs to govern DoD procurement worldwide.

Mr. Parsons received his bachelor's degree in psychology from St. Joseph's University, Philadelphia, PA, and holds two master's degrees—one in administration with a concentration in procurement and contracting from George Washington University, Washington, DC, and the other in national resource strategy from the National Defense University. He is a graduate of the Industrial College of the Armed Forces and the Defense Systems Management College Executive Program Management Course. Mr. Parsons holds the Acquisition Professional Development Program's highest certifications in contracting and program management. He also is a Certified Professional Contracts Manager, National Contract Management Association.

Determining the Appropriate Size of the Contracting Workforce: Yes We Can!

Tim Reed—Associate Professor, Naval Postgraduate School. Dr. Reed teaches master's courses in acquisition management. He also taught at the Air Force Institute of Technology (AFIT), where he created the Strategic Purchasing Graduate Degree Program, the University of Dayton, American University (Washington, DC), and the University of Maryland (University College). He has also taught visiting seminars at American University in Cairo and Instituto de Empresas in Madrid. His Air Force contracting experience includes F-22 Fighter, C-17 Cargo Transport, and serving as director of Joint Contracting Command-North, Kirkuk, Iraq. At the Pentagon, Dr. Reed was responsible for implementing strategic sourcing and commodity councils for the DoD and the Air Force. He earned a PhD in Strategic Management and Entrepreneurship from the University of Colorado and is a certified purchasing manager (C.P.M.) with the Institute of Supply Management. [tsreed@nps.edu]

Abstract

The increasing pace of change in the federal acquisition environment, an emphasis on increasing contract management accessions, and intense pressure to cut operating budgets has increased the interest in the models available for use by the DoD to (1) measure contracting organization workload and (2) assign adequate resources to effectively manage the workload with an acceptable level of risk. An essential requirement for organizational success is to ensure that the correct number of resources, with the correct competencies, is available at the point of need at the correct time to accomplish the mission. In order to correctly train and assign resources, one must first understand the nature and amount of work to be accomplished. This paper finds that contracting workload assessment is not conducted in a consistent manner within DoD nor among the various individual Service components. In fact, in many organizations, it is not conducted at all. Seven steps that contracting organizations can take to identify contracting workload and manage it accordingly are presented.

Introduction

This study focuses on identifying methods used to assess the workload of government contracting personnel. In its most basic form, this research seeks to move the field toward answering the question, "What size should my contracting organization be?" The increasing pace of change in the federal acquisition environment, an emphasis on increasing contract management accessions, and intense pressure to cut operating budgets has increased the interest in the models available for use by the DoD to (1) measure contracting organization workload and (2) assign adequate resources to effectively manage the workload with an acceptable level of risk.

An essential requirement for organizational success is to ensure that the correct number of resources, with the correct competencies, is available at the point of need at the correct time to accomplish the mission. In order to correctly train and assign resources, one must first understand the nature and amount of work to be accomplished. Simply stated, a leader is unable to effectively deploy resources (which should be step 2) without first understanding the work to be done (step 1). This maxim holds true for leaders, whether leading in fast-food restaurants or leading in forward deployed military units. It also holds true for acquisition and contracting organizations.

Through a review of existing literature and models currently in use by government and industry contracting (also sometimes referred to as purchasing/procurement) organizations, I identify a gap between the models and processes available to identify workload levels and the models and processes currently used in DoD organizations.

What is the right size for the organization? I acknowledge at the outset that the answer to this quantitative question is not in itself sufficient for organizational success. It is not simply the number of workers but also the competencies of those workers that is essential in meeting mission requirements. However, competency assessment is not the subject of this research. Attempts to measure contracting organization competencies have been conducted in the past and are the focus areas of several recent human capital planning initiatives. The primary focus of this paper is on the partner of organization competency: identifying methods to assess workload in the DoD, Federal Civilian, and other commercial contracting organizations, and using that information to staff organizations accordingly.

Literature Review

A review of the literature revealed that it is conventional wisdom that growth in the DoD acquisition workforce is thought to be a necessity (e.g., Acquisition Advisory Panel, 2007; DoD, 2010; Gansler, 2007). However, while subjective rationale is provided in the workforce planning literature, no quantitative basis for specific growth figures was identified. The Defense Business Board (2010) provides the broad logic for the growth target:

> Between 2010 and 2015, DoD will grow its DAW [Defense Acquisition Workforce] by 20K (from 127K to 147K), more than 15 percent. Ten thousand (10K) of the total will be from contractor conversions (insourcing) and 10K will be new hires (new billets). This increase will restore the DAW to late 1990s levels and is intended to restore core capabilities. (Defense Business Board, 2010, p. 5)

The rationale conveyed appears to be based on a perception that contracting organizations were generally adequately staffed in the mid-1990s. This perception is the fundamental basis for establishing the goal to increase the DAW by 20,000. I was unable to identify a workload analysis that supported the notion that the staffing levels in the 1990s were adequate. Nor was I able to locate a quantitative analysis for the proposed 20,000 increase in the DAW. The lack of an analytical foundation for the increase in the DAW begs the following questions: If there is no answer to why 20,000 more positions is the correct number for the increase, then how do we know to which Service or buying office the newly created positions should be assigned? How do we know which offices are currently adequately staffed and which offices are critically understaffed? What will be the most effective method to allocate these new positions to the offices with the greatest need?

In order to answer these questions, the DoD requires a workload assessment model and a resource allocation model based on the projected workload of a buying office. While it may not be practical to implement a DoD-wide solution, a robust model for each Service, major command, or agency should be attainable. The following sections cover the extant literature from government and academic sources.

Government Accountability Office (GAO)

GAO investigations continue to serve as a reminder of both the distance traveled on workforce strategy development, and the miles yet to go. In September 2010, the GAO released a report entitled *Human Capital: Further Actions Needed to Enhance DoD's Civilian Strategic Workforce Plan*. The audit report found that key requirements such as identifying funding for training civilian employees, analyzing workforce skill gaps, and assessing progress and results have not been fully addressed. The report also indicated that the current DoD plan does not specify the appropriate acquisition workforce makeup and has not developed guidance to help program offices meet workforce planning objectives (GAO, 2010). The report cites the 2010 *Quadrennial Defense Review (QDR)* as seeking "an appropriately sized cadre of acquisition personnel who have the skills and training necessary to successfully perform their jobs" (GAO, 2010, p. 2). However, there is no guidance as to what size an appropriately sized cadre should be, nor how to determine the appropriate size.

Office of Federal Procurement Policy (OFPP)

The Office of Federal Procurement Policy (OFPP) in the Office of Management and Budget was established by Congress in 1974 to provide overall direction for government-wide procurement policies. OFPP received a significant report on the acquisition workforce in 2007. The Acquisition Advisory Panel was authorized by Section 1423 of the Services Acquisition Reform Act of 2003. The panel was charged to review and recommend any necessary changes to acquisition laws and regulations as well as government-wide acquisition policies. In the Acquisition Advisory Panel's resulting report to the OFPP in 2007, they found that "without a workforce that is qualitatively and quantitatively adequate and adapted to its mission, the procurement reforms of the last decade cannot achieve their potential, and successful federal procurement cannot be achieved" (Acquisition Advisory Panel, 2007, p. 330).

Other findings of the panel included that the complexity of the federal acquisition system as a whole has markedly increased since the 1980s; that few agencies have systematically assessed their acquisition workforce; that procurement obligations grew by 60% in the past five years; that the qualitative nature of the procurement activity has also changed, placing greater demands on the acquisition workforce for capability, training, time, and sophistication; and that a significant shift from the acquisition of goods to the acquisition of services has occurred, placing additional demands on the acquisition workforce in requirements definition, contract formation process, and in contract management (Acquisition Advisory Panel, 2007).

The panel also identified the changing nature of contracting processes as having a significant impact on the acquisition workforce. For example, the use of interagency awards and schedules to meet requirements has often allowed for the timely issuance of agreements, which allows a strained workforce to meet customer needs. However, the use of these schedules has contributed to other problems occurring from the failure of agencies to fully develop requirements, the failure to secure competition in using these vehicles, or the failure to manage contract performance under these vehicles (Acquisition Advisory Panel, 2007).

Other findings included the increased complexity involved with utilizing best value awards as opposed to lowest price awards and the additional burden of past performance assessment prior to award. In addition, the panel also identified that both government-wide and agency-specific efforts to respond to the new challenges of today's acquisition system have focused on the nature of the skills required for success in today's contracting environment. They have not ascertained the number of personnel possessing those skills that are required given the level of present or future agency acquisition activity (Acquisition Advisory Panel, 2007, p. 366).

Department of Defense (DoD)

The DoD recently published the *DoD Strategic Human Capital Plan Update—The Defense Acquisition Workforce* (DoD, 2010). This document is prepared to meet the statutory reporting requirements established in multiple National Defense Authorization Acts. As such, it provides a tremendous amount of information on workforce demographics and strategies. This report provides rationale for increasing the size of the acquisition workforce, which is in sync with the perception that the DAW needs to return to mid-90s staffing numbers. Specifically, it states, "The increase of approximately 20,000 [employees] will rebalance the organic acquisition workforce to better address inherently governmental and other critical functions. This will help mitigate the imbalance created by significant outsourcing of acquisition functions since the end of the Cold War" (DoD, 2010, p. 2–10). The report references several factors supporting an increase in the workforce, including the following:

1. the dramatic increase in annual spend levels since 2001;
2. the tesults of the Dayton Aerospace SACOM reviews of major program offices in the Air Force and Navy and a subsequent Air Force assessment of their workforce assigned to major programs;
3. the DoD competency assessment and bottoms-up review conducted by the OSD and component contracting leaders;
4. the internal DoD analysis of a variety of RAND studies on the acquisition workforce;
5. the numerous external studies, including GAO reports, that recommended the DoD increase the size of the acquisition workforce; and
6. the Defense Acquisition Workforce Structures and Capability review (Section 814, NDAA FY06).

These arguments generally convey the contracting leadership message to "send us more help" and serve as the basis that an increase in the size of the acquisition workforce will contribute to an increase in the effectiveness of mission performance. However, while a review of the open-source literature listed above found arguments for increasing the size of the acquisition workforce in general, no objective basis for the precise increase of 20,000 acquisition workforce employees was found.

RAND

The RAND Corporation (which is a Federally Funded Research and Development Center, FFRDC, for the DoD) is one of the primary organizations that has contributed to the literature relevant to acquisition workforce management. A notable RAND study within its National Defense Research Institute is a report titled *Civilian Workforce Planning in the Department of Defense*, published in 2006. The study sought to describe the existing workforce planning process at individual military installations in order to identify challenges to workforce planning at these bases and to consider options for DoD-wide workforce planning and OSD support for installation-level planning. The four basic steps of the model developed by the study effort are the following:

1. forecast workforce requirements (staffing levels and competencies demanded in the future),
2. project workforce supply,

3. identify gaps between supply and demand, and
4. develop strategies that address key gaps. (Gates, Eibner, & Keating, 2006, pp. xiv-xv)

Gates et al. (2006) discovered that unlike some non-governmental agencies with fewer manpower restrictions, customer demand is not the only factor that managers must consider in assessing DoD workforce demand.

> In the DoD, local managers face constraints on the total number of civilian work years they are allowed, as well as the total wage bill for civilian personnel. These additional constraints complicate gaps analysis, because local managers must be conscious of at least two gaps: that between the required (the estimated workforce needed or required to accomplish the organization's goals) workforce and the workforce supply, and that between the budgeted (the workforce that can be supported with resources that have been budgeted for civilian personnel in that organization) workforce and the workforce supply. (Gates et al., 2006, p. 47)

A follow-on report (Gates, 2009) found that demand analysis involves two important types of data: projections of customer demand and data that allow that demand to be translated into workforce requirements. In other words, there must be a set of ratios, workload factors, or process times that allow the researcher to interpolate the raw demand information into workforce requirements. The researchers found that a lack of data, both on the skills and competencies of the workforce and on customer demand, limits workforce planning throughout the DoD. The RAND investigation found that given the lack of available information on workforce requirements, size, quality, and mix, it was not possible to assess whether more workers, more highly skilled workers, or a different mix of workers would improve acquisition outcomes (Gates, 2009).

Federal Acquisition Institute (FAI)

The FAI is assisting with the initial efforts to assess contracting workload in federal civilian agencies and has taken a noteworthy leadership position on broad-based competency assessment of the DAW.

In 2007, the FAI issued a report presenting the results of its 2007 Contracting Workforce Competencies Survey. The survey targeted the GS-1102 series in the civilian agencies, including military personnel working outside the DoD performing contract specialist duties. In 2008 the FAI conducted a follow-up competency survey, *2008 Acquisition Workforce Competencies Survey Results Report and Survey Content*, which revealed that the average response improved for each of the contracting competency areas (as well as for the contracting officer technical representative and for the program manager; FAI, 2009).

The report stated that overall, contracting workforce technical competencies are at expected levels. "Of the 17 technical competencies surveyed, gaps requiring attention were identified in project management, defining requirements, and financial management. General business competency gaps were identified in influencing/negotiating and oral communications" (FAI, 2007, p. 2). Personnel working in DoD organizations were not surveyed, thus generalizability to the DoD may exist, but is uncertain.

An objective critique of the FAI competency assessment offers that any time self-reported competency assessments are conducted, there is the risk of self-report bias and assessment inflation. Conducting objective interview- or scenario-based assessments with a sample of the population and comparing them to self-assessment scores would provide useful validation baselines regarding the accuracy of the self-reported competency assessments.

In 2009, the Office of Federal Procurement Policy addressed the need for workload models in the *Acquisition Workforce Development Strategic Plan for Civilian Agencies—FY 2010–2014* (OFPP, 2009). To assist civilian agencies with preparing workforce plans, the OFPP provided project model assistance along with the FAI:

> Because agency missions and acquisition activities differ considerably, there is no simple formula that can relate the size and composition of an agency's acquisition activity to its ideal workforce size. In developing a target acquisition workforce profile, agencies should examine their current acquisition management practices and determine where performance is hindered by insufficient resources. In particular, agencies should plan to increase the size of their acquisition workforce so long as the cost-savings and performance improvement benefits to taxpayers from better acquisition management exceed the cost of the additional acquisition employees. Additionally, FAI will develop and maintain an online toolkit for use by the agencies that will include various projection methodologies that agencies can use as part of their workforce analysis. (OFPP, 2009, p. 9)

FAI has since established an online community that shares workload projection tools. In keeping with the OFPP's assessment that the most appropriate model may vary by agency, seven different model types have been made available. The models available include project-based, program-based, multi-dimensional, regression, volume-based, transaction, and conceptual-combination models. The specific characteristics of these models will be discussed further in the model analysis section of this article.

Purchasing Workload Ratios and Measures

The academic literature offers several studies on purchasing and contracting organization workload measures. In attempting to determine the best overall workload measurement method, Monczka and Carter (1978) urged caution when selecting a methodology. They found that aggregate standards (e.g., actions or spend per buyer) were preferable to time standards (average time required to complete specific contracting actions) because "detailed time standards do not appear to yield results that are sufficiently superior in most purchasing departments to justify their development" (Monczka & Carter, 1978, p. 39). However, a critique of the actions or spend per buyer methods identifies a significant shortcoming: the failure to assess the complexity of the work or the quality of the output.

In a study of 17 government procurement agencies at the county level, McCampell and Slaich (1995) found that two benchmarks provided insight into buying organization performance. The first measure is the average dollar volume obligated annually per professional staff member (buyer). The second measure is the mean cost per dollar obligated (CPDO; McCampbell & Slaich, 1995). The dollars-per-buyer measure was found to be superior to orders- or action-per– buyer measures due to an absence of how an *order* or *action* was defined from organization to organization. The variability in these definitions substantiates the argument that the weights applied to variables should be made at lower organizational levels, since agency-wide weights and definitions would not be appropriate or reasonable for all contracting organizations within an agency. Furthermore, this measure could be manipulated by pursuing inefficient methods (issuing multiple orders rather than pursuing a more efficient, consolidated order process). Auditors may conclude that such a reduction in orders may provide a logical basis for staff reductions (McCampbell & Slaich, 1995). The study found that the average dollar volume obligated annually was $10.7 million, which is in the range found in the CAPS benchmarks ($3.4 million in aerospace to $47.9 million for food service; McCampbell & Slaich, 1995, 34).

The CPDO benchmark was found to be particularly useful to the government sector. It is based on available information, and it is easy to understand. The authors of this study also found that dollar-based calculations would be less likely to cause government auditors to mistake increased efficiency (fewer orders) as a cause for staff reductions (McCampbell & Slaich, 1995). CPDO would also be of interest to organizations pursuing consolidated buying strategies, since larger organizations using centralized or strategic sourcing processes are likely to achieve efficiencies in procurement. The limiting factor of applying CPDO in such an environment is that strategic sourcing efforts often take a great deal of upfront work, and then these efforts actually serve to reduce total dollars obligated, which has a negative impact on the measure. Another caveat would be to ensure that the measure is used in a competitive environment (to ensure award prices are not kept high to improve the metric) and in an aggregated fashion, rather than applying the measure to individual buyers (aggregation should ensure there is no skewing by individuals attempting to pursue “bad buying” practices; McCampbell & Slaich, 1995). The study found that the mean CPDO was $0.0104, which is in the range found in the CAPS benchmarks, $0.002 to $0.05 (McCampbell & Slaich, 1995, p. 34).

Also in 1995, Black (1995) developed the Workload Index Model. Black’s model is an analytical attempt to compute a workload index that accounts for differences in the types of work and in the complexity of the work being performed (Black, 1995). Earlier models discussed used dollars obligated or orders processed as the common basis for measurement. Black posited that non-weighted measures such as the average number of actions per employee, average dollars obligated per employee, and average days to process an action must be avoided (Black, 1995). His rationale is that these measures fail to account for the relative (weighted) differences in work tasks and staffing across offices examined. A small average number of procurements (or dollars) processed per staff member does not necessarily indicate poor performance; nor does a large average number of procurements (or dollars) processed per staff member necessarily indicate exceptional performance (Black, 1995, p. 45). To address this, Black’s model added weighting to the output of each worker by their pay level (e.g., GS-11, GS-12, GS-14, etc.). The higher level workers are expected to produce higher volume than lower level workers. Black’s model improved on other models by addressing the likelihood that the experience composition of one group of individuals may be vastly different from a more experienced organization of the same size differences. However, just as one group of twenty contracting professionals is not necessarily as equally capable as another group of twenty contracting professionals, one GS-14 is not necessarily as capable as another GS-14. Thus, controlling for wage grade alone still provides for a great deal of variability in the model.

In 2004, a study of procurement benchmarks, combined with the performance of organizations at various levels above and below benchmark means, provided interesting results (IOMA, 2004). The study ranked firms procurement organizations in two categories: efficiency and effectiveness. The firms were identified as “world class” if they were either (1) in the top quartile of both efficiency and effectiveness benchmarks or (2) in the top 10% of either of the two benchmarks (IOMA, 2004, p. 7). The study then identified the firms’ cost-per-dollar-obligated ratios. Procurement cost as a percentage of spend was 0.72% at world-class firms in efficiency and effectiveness, compared to the 1.02% overall benchmark. Further, this study shed light on the impact of high quantity and quality output by finding that the cost-to-spend ratio is 0.92% for firms in the top 10% of effectiveness and 0.32% for those in the top 10% of efficiency (IOMA, 2004, p. 7). Therefore, although it may seem that higher quality would require higher cost, it does not appear to be the case, because the average world-class firms executed at a lower cost-to-spend (0.92% and 0.32% versus the 1.02% average). Other findings from this study include that world-class companies use relatively fewer people (54 FTEs per billion dollars spent versus the mean of 104 FTEs per billion dollars spent) and that they invest more heavily in technology ($24,308 per FTE as compared to the mean of $7,717 per FTE). Finally, world-class organizations shift investments and resources to higher value activities (16% of costs spent on order processing versus the 22% mean, and 11% of costs to supplier management and development versus the 2% mean; IOMA, 2004, p. 7).

Performance Unit Costing (PUC)

The review of the literature so far illustrates several methods to measure work and performance. It also identifies a significant absence of quality measures in most models and benchmarks. A series of publications (Sorber & Straight, 1989, 1991, 1995; Straight, 1999, 2000) have made the case for procurement organization evaluation via Performance Unit Costing (PUC). This method considers the cost of operations relative to performance units. *Performance units* are completed actions adjusted for the level of the quality of the output. Examples of quality factors include timely award, timely delivery, fair and reasonable prices, and customer satisfaction (Sorber & Straight, 1995).

PUC is calculated by multiplying the number of *output units* (e.g., contract actions) by an achieved quality index (from 0.00 to 1) composed of some of the factors above. The result is the quantity of performance units. The number of performance units is then divided into the operating cost of the procurement organization to determine the cost per performance unit (Sorber & Straight, 1995). For example, 900 units of output at an achieved quality index of 0.65 yields 585 performance units. If the procurement organization costs incurred were 10,000, then the cost per performance unit would be $17.09. Obtaining higher output levels while maintaining quality and cost would decrease the performance unit cost. Higher quality achieved at the same cost and output would also decrease PUC. Managers are provided with the insight that increasing quality factors may increase cost, but they may also identify some components of the quality index that can be affected without increasing cost, and other quality factors that can be improved to reduce the cost per performance unit. The PUC methodology allows managers to move away from single-factor workload indicators such as procurement lead time, action quantity, or dollars obligated. It combines the resource perspective of the cost to run the organization with the quantity and quality of the work performed. The model also has the flexibility to involve customers in determining quality measures and their relative weights or importance (Sorber & Straight, 1995).

The PUC model seems to improve upon the Workload Index Model discussed previously by considering the total cost of the operation as the basis for analysis rather than the GS levels of the workforce, which are subject to step level gradation variability (all GS-14s are not the same, nor are they compensated the same). In addition, it allows for weighted workload credit depending on variable types of work output, and most important, it recognizes that all output is not the same (some work is of better quality than other work; Sorber & Straight, 1995).

The Center for Advanced Purchasing Studies (CAPS)

CAPS is sponsored by the Institute of Supply Management and works with industry supply management executives and academics to develop and share knowledge and best practices. It conducts recurring surveys and publishes regular reports on key areas of procurement and supply management. These publications allow commercial purchasing organizations to compare themselves with other organizations at a macro level as well as with organizations within their industry sector. Based on surveys of procurement organizations, the CAPS provides a snapshot overview of 20 different key performance indicators (Wade, 2010). Among the 20 industry variables that the CAPS tracks related to procurement, there are 11 that apply to both the public and private sectors:

1. The total dollars spent by a procurement organization as a percent of total firm budget (how much of an organization's needs are acquired via contract, and what is procurement's relative impact/importance to the total organization);
2. Supply management operating expense as a percent of total spend (how much does it cost to spend each dollar of supplies or services that the organization procures);
3. Total spend per supply management employee (contract dollars awarded by the average procurement specialist);
4. Supply management operating expense per supply management employee (the total cost—pay, training, benefits, etc.—of the average member of the workforce);
5. Annual spend on professional training per supply management employee;
6. Professional training hours completed per supply management employee;
7. Supply management group retention rate;
8. Cost reduction savings as a percent of total spend;
9. Cost avoidance savings as a percent of total spend;
10. Average order/action processing cost; and
11. Average cycle-time (in days) from requirement approval to issuance of order/contract. (Institute of Supply Management, 2010)

This list of benchmarks presents an immediate opportunity for contracting leaders to identify those benchmarks that measure key performance areas linked to their organization goals. Assessing organization performance in the identified areas and comparing the performance results to the benchmarks will allow leaders to identify the current level of performance, the trends in performance over time, and the establishment of organization performance goals.

While the applicability and usefulness of these benchmarks will vary among organizations, the first three benchmarks should be of particular interest to all DoD contracting organizations. Item 1 allows leaders to convey contracting's contribution to the Service's mission; Item 2 allows a comparison to other organizations on the efficiency of the unit; and Item 3 identifies the size of the portfolio that the average buyer can execute. These ratios can provide insight into workload execution and actionable information for contracting leaders.

Some of the interesting benchmarks in the 2006 CAPS report showed that the supply management operating expense per employee was $107,803. It is important to note that operating expenses per employee are calculated in different ways depending on the firm, but the measure always includes employee salary at a minimum (IOMA, 2006, p. 18). Given the difficulty in collecting operating expense data in some DoD organizations, establishing salary as the employee expense metric may allow for the creation of a simplified and consistent measure between organizations.

The successful application of CAPS benchmarks in a federal agency contracting organization is illustrated in the workload assessment conducted in 2004 at the Department of Homeland Security (DHS; Sorber & Bodnar, 2004). The high-level DHS staffing analysis of procurement resources was conducted to facilitate the largest government reorganization in U.S. history. The analysis consisted of a cost-to-spend ratio analysis using FY 2002 total obligations and salary expense. The study also calculated spend-per-employee using total obligations and number of employees. It compared the findings to benchmarks published by the CAPS. The study found that the DHS buying offices' cost-to-spend ratios ranged from 0.20% to 2.28% with a mean of 1.06%. The study used cost-to-spend ratios available from other federal buying offices for comparison. The comparison ratios ranged from 0.71% at NASA–Goddard and 0.86% at the Department of Housing and Urban Development (HUD) to 2.31% at the Environmental Protection Agency (EPA). The mean of comparison agency cost-to-spend was 1.35%. The CAPS benchmark for mean cost-to-spend in the aerospace industry is 2.21%. The DHS compared favorably in both range and mean relative to the benchmark and comparison agency cost-to-spend ratios (Sorber & Bodnar, 2004).

When looking at spend-per-employee, DHS organizations ranged from $2.8 million to $44 million with a $12.4 million mean. Comparison agencies ranged from $3 million to $8.9 million and had a mean spend-per-employee of $6 million. The DHS had a higher average and a much wider range of spend-per-employee than the comparison agencies. By comparison, the CAPS benchmark mean for aerospace industry procurement was $5.3 million. The researchers then considered the upcoming planned FY 2004 obligations to calculate FTEs required. By dividing the planned obligations by the $5.3 million and the $6 million agency and industry benchmarks, the researchers identified a range of imputed FTEs appropriate for meeting the projected contracting office workload.

However, since the researchers calculated average spend-per-employee as $12.4 million, it seems that $12.4 million would have served as a reasonable estimate, rather than the $5.3–$6 million estimate that was used in the study. The larger number could have at least been used to illustrate an alternative position with a slightly higher risk associated with it, should the DHS have wished to accept that risk. Given that the factor is double the benchmarks used, the argument for accepting some risk beyond $6 million spend-per-employee would be warranted. Using the lower risk benchmarks, the authors identified a requirement for 220 FTEs. When factored with the average DHS procurement salary of $150,650 (the planning average salary provided by the DHS), the result was a FTE budget of $32.9 million. Given that this is the lowest risk profile, $32.9 million should be considered the maximum possible FTE budget.

An interesting further finding of the study was the identification of the fees charged by agencies (such as GWACs, GSA, GovWorks, etc.) for performing contracting work for the DHS. The fees ranged from 0.75% to 8%. The researchers calculated an average fee of 2.5% and used it to illustrate the cost that would be incurred if requirements were sent to outside agencies for obligation. The researchers found that applying a 2.5% average fee to the projected obligation total for FY 2004 would result in $43.5 million in fees. When compared to the worst-case FTE budget of $32.9 million, it is clear that use of outside agencies should be minimized in this example. However, for organizations with cost-to-spend ratios above 2.5%, a compelling argument for seeking outside support could be made. While the DHS study provides a great deal of insight into procurement workforce evaluation, it should also provide motivation for procurement leaders to ask, "What is my cost-to-spend ratio?", if for no other reason than to better understand the implications of using outside procurement organizations.

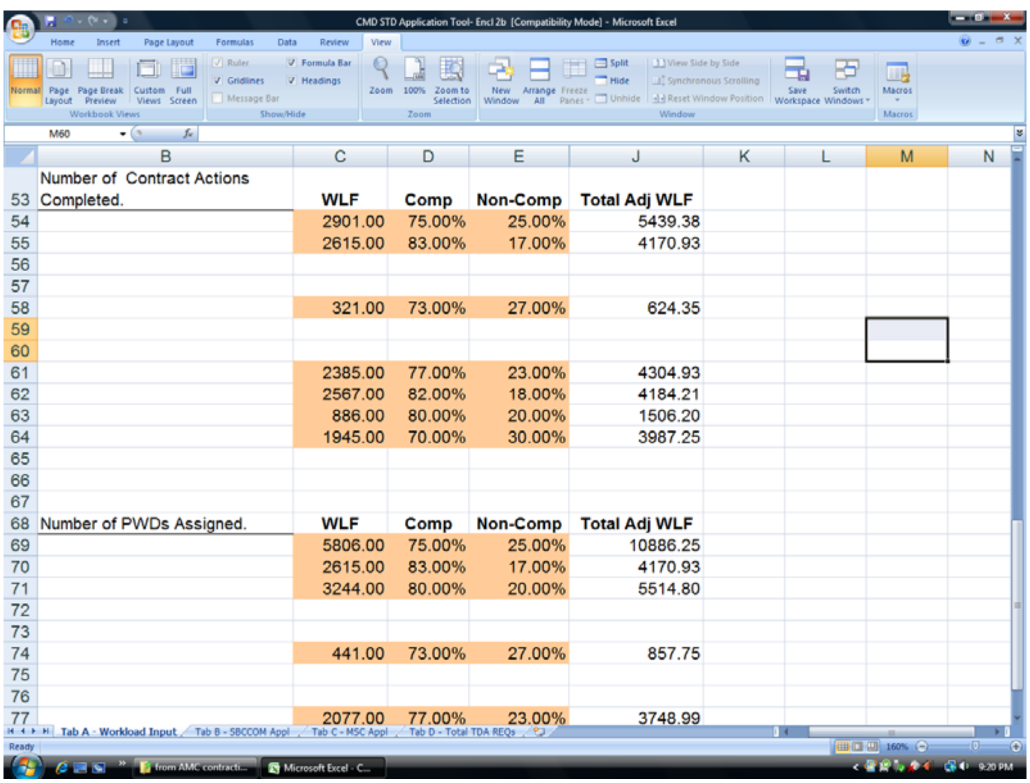
Contracting Organization Workload Models

Given the significant number of new workers expected to be hired by DoD contracting organizations in the next several years, leaders are now presented with a tremendous opportunity to determine the optimum method of apportioning resources and measuring performance. A review of workload and performance measures used by various contracting organizations is presented in the following section.

Army Workload Models

The Army has primarily relied on a decentralized workload assessment process. This process allows the various commands to develop workload models for application within their organizations.

Perhaps the best developed workload model has been developed by the U.S. Army Material Systems Analysis Agency (AMSAA). The AMSAA has been tasked with preparing manpower models for Army acquisition organizations since 1987. In 1999, the Army Material Command directed the AMSAA to baseline all functional areas in the acquisition process, including program management, staff/policy support, and contract administration. The model developed as a result of this baseline was finalized in 2002. Two clusters developed based on the types of work accomplished: weapon system acquisition and installation/camp support. Different process action times (PATs) or task completion times were used in each of the two sectors (J. Henderson, personal communication, May 4, 2010). An example of the AMSAA model is depicted in Figure 1.



	B	C	D	E	J	K	L	M	N
53	Number of Contract Actions Completed.	WLF	Comp	Non-Comp	Total Adj WLF				
54		2901.00	75.00%	25.00%	5439.38				
55		2615.00	83.00%	17.00%	4170.93				
56									
57									
58		321.00	73.00%	27.00%	624.35				
59									
60									
61		2385.00	77.00%	23.00%	4304.93				
62		2567.00	82.00%	18.00%	4184.21				
63		886.00	80.00%	20.00%	1506.20				
64		1945.00	70.00%	30.00%	3987.25				
65									
66									
67									
68	Number of PWDs Assigned.	WLF	Comp	Non-Comp	Total Adj WLF				
69		5806.00	75.00%	25.00%	10886.25				
70		2615.00	83.00%	17.00%	4170.93				
71		3244.00	80.00%	20.00%	5514.80				
72									
73									
74		441.00	73.00%	27.00%	857.75				
75									
76									
77		2077.00	77.00%	23.00%	3748.99				

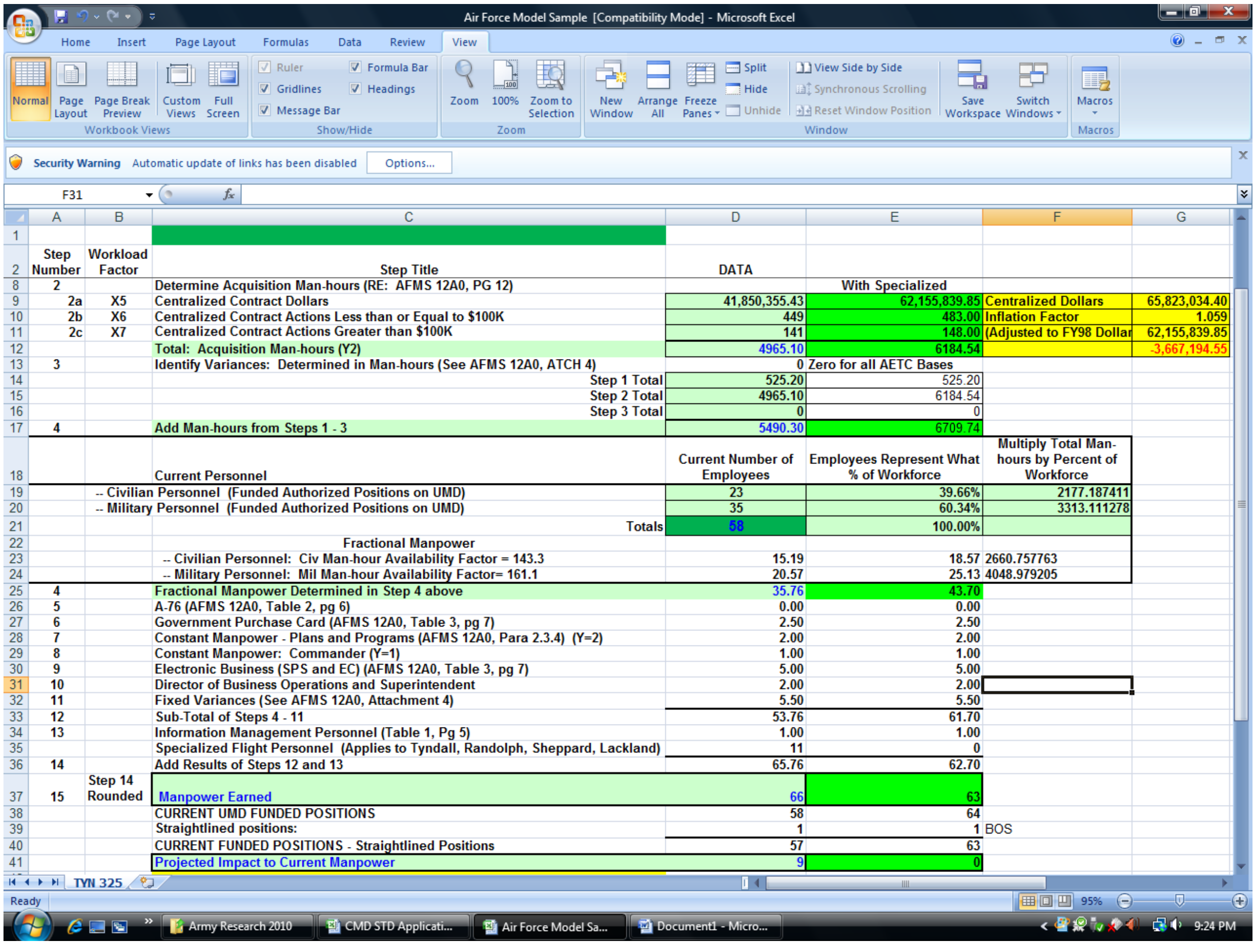
Figure 1

The primary workload factors used in the AMSAA model are (1) contract actions, (2) solicitations, (3) the ratio of competitive to non-competitive actions, and (4) the number of acquisition systems managed. An interesting aspect of this model is the weighting applied to completive actions. Based on a regression analysis of actions processed, the AMSAA has assigned a 4.5 multiplier to non-competitive (e.g., sole source) contract actions. In other words, a non-competitive action is credited for 4.5 times the process action time allowed for completion when compared with a competitive action (J. Henderson, personal communication, May 4, 2010). The last complete model run was in 2006; however, high-level assessments for the ACC as a whole have been accomplished since then.

Air Force Workload Models

In 2001, the Air Force published a manpower standard (AFMS) for operational contracting (AFMIA, 2001). Operational contracting focuses on meeting the needs of airmen at the base or installation level, as opposed to systems contracting, which focuses on developing and acquiring major weapons systems such as aircraft. The AFMS recognizes key workload indicators such as dollars obligated and total actions completed. It also recognizes that large-dollar actions are more complex than small-dollar actions, and as such, rewards more process time credit for actions above $100,000 than for those below $100,000. The model recognizes the impact of expeditionary deployments on an organization and has a mechanism for awarding manpower for such activity. It also recognizes the importance of the support roles of the contracting organization, and it awards manpower for Government Purchase Card (GPC) oversight, small business program administration, commander's support staff, and IT support. The process time standards were developed by recognizing over 150 individual types of activity in the procurement process and at least 50 types of activity in the contingency contracting environment (AFMIA, 2001). As such, it is one of the most thorough contracting manpower models produced. The manpower standard workload formulas can be inserted into standard spreadsheet software applications for ease of computation. However, the parsing of data required to translate existing data into a useable format (e.g., the elimination of non-qualifying contract activity) can be burdensome.

Because the Air Force model is more robust in many ways when compared to other agency models, it has been favored as the model of choice by many in non-Air Force DoD agencies and has become the default model used in joint basing workload transfer negotiations. Despite the praise this model has received from many users, criticism for the standard has grown in recent years. Of particular note is that the manpower formula is outdated because it is based on the mean (or average) time for executing activities in 1998. As identified in the literature review, actions have become more complex and time-consuming to execute in the past 12 years, and the number of complex contract actions has increased while less complex actions have decreased, and have often shifted to GPCs. An example of the Air Force Operational Contracting Model is depicted in Figure 2.



	A	B	C	D	E	F	G
1							
2	Step Number	Workload Factor	Step Title	DATA			
8	2		Determine Acquisition Man-hours (RE: AFMS 12A0, PG 12)		With Specialized		
9	2a	X5	Centralized Contract Dollars	41,850,355.43	62,155,839.85	Centralized Dollars	65,823,034.40
10	2b	X6	Centralized Contract Actions Less than or Equal to $100K	449	483.00	Inflation Factor	1.059
11	2c	X7	Centralized Contract Actions Greater than $100K	141	148.00	(Adjusted to FY98 Dollar	62,155,839.85
12			Total: Acquisition Man-hours (Y2)	4965.10	6184.54		-3,667,194.55
13	3		Identify Variances: Determined in Man-hours (See AFMS 12A0, ATCH 4)	0	Zero for all AETC Bases		
14			Step 1 Total	525.20	525.20		
15			Step 2 Total	4965.10	6184.54		
16			Step 3 Total	0	0		
17	4		Add Man-hours from Steps 1 - 3	5490.30	6709.74		
18			Current Personnel	Current Number of Employees	Employees Represent What % of Workforce	Multiply Total Man-hours by Percent of Workforce	
19		-- Civilian Personnel (Funded Authorized Positions on UMD)		23	39.66%	2177.187411	
20		-- Military Personnel (Funded Authorized Positions on UMD)		35	60.34%	3313.111278	
21			Totals	58	100.00%		
22			Fractional Manpower				
23			-- Civilian Personnel: Civ Man-hour Availability Factor = 143.3	15.19	18.57	2660.757763	
24			-- Military Personnel: Mil Man-hour Availability Factor= 161.1	20.57	25.13	4048.979205	
25	4		Fractional Manpower Determined in Step 4 above	35.76	43.70		
26	5		A-76 (AFMS 12A0, Table 2, pg 6)	0.00	0.00		
27	6		Government Purchase Card (AFMS 12A0, Table 3, pg 7)	2.50	2.50		
28	7		Constant Manpower - Plans and Programs (AFMS 12A0, Para 2.3.4) (Y=2)	2.00	2.00		
29	8		Constant Manpower: Commander (Y=1)	1.00	1.00		
30	9		Electronic Business (SPS and EC) (AFMS 12A0, Table 3, pg 7)	5.00	5.00		
31	10		Director of Business Operations and Superintendent	2.00	2.00		
32	11		Fixed Variances (See AFMS 12A0, Attachment 4)	5.50	5.50		
33	12		Sub-Total of Steps 4 - 11	53.76	61.70		
34	13		Information Management Personnel (Table 1, Pg 5)	1.00	1.00		
35			Specialized Flight Personnel (Applies to Tyndall, Randolph, Sheppard, Lackland)	11	0		
36	14		Add Results of Steps 12 and 13	65.76	62.70		
37	15	Step 14 Rounded	Manpower Earned	66	63		
38			CURRENT UMD FUNDED POSITIONS	58	64		
39			Straightlined positions:	1	1	BOS	
40			CURRENT FUNDED POSITIONS - Straightlined Positions	57	63		
41			Projected Impact to Current Manpower	9	0		

Figure 2

Furthermore, critics assert that the manpower formula does not reflect the complexities of today's business processes such as the Management and Oversight of Acquisition of Services Process (MOASP), the Performance-Based Service Contracts, the Standard Procurement System, the competitive sourcing for multiple installation support, the increased post-award contract administration burden of service contracts on installation contracting offices, the strategic sourcing efforts which require much more pre-award activity in order to develop commodity strategies, and the increased contingency deployments. In addition, the types of work that receive no credit in the Air Force model are a concern for many. For example, there is no credit given for dollars obligated or actions processed that are modifications to contracts, nor for processing orders off of centralized contracts, nor for awarding or processing utility contracts. The work associated with these efforts can be substantial, yet it is not credited in the Air Force model. The rationale for withholding credit is that post-award and order processing was "built in" to the original time standards. In other words, in the manpower standard, when you are given credit for awarding a contract, you also earn all the necessary manpower to administer the contract. Given the changes in complexity and number of these types of actions since 1998, and the tremendous growth in multi-year contracts (which were much more rare in 1998), it calls into question whether the original built-in process times are still an accurate reflection of the actual time required to complete the activities today. A final critique of the Air Force model is that it is perceived to be similar to the time and motion studies conducted in the mid-twentieth century. Time and motion studies focus on increasing the efficiency in a process and measuring the time required to complete tasks. Although the models measure the time required to accomplish process tasks, they do not take into account the quality of the outputs that result from the process.

Separate and distinct from the Air Force operational manpower standard is the Air Force Workload Assessment Model (WAM) for weapon systems contracting developed by the Aeronautical System Center (ASC) at Wright Patterson AFB, Ohio. This model relies on stakeholder assessments of the number of hours required for tasks at differing dollar thresholds. For example, an organization may earn 245 hours to complete a sole source contract from $1 million to $5 million but earn 575 hours to complete a contract from $25 million to $50 million. Similar threshold-based earned hours are awarded in service contract, competitive contract, and delivery order categories as well. In all, there are 49 differing actions that organizations can earn credit for. There are 16 modification types (supplemental agreements, funding actions, etc.), 10 undefinitized contract types (letter contracts, terminations, option exercises, etc.), 15 definitization actions (task order, delivery order, undefinitized contract action [UCA] definititization, etc.), and eight miscellaneous actions (Freedom of Information Act [FOIA] requests, congressional inquiries, etc.). Stakeholder groups meet to assign process times for each of these types of work (D. Baker, personal communication, March 22, 2010).

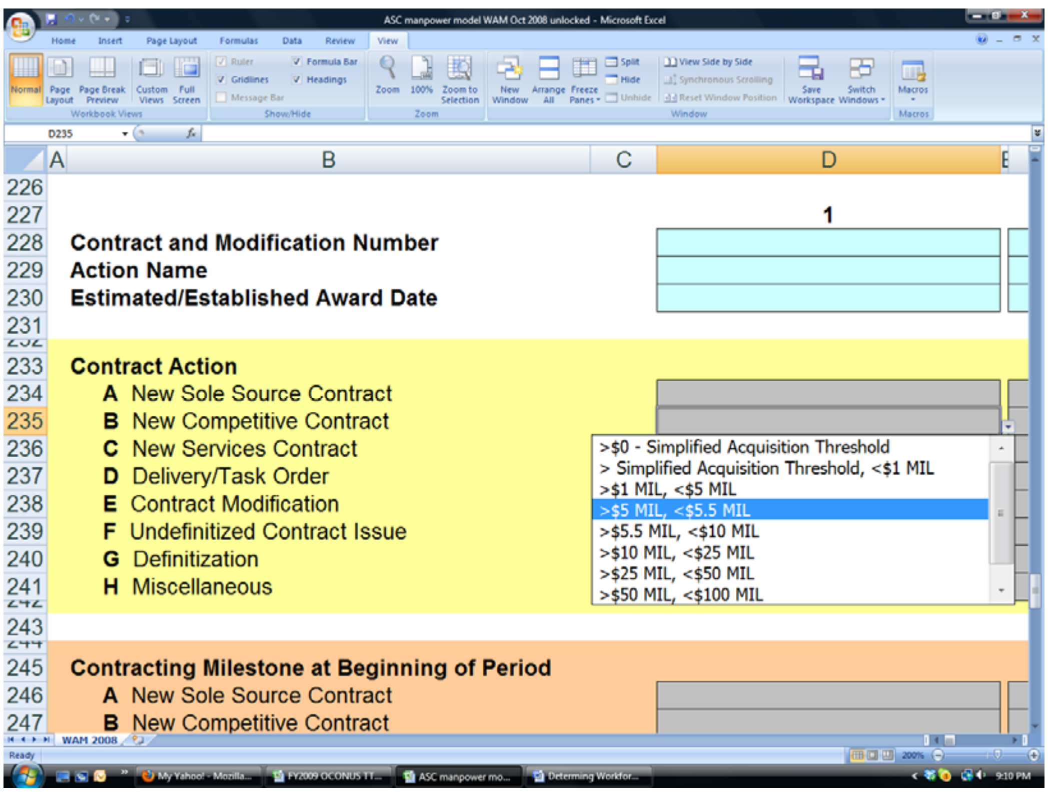


Figure 3

Workload is determined through an annual data call exercise in which each buyer (with workload) on the installation (approximately 700) completes a spreadsheet by simply identifying the contract or program they are working on and then identifying, via dropdown boxes, each of the actions they (1) accomplished in the past three months and (2) are scheduled to complete in the coming three months (see the WAM model example in Figure

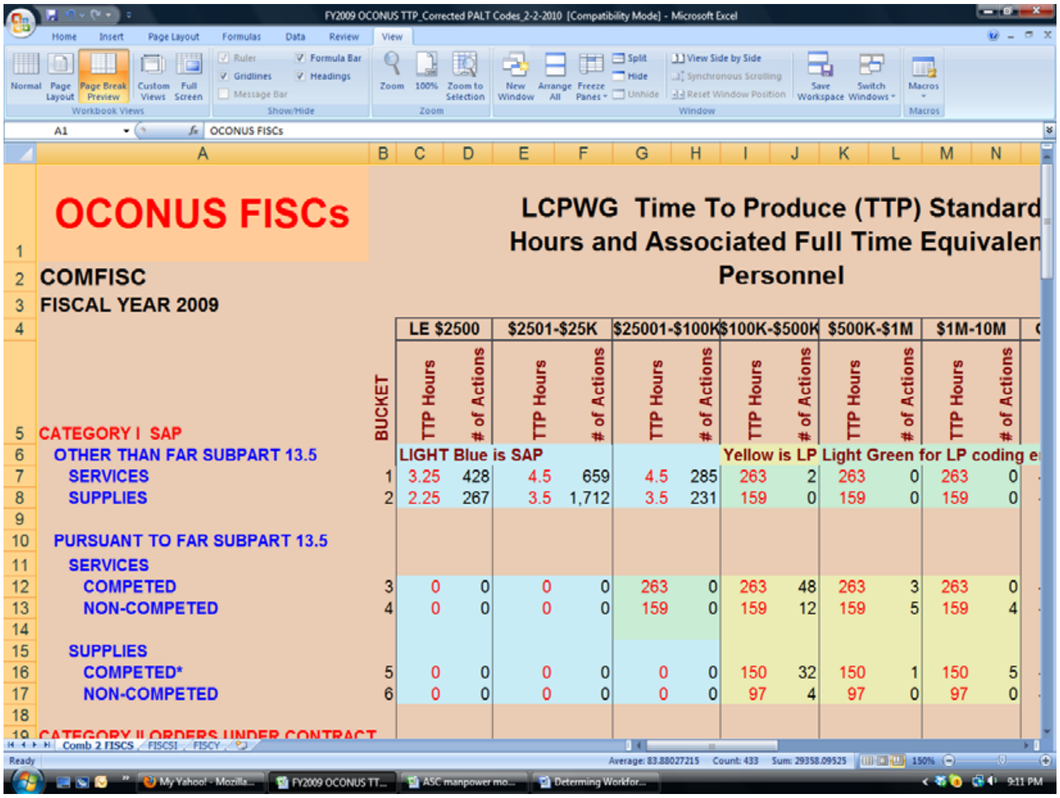
3). The assigned hours “earned” are not displayed to the buyers, and all workload assessment computations are calculated after submission. The data are aggregated through contracting offices and reviewed by contracting leaders so that they can concur with the input (D. Baker, personal communication, March 22, 2010). The data are further refined by assigning earned credit based on where the action is within the acquisition cycle. In other words, buyers earn partial credit for completing any of the 12 different portions of larger tasks of work in progress (e.g., 25% of related task hours for reaching *RFP issued*, or 70% for *negotiations complete*). Further refinements occur based on the complexity factor assigned to the program office. Through stakeholder discussions, factors such as congressional visibility, program maturity, higher headquarters or PEO review thresholds, technical complexity, personnel mix and history, etc., are considered, and an indirect multiplier factor from 0.1 to 0.4 can be added to the workload input to compensate for additional workload due to program complexity (D. Baker, personal communication, March 22, 2010).

A weakness of WAM is that it requires a manual data call once a year and a periodic validation by stakeholders of the earned hours attributed to workload types. It also relies on individual procurement specialists to accurately input their workload, determine the appropriate complexity level for the work, and determine the degree of completion of the total effort. In addition, it does not account for types or grades of workforce personnel. Forty hours earned through an action covers one FTE for a week, whether it is a GS-9 with two years of experience or a GS-13 with twenty years of experience. To account for this, if a contracting office has a significant departure from the normal distribution of grade levels, the indirect complexity factor is designed to compensate for that shortfall.

Navy Workload Models

Naval Supply Systems Command (NAVSUP) uses the *Time to Produce* (TTP) workload model to measure work accomplished. The model was originally developed by the Fleet Industrial Supply Center (FISC) Norfolk at their Philadelphia location. The model uses PATs developed by two subject matter expert groups (representing simplified acquisitions and large acquisitions). The TTP model relies on data collected each month on completed actions. The data set includes product and service definitions of the action. The data are placed into simplified or large acquisition buckets. The headcount for the actions is tracked at the FISC level.

A separate productivity model measures the actual productivity of the contracting specialists via a tally of simplified and large contract actions completed. Complexity is accounted for in this model by placing more complex actions in the “large acquisition” bucket, irrespective of the dollar level (S. Pierce, personal communication, May 7, 2010). Both the TTP model and the productivity model can be used to assess activity at the FISC-wide level, at the aggregate FISC level, or at the individual operating location. Due to the wide variability in average productivity per year and the wide variability in the nature of work performed, the models are best used to compare year over year performance trends at individual locations rather than to assess each location’s capability relative to other locations (S. Pierce, personal communication, May 7, 2010). An example of the TTP model is depicted in Figure 4.



OCONUS FISCs

LCPWG Time To Produce (TTP) Standard Hours and Associated Full Time Equivalen Personnel

COMFISC

FISCAL YEAR 2009

	BUCKET	LE $2500 TTP Hours	LE $2500 # of Actions	$2501-$25K TTP Hours	$2501-$25K # of Actions	$25001-$100K TTP Hours	$25001-$100K # of Actions	$100K-$500K TTP Hours	$100K-$500K # of Actions	$500K-$1M TTP Hours	$500K-$1M # of Actions	$1M-10M TTP Hours	$1M-10M # of Actions
CATEGORY I SAP													
OTHER THAN FAR SUBPART 13.5		LIGHT Blue is SAP						Yellow is LP		Light Green for LP coding e			
SERVICES	1	3.25	428	4.5	659	4.5	285	263	2	263	0	263	0
SUPPLIES	2	2.25	267	3.5	1,712	3.5	231	159	0	159	0	159	0
PURSUANT TO FAR SUBPART 13.5													
SERVICES													
COMPETED	3	0	0	0	0	263	0	263	48	263	3	263	0
NON-COMPETED	4	0	0	0	0	159	0	159	12	159	5	159	4
SUPPLIES													
COMPETED*	5	0	0	0	0	0	0	150	32	150	1	150	5
NON-COMPETED	6	0	0	0	0	0	0	97	4	97	0	97	0
CATEGORY II ORDERS UNDER CONTRACT													

Figure 4

Defense Contract Management Agency (DCMA) Model

Today the DCMA uses the Performance Labor Accounting System, or PLAS, to capture work performed. The PLAS requires DCMA personnel to track their hours on a daily basis and attribute them to a program or contract. Much like a timecard system, the PLAS allows the DCMA to track the hours and processes performed in support of specific contracts and aggregates information into multiple reports, including types of contracts supported, agencies supported, processes performed, etc.

The PLAS can also be used to calculate relative efficiency level comparisons between operating locations. (D. Peterson, personal communication, April 20, 2010). The PLAS also allows calculations for earned value management in different functional areas. The PLAS feeds information into the DCMA's Enterprise Planning system, which allows the agency to calculate the projected workload, as well as the type of support environment (e.g., pre-contract activity, post-award activity, contingency activity, etc.) and, as a result, the workforce required (R. Sawlsville, personal communication, March 30, 2010).

The PLAS is a rich source of information for DCMA leaders. Its ability to capture actual touch times required to administer contracts is useful. The DCMA has assisted other organizations in baselining their workload by providing PLAS data on process times. However, some say that navigating through its 100 process codes and hundreds of contract numbers is not particularly user-friendly. The difficult interface is suspected of reducing the accuracy of information collected because the system relies on buyers to seek out contract types and process codes on a daily basis. If buyers perceive the interface to be too complicated and utilize the system option to reproduce yesterday's entry as today's input, then this eventuality serves as a threat to data accuracy.

Federal Civilian Agency (FAI) Models

As discussed in the literature review, the Federal Acquisition Institute has been tasked with developing a community of practice and sharing workload models utilized by federal civilian agency contracting offices. The FAI has made seven different models available for agencies to use to develop workload assessments.

1. Project-Based Combined Model developed by the Department of Energy. This model identifies staffing needs based on project-level characteristics. These characteristics include the annual value of project work to be executed, the type of project, the project complexity, the manner of execution, the project phase, the level of regulatory involvement, and the degree of external influence.
2. Multidimensional Model being developed by the Department of Veterans Affairs. The model focuses on tasks in acquisition planning and pre-award and post-award activities.
3. Program-Based Model from the Department of Transportation–Federal Aviation Administration. The model uses historical program data to derive recommended staffing levels for major acquisition programs.
4. Regression model that provides two options to the user. Option one is to baseline agency spend to FY 2000. The model indicates that one contract specialist is required for each $5 million in spend. In option two, the regression model indicates that for each 45 contracts awarded, one additional GS-1102 FTE is required. This model is very limited in application and does not consider complexity factors.
5. Volume-Based Surge Tool developed for use as a result of the American Recovery and Reinvestment Act. The model allows the use of agency work volume growth from a baseline spend year and can be refined through human capital planning and analysis.
6. Transaction Model based on agency procurement spend and contract manager staff counts from 2000–2008. The model requires input of actual spend and workforce for each year. An average productivity per contract manager over the eight-year period is computed and divided into current FY projected spend.
7. Conceptual Combination Model developed by the FAI. This model appears to be the most thoroughly developed of the seven options. It is agency-specific and requires agencies to identify complexity, risk, workforce productivity, and other elements. Agencies can adjust weights ratios and factors to better represent the agency operating environment. The model uses a baseline workforce factor of $15.8 million for the average productivity of contract managers. Of note is that the model uses a factor calculated for the years 1993–1996 as a time period in which contracting offices were considered optimally staffed for contracting professionals.

All Federal Civilian Agencies have a contracting representative member of the FAI modeling working group that can provide access to the various models. The DoD does not have a similar working group to facilitate the sharing of model information.

Conclusions and Steps for Contracting Leaders

This study finds that procurement workforce performance measurement and workload assessment have been areas of study for at least 70 years. There is a wide variety of benchmarks and models available to serve as the basis for government models. However, the review of the government organization literature indicates that the question of workload assessment has been given significantly less attention than output measurement, and that output measurement has been conducted primarily with overly broad measures such as dollars obligated and actions completed. Further, the preponderance of the workforce modeling activity is now focusing on (1) measuring the size of the organization (impacts of retirement, accessions, etc.), (2) measuring the descriptive statistics or demographics of the workforce, and, to a lesser degree, (3) attempting to measure the capabilities of the organization vis-à-vis competency assessments (Lamm & Reed, 2009). While these assessments present leaders with important pieces of information, they are incapable of answering the critical question: How much work will we need to do? Understanding the competencies and capabilities of an organization assists managers in developing a "mixed" human capital strategy; however, the literature indicates that leaders cannot determine the mix of capabilities required without also determining the number of workers needed. The two variables affect each other with such great significance that to consider one in the absence of the other is an endeavor destined for failure.

This study and extant literature (e.g., Reed, 2010) have found that workload measurement in DoD contracting organizations is either performed inconsistently or not at all. Contracting leaders can take immediate steps to begin measuring workload and assigning staffing appropriately based on workload. Multiple models, ratios, and processes have been presented in this article, and one or more may present opportunities for your organization. However, based on my evaluation of the literature and current processes, the following seven steps can be taken at the lowest implementation cost to provide leaders with immediate assessment of their workload and staffing.

1. Define your strategic intent and identify quality measures that reflect your intent (timely award, timely delivery, fair and reasonable prices, customer satisfaction, corrective actions, etc.).
2. Conduct a cost-per-dollar-obligated (CPDO) analysis for the previous fiscal year for your organization. If you do not have access to all operating expenses (many leaders do not), use the salary cost of the workforce as your operating cost. If salary cost is not available, contact your personnel office to determine the average "burdened" compensation and support cost for your organization, or for the various grade levels of personnel in your organization, and compute a rolled-up salary cost. The more exact that you can be when determining cost, the better; however, the consistency of your agency's approach from organization to organization and year to year is the most critical concern.
3. Conduct a similar CPDO analysis for the past three years to determine the trend for your organization and to establish an average CPDO.
4. Measure the quality of your outputs (consistent with your strategic intent) now and over time to determine trends and averages.

5. Compare your organization to industry benchmarks, and to similar organizations in your Service or Department. Address the differences between your CPDO and the benchmarks. What are the potential explanations for the differences? What can you do to address the differences? If your CPDO is significantly lower than benchmarks and comparable organizations, determine the explanatory factors. A relatively low CPDO may indicate your organization is extremely efficient, or perhaps indicate that opportunities to enhance quality may exist if more resources were added to your team.
6. Set CPDO and quality goals for your organization.
7. Identify the estimate of your future work. This remains one of the most difficult tasks. Budget proposals, Future Years Defense Program (FYDP), Program Objective Memorandum (POM), and appropriations legislation may provide information upon which to construct rough order estimates on either the total amount or departure trend from previous year obligations that your organization may experience. Develop complexity and risk assessment weights based on the type of monetary obligations, and product/service mix that your organization is projected to procure.

Taking these seven steps will not only provide contracting leaders with valuable insight into the amount and nature of the work their organization is to perform, but also information regarding the actual performance of the work. Further, it will allow for the development of quality measures linked to the leader's strategic intent and allow for the establishment of quality performance goals for the organization, rather than the volume performance measures currently in use.

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How Can Civilian Retention in the Army Contracting Command Contracting Professional Community Be Affected?

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Abstract

There is a civilian retention issue within the contracting professional community at the Army Contracting Command (ACC). This research paper explores the causes and impacts of it, and offers solutions. The presented solutions are supported through the introduction of a novel formula which provides helpful indicators for the issue.

Introduction

There is a perceived civilian retention issue pertaining to the contracting professional community within the Army Contracting Command (ACC) identified by several of the ACC contracting organizations when they have presented briefings at various Commander's Conferences and offsite meetings, and in conversations with the ACC Executive Director and Deputy Executive Director. These discussions have also transcended to other senior management within the ACC contracting organizations and have even been topics of discussion in other ACC events such as the ACC Training Conference in June 2010. The ACC also has a Human Capital Plan designed to strategically address a number of issues pertaining to ACC workforce issues. Civilian retention is one of the issues identified therein as needing action. In a dialogue with the ACC Executive Director, Mr. Jeff Parsons, in August 2010, he referenced his belief that there was a problem with retention of contracting professional employees and expressed interest in research surrounding the issue and potential solutions, as applicable (J. Parsons, personal communication, August, 2010). For purposes of this paper, the contracting professional is defined as one who is classified in the 1102 series under federal government personnel classification guidelines. The contracting professional community will be referred to as the 1102 community hereforth.

Literature Review

A large amount of research that relates to employee retention is existent. It ranges from focused studies on just a single company or industry, such as that found in Ramlall (2003), to studies with over 24,000 employees, as found in Hausknecht, Rodda, and Howard (2009). Additionally, much of management theory pertaining to employee attitudes is attributable to Herzberg and his findings from the 1950s and 1960s (1959 and 2003). Therein, Herzberg makes a definitive distinction between hygiene and motivational factors as they pertain to employees. In particular, he posits that money is not something that will be a satisfier for an employee (2003). It has been found that these conclusions have been looked at in such a way that there is a belief that money is not an important retention tool. Studies show that untrue; money plays a major factor in employee decisions on either staying with or leaving an organization (Laabs, 1998). Additionally, there is quite a difference in opinion that exists as to the number one cause of employee voluntary departures. Some say it is pay (Pink, 2009; Towers Watson, 2010). Others say it is lack of job engagement (Martin & Schmidt, 2010). It has been shown that some employees have a need for recognition. In these cases a company should focus on its star performers, and employees critical for mission execution who have not achieved star status (Cosack, Guthridge, & Lawson, 2010). In any case, it is clear that the cost of losing employees is significant. Loss of an employee could cost double the amount of the departing person's salary (Heathfield, n.d.; Cascio, Young, & Morris, 1997), in addition to productivity losses. There are predictive elements of behavior for those who may be considering departure of a company or organization (Avey, Luthans, & Jensen, 2009; Barrick & Zimmerman, 2009). There are tools available to assist an organization in determining if they have a retention issue, and which areas need corrections or adjustments. First, an organization can perform an analysis based on the novel formula introduced within the paper. An organization can also perform a targeted "stay survey" like the one discussed herein. A stay survey can give you insights from employees who have a vested interest in the organization as indicated by years they have worked for the organization. Based on information obtained during the survey period of this research, there are locations in the Army Contracting Command (ACC) where this is a civilian retention issue. Initially, when the issue was being considered for research, it was reviewed to determine if there was an issue across all of the Department of Defense (DoD) in the contracting professional community. It was clear very quickly that the retention issue did not transcend the DoD (USD[AT&L], 2010). Of note, there is a portion of the research that points to mitigating the retention issue before employees are even brought on board (Collins, 2001). Pre-hiring initiatives include the act of "on-boarding" new employees before their first day of work by providing information on the organization, and identification of a sponsor who will stay in touch with the new employee during the first several months of employment (Sullivan, 2007). At the conclusion of the paper, several recommendations are presented for use by the ACC and other organizations that have retention issues.

Is There a Retention Issue?

Hypothesis 1a: There is proof that there is a systemic civilian retention issue in the ACC 1102 community. The basis of this research is that there is a perceived issue pertaining to contracting professional employees leaving organizations within the ACC. The first issue is whether or not this is perception or fact. The first resource reviewed is Appendix 1 of the *DoD Strategic Human Capital Plan Update, The Defense Acquisition Workforce* of April 2010.

Based on the information therein, we find there is not a civilian retention issue for 1102s for the DoD as a whole. This was an important fact to understand the scope of the issue. That outcome would have potentially redirected the entire scope of the issue. The information shows that 1102s are targeted for growth of over 20% from the baseline of FY 2009 through FY 2015, due to an increased workload and the ever-increasing need for specialization in the field. Further, the document indicates that certain retention initiatives appear to have benefited the DoD in retaining acquisition professionals in general. It states, "there was a 25 percent decrease in losses across the workforce…in FY 2009 as compared to FY 2008. Turnover, excluding administrative losses, decreased from 8.9 percent in FY 2008 to 6.5 percent in FY 2009" (USD[AT&L)], 2010a, p. 1–11). While part of that decrease can be attributed to economic uncertainty and the reluctance of employees to look for alternative employment, the initiatives appeared to have a positive impact. Additionally, the Appendix 1 to the aforereferenced Appendix 1 contains more detailed information pertaining specifically to contracting professionals. It indicates that there were 23,752 in the contracting workforce in the DoD in FY 2009; regarding workload, a total of $384 billion was obligated in FY 2009 (USD[AT&L)], 2010b). Of those, 7,741 were civilian contracting professionals supporting Army work. The document further states while the 1102 community was somewhat level from FY 2001 through FY 2008, workload increased by over a third. Also, 36% of the 1102 workforce is either eligible for retirement or will be eligible for retirement within the next five years. Initiatives to increase the workforce are articulated and serve to counterbalance projected losses and to actually grow the 1102 workforce for the DoD community (USD[AT&L], 2010b).

In Losey's review of a report from the Partnership for Public Service and Booz Allen Hamilton dealing with attrition in government jobs from an overall perspective, attrition rates declined significantly from 2008 to 2009 to only 5.8% (2010). It is believed that this significant decrease is due to current economic conditions. Attrition rates for critical employees, however, are much higher. This was a significant impact as mission-critical employees and new hires consume a lot of resources in bringing them onboard and training them. This also could be an indicator that candidates are not matched well for the job in which they are hired, the employee is not given adequate training, or their salary does not remain competitive with other employers (Losey, 2010).

In a dialogue that was conducted with the Naval Sea Systems (NAVSEA) Command Executive Director for Shipbuilding, Ms. Theresa Ryan revealed that retention is not a recent issue with their workforce. They have hired a large number of interns to supplement their workforce. However, in the future, retirement could be an issue as they have a large number of retirement-eligible employees (T. Ryan, personal communication, December 2010).

Personal communications (various) with representatives of management of the AMCOM, TACOM, and CECOM Contracting Centers have revealed that each believes they have retention problems based on Center-specific data depicting numerous vacancies and jobs that they have to fill. In the instance of the TACOM Contracting Center, additional time was spent at their office in Warren, MI, to aid in understanding the results of a recent climate survey they administered. The source of the retention issue is different for each of the aforementioned Centers. However, each has at least one competitive entity within their geographic area that has caused pressure on their personnel on board number and experience level. The 413th Regional Contracting Office in Hawaii does not currently have a problem with retaining 1102 personnel. However, they went through a somewhat painful set of processes to remedy a retention issue. More on each of the organizations will be discussed in the survey section of this paper. The data suggests the ACC does have civilian retention issues within the 1102 community.

Goldsmith puts forth the notion that the "best performers of a company were no longer interested in sacrificing their lives for the good of the organization…[as they] believed that their corporation would [let them go] when they no longer met [the company's] needs….Free agency meant that each employee was operating like a small self-contained business rather than a cog in the wheel of a large system" (2007, p. 212). Goldsmith also points out that in today's market, employees look out for themselves, in a departure from practices of the past.

What Do Surveys Say?

Many companies administer exit surveys to determine the thoughts of employees when they leave. Without critically thinking through the exit survey process, one may have results that do not yield valuable information. Bridget Mintz Testa, in *Workforce Management*, captures related recommendations from Robert Tate, PricewaterhouseCoopers (2010). The recommendations include surveying “only those who leave voluntarily,” and compare them with business unit performance and employee performance reviews (Testa, 2010). This would give a more balanced viewpoint of why an employee left the company, and would potentially have actionable survey information. The theory extends that if an employee leaves involuntarily, the survey may not provide relevant or useful information at all.

While exit surveys are useful, a more proactive approach would be to apply a “stay survey.” The concept of a stay survey is to target individuals who have a requisite amount of time and effort invested with an organization and find out strengths of that organization, and those areas which can be improved. This would theoretically turn into a revelation of information which would then be translated into action resulting in a higher retention rate. This concept was introduced to the author by an innovative ACC human capital strategist, Copper Perry, who had many years of experience working for various government organizations. It appears that the concept is very similar to that of employee retention surveys, which do not have a very large following at this time. It is observed that organizations sometimes use overarching climate surveys for the entire organization to find out answers to a variety of questions. However, they are not primarily targeted at retention.

Sullivan noted “pre-exit” interviews can be used to try to determine why employees were willing to stay with a company (1997). This appears to be the precursor to the stay survey. Sullivan created a list of questions that he provides for a company wishing to conduct one of these surveys. The two most compelling questions were “why do you stay?” and “if you ever considered leaving…what kind of ‘trigger’ would it take to get you to consider leaving?” (Sullivan, 1997). Deutsch discussed the usage of “employee retention surveys” as a tool to boost retention. According to Deutsch, these are most useful if a company has a high turnover rate. He is clear that action plans should be developed by the company administering the survey as a method of following up to ensure retention issues are addressed (n.d.). In a *PeoplePulse* newsletter, stay surveys are discussed with reference being given to Dr. Sullivan for the focus and nature of sample questions (2007).

With Ms. Perry’s assistance, parameters were developed for the pilot of the stay survey. The target of the ACC pilot was the AMCOM Contracting Center, which is an organization within the ACC that has approximately 700 personnel authorizations. It was agreed that those having four or more years of experience at the Center would be in the selectable pool for the survey. This was an important decision point as it was decided that those with four years of experience had invested both experiences and training into the organization. At that point, there were three employees with four years of experience at the AMCOM Contracting Center from each of the then-existing 10 Directorates at the Center who were randomly selected to participate. For administration purposes, it was decided that the survey would be administered by interview for two reasons. First, since this was the first application of the survey questions, face-to-face interviews would control the unknown. Second, the questions were designed to be open-ended, and they were carefully crafted so as to not lead any of the participants to a particular answer or conclusion. It was decided that the interview approach again would be the best methodology in capturing responses.

Table 1 contains the list of ten questions in which Ms. Perry and the author came to agreement.

Table 1. Questions for Stay Survey

1. If you were to win the lottery and resign, what would you miss the most about working here?
2. What keeps you here? What about your job satisfies you?
3. What might entice you away?
4a. What aspects of working here do you like the best?
4b. What aspects of working here do you like the least?
5. Are you recognized for your accomplishments?
6. What motivates you to excel in your position?
7. Do you believe our leaders understand the value of people?
8. Do you believe our leaders understand the organization's mission?
9. What are the most important improvements we could make?
10. What are you struggling with? What would make your life easier?

As one would expect, there were multiple answers to most of the questions. The challenge from the initial set of results was then to compile the results in a meaningful way and use them as an action tool and a communication tool to the workforce. The results of the survey were published in the Center's emagazine; this was also restarted in an effort to increase communication with the workforce.

The challenge for this particular research was to expand usage of the survey to other select sites within the ACC for compilation. Additionally, one ACC Center coincidentally conducted a much more comprehensive climate survey. There were some questions from their climate survey that were somewhat related to the focus of the stay survey. Therefore, the answers to some of the questions from the climate survey have been used for comparison purposes. Compilation from all of the data received is found in Table 2 with the top response or responses indicated for the questions.

Table 2. Survey Responses

Questions	AMCOM	CECOM/ APG	TACOM**	413th CSB (in Hawaii)	CECOM/ Belvoir	CECOM/ Other***
What will entice you away?	Money—41%	Money—44%	Money related—Bonuses, Pay, or Less Stress	Money related—45%; Retirement—45%	BRAC or relocation—50%	Money related
Biggest suggested improvements	Recruitment & Training—55%	Personnel related (e.g., manning & training)—44%	Ratings/ Process, Recruitment, or Part-time Employment	No item listed at greater than or equal to 20%	Recruitment & Training—67%	Better use of automation and interface of systems
What do you like the best?	People—26%; Independence—23%	Work related—56%; People—31%	XXX	People—64%; Work related—36%	People—50%	Meeting soldiers' needs
What satisfies & keeps you here?	Job & Mission—36%	People & Mission—75%	XXX	Job & Mission—82%	People & Mission—50%	Coworkers and support of soldiers
What motivates you to excel?	Self-satisfaction—38%	Personal Drive—60%	Pride in Work	Personal Drive/ Work Ethic—55%	Personal Pride—50%	Support of soldier

Note. **The TACOM climate survey had similar questions in three of the five questions as noted above. Due to the answer options being dissimilar from the stay survey construct, comparable statistical information could not be incorporated. ***Consisted of Huachuca and Monmouth—not enough statistical data to display percentages.

The results from this survey reveal interesting information. What is clear from the background information received is that each location has different factors impacting its workforce. Labor market, local community unemployment, the presence of organized labor, the number of competing federal contracting organizations, and how the specific organization recognizes and pays its employees (includes pay system(s)) all play a part in the retention issue.

The first data conclusion is that employees will leave their current organization for more money. That was the largest response across the board at the different locations. (The only deviation was at Ft. Belvoir where there were just six respondents, and BRAC and re-location has been a prominent factor as CECOM has recently had their headquarters move from Monmouth to Aberdeen Proving Ground.) Money in this context would extend to the extrinsic rewards of either a higher salary, promotion, or the hope of higher bonuses. That may be surprising to some, as it appears to differ with the perception of Herzberg's theory. However, these results are very similar to other data and information gained through this research. As stated earlier, the construct of the survey questions were designed to be open-ended so as to not lead the respondents in this somewhat controversial area, in particular. Having money-related factors being the leading answer with over 40% of respondents is very telling. It clearly shows that an organization absolutely has to include extrinsic rewards in its retention plan.

The second conclusion is that in the three continental United States ACC organizations, the personnel process is the biggest thing that should be improved. These percentages go from the mid-40th percentile up to 60%. Again, this is a very strong indicator for those organizations, and could very well be symbolic of the contemporary issues facing the ACC. These issues range from getting more experienced personnel on board, to getting appropriate mentoring and training programs in place for those who are new employees to the Army or to their respective organizations, to other suggestions related to the personnel process.

The 413th Combat Support Brigade (CSB) Regional Contracting Office (RCO) located in Hawaii was the lone surveyed activity in which personnel was not identified as the most needed improvement issue. As it turns out, they went through some rather dramatic organizational issues relating to 1102 personnel in the last couple of years. The journeyman grade structure was lower at the RCO than at other federal organizations in Hawaii. The RCO supported and instituted the increase of the journeyman level grade from the GS-11 level to GS-12, and Team Leaders were increased from GS-12 to the GS-13 level to be competitive with the other organizations in the area, and to be consistent with the complexity of work. Effort was also provided to increase the number of overhires to cover mission-required services. The purpose of this was to increase the time an employee could work on an action, and to cut the amount of overtime required by then current employees. This would have the effect of increasing the quality of each work product, and increasing the quality of life for the employees. An additional office was opened to better align operations with the customer base and reduce commute time for several of the employees. Further, there was an agreement forged across the multiple Services in the area regarding hiring personnel from another organization when promotions are not involved. This agreement turned the personnel environment into one of cooperation instead of one of competition. Overall, employee morale at the RCO went up as work quality went up.

A third important conclusion from the surveyed data is that employees are motivated very strongly by either personal pride or their work ethic. This percentage is again from approximately 40% to 60% of those who responded. This provides clear thinking about the concept of retention, motivation, and potential responses by the organization to the talent that they have in-house.

A fourth conclusion is that employees are satisfied on their job by their work and the people with whom they work. This was another strong indicator ranging from approximately 40% to 80%. Development of workplace culture and high-performing teams can contribute to this positive experience. As it is shown later in this paper, there are a number of things an organization can do to maximize a person's talents and keep them engaged and satisfied at the same time.

A fifth conclusion is that when asked what employees liked the best about their job, they replied that it was both the people, and their support of their mission, or current job. That range was from the mid-20th percentile to approximately 60%. The answers to this question are very similar to those of the prior two questions. That is a consistent finding as the questions are very close in construct. That was done to see if these open-ended questions would yield different or similar answers. What this means is that, again, organizations should make the employer-employee contract one where people enjoy their work. Part of this is job engagement; part of this is having adequate resources; and part pertains to integration of an employee into the corporate mission and culture.

The survey responses were very descriptive and are loaded with information that the home organizations will be able to follow up with action for improvement. However, for the purpose of this research paper, those complete details will not be revealed herein.

Of note, the TACOM Contracting Center benefited from a pool of available talent from the depressed auto industry. Their survey revealed that an overwhelming number of employees (94%) would not consider employment outside of the government. That is good news for the TACOM Center. Separately, the TACOM Center invests a significant amount of time in going over employee individual development plans (IDPs). Their process includes each IDP being briefed all the way to the senior management level at the Center. Additionally, employee selections get integrated into the IDP process. For example, if an employee is not selected for a position due to reasons associated with a weakness in ability or experience, this information flows to the employee's IDP for additional training, or a potential rotation in another part of the Center's operations. Because of this practice, each employee has a higher likelihood of being developed and having a job that provides them with challenges that match their skillset or development needs. This potentially opens up opportunities for the employee in the future. This is viewed as a best practice.

Hausknecht et al. (2009) found in an extensive study of over 24,000 respondents that "job satisfaction, extrinsic rewards, constituent attachments, organizational commitment, and organizational prestige" (p. 269) were listed as top reasons that employees in a non-related industry wanted to stay. Detailed and differentiating analyses were provided for hourly and non-hourly employees (Hausknecht et al., 2009).

Avey et al. (2009) cited an American Psychological Study from 2007 and determined that workplace stress is a major contributor in driving people to search for jobs in other organizations. Several of the contributing factors to stress included workload, poor supervisor and employee relationship, job security, and heavy travel requirements (Avey et al., 2009).

Lee, Gerhart, Weller, and Trevor (2008) found that not all voluntary separations were a result of dissatisfaction. In particular it was noted that unsolicited offers and family issues drove job changes for some employees, while not being reflective of dissatisfaction (Lee et al., 2008). It has been observed that many instances of interns from the AMCOM Contracting Center leaving for other organizations came from unsolicited offers.

The Partnership for Public Service and Grant Thornton (2010) conducted a study of 68 Chief Human Capital Officers (CHCOs) in the government and made several conclusions. First, they determined that there were seven major obstacles to having a strong workforce. Those seven items are listed in Table 3.

Table 3. Seven Obstacles to a First-Class Federal Workforce

1. A cumbersome, complex hiring process
2. Antiquated pay and classification system and ineffective performance management
3. Uneven relationships between CHCOs and OPM
4. An HR workforce that too often lacks the competencies needed going forward
5. Manual processes and a lack of robust HR IT solutions
6. Insufficient leadership and workforce management skills among too many federal managers
7. Adversarial relationships between high-level management and employee unions

Note. This table has been adapted from Partnership for Public Service and Grant Thornton (2010).

Out of the seven barriers, a few of these are applicable to the retention issue. Looking at the first obstacle, it was shown that the CHCOs did not believe they had adequate hiring tools. They believed that provisions for student loan repayments and retention bonus provisions were inadequate. They further indicated that much of the flexibility desired emanated from the complexity of public law (Partnership for Public Service & Grant Thornton, 2010).

On the second obstacle, some CHCOs indicated that market pay would be a useful tool. However, they indicated that classification would provide a challenge. Also, the concept of pay for performance is an issue that has been a problem for organized labor; a solution for that has not been found yet (Partnership for Public Service & Grant Thornton, 2010).

Regarding the third obstacle, thoughts are captured from the CHCOs which reference the need to expand ways to compensate employees beyond the typical extrinsic rewards of salary and monetary awards. They point out that in their view, employees are not motivated by money and they want to serve the country with their service. The CHCOs further point out that government employees are motivated through other means such as recognition or by mission involvement, and other available tools such as alternate work schedules (Partnership for Public Service & Grant Thornton, 2010).

Skipping ahead to the final obstacle, it pertained to the chilly relationship that labor and management have had over the last several years. This is an issue that is discussed in another section herein (Communications—Labor). But it is noted that the CHCOs believe this is a relationship that can be very beneficial as a tool to pulse the feeling of the employees (Partnership for Public Service & Grant Thornton, 2010).

Pay

Pink (2009) writes that the "most important aspect of any compensation package is fairness" (p. 171). He further describes that fairness should be construed as similar compensation for similar work.

In the instant issue, would one believe that all GS-12s in the 1102 community have the same level of responsibility and work? What about GS-13s? What about GS-14s? What if an organization has a GS-13 who is a Contracting Officer and another GS-13 who is not a Contracting Officer? There is clearly a distinction in responsibilities between many employees at the same grade level. Issues of equity are sometimes brought up in this context. Pink also views this as an external issue as well as one inside just a single organization (2009). While Pink believes money is not a motivator, he believes it can be a de-motivator when fairness is not in play. A novel approach supported by Pink is that an organization should identify their top talent and pay them above the market average in order to stay ahead of the competition and keep talent from leaving (2009). It would completely dispose of the money issue.

Other Concerns

Impact of Losing Employees

There is considerable information available identifying costs associated with losing employees. When an organization loses employees, no matter the reason, there will be an impact to mission due to loss of expertise, and there will be an accompanying cost associated with the recruiting, hiring, and training of a new employee. Of note, loss of an employee could cost from 100% to 200% of their annual salary (Heathfield, n.d.). Heathfield also points out that "Employee retention is one of the primary measures of the health of your organization. If you are losing critical staff members, you can safely bet that other people in their departments are looking as well" (n.d., p. 1). Wayne Cascio, who has performed a significant amount of research and writing on the costing of human resources, led a team of authors in talking about the cost of the departure of an employee and replacement running from approximately 90% to 200%, depending on the skill responsibility level of the employee (Cascio et al., 1997). Therefore, based on independent sources, the cost of losing an employee could be double the departing employee's salary. This provides a significant degree of risk to an organization if market or other indicators foster employees to leave. The biggest risk associated with losing an employee, though, will be the degradation of the mission execution and the increased cost transferred to the customer (Farrior, 2003).

Cascio further explored the predictive nature of attitudes on subsequent behaviors. He determined that there may be some behaviors that are predictive in nature regarding subsequent activities such as leaving an organization (Cascio, 2000). Of interest, he used the example of a company employing a set of survey questions to assist in how they perceived employee attitudes. From the answers they gave, the company made adjustments in how management approached certain issues relating to the company or to the employees (Cascio, 2000). He further discusses that even though the company used 70 questions in its survey, it appeared there were only three questions that predicted "an employee's attitude about his or her job:

1. I like the kind of work I do.
2. I am proud to say I work at (the company).
3. How does the way you are treated by those who supervise you influence your overall attitude about your job? (Cascio, 2000, p. 153)

The Issue of Money

Hypothesis 1b: Given that there is proof that there is a civilian retention issue in the Army Contracting Command 1102 community, extrinsic rewards (i.e., salary and monetary awards) will not be a primary factor in addressing the issue.

The Herzberg Effect

Herzberg established himself as a pioneer in the study of motivation of an employee. He is best known for his two-factor theory of motivation and hygiene on job attitudes which was first captured in *The Motivation to Work* in 1959. His primary findings indicated that the differences in accounting for motivation and demotivation were distinct. His research surveys were also defined by their use of “semi-structured” (Herzberg, Mausner, & Snyderman , 1959, p. 16) questioning to ensure the data was not slanted or corrupted by biases.

In 1968, and republished in 2003, Herzberg looked at the subject of motivation again in a *Harvard Business Review* article. In it, he first tackled what he termed myths about motivation. A list and brief description of each myth follows in Table 4.

Table 4. Motivational Myths and Selected Herzberg Quotes

1. Reducing time spent at work—Motivated people seek more hours of work, not fewer.
2. Spiraling wages—Have these motivated people? Yes, to seek the next wage increase.
3. Fringe benefits—The costs of fringe benefits in this country has reached (new heights) and we still cry for motivation. These benefits are no longer rewards; they are rights.
4. Human relations training—Over 30 years of teaching and…practicing psychological approaches…have resulted in costly…programs and, …the same question: How do you motivate workers?
5. Sensitivity training—With the realization that there are only temporary gains from comfort and economic and interpersonal (kick in the pants), personnel managers concluded that the fault lay…in the employees’ failure to appreciate what they were doing.
6. Communications—The professor of communications was invited to…help in making employees understand what management was doing…. But no motivation resulted, and the…thought occurred that perhaps management was not hearing what the employees were saying.
7. Two-way communication
8. Job participation—…job participation often became a ‘give them a big picture’ approach…but still…no motivation.
9. Employee counseling—…it was found that the employees harbored irrational feelings that were interfering with the rational operation of the factory. …the counselors had forgotten their role of benevolent listeners and were attempting to do something about the problems they heard about.

Note. This table has been adapted from Herzberg (2003).

Herzberg said that each of these myths failed in succession, and as a result, led to the next of the nine myths for motivation in order (2003).

He then revisited the core issue of hygiene factors versus motivator factors which addressed job attitudes. Herzberg said that since his original study, there have been several studies from several countries, “making the original research one of the most replicated studies in the field of job attitudes” (1968, p. 5). He further allowed that the factors of satisfaction (motivator) and the factors of hygiene (dissatisfaction), while different according to the whole body of research, are not polar extremes. Hence, "the opposite of job satisfaction is not job dissatisfaction but, rather no job satisfaction" (1968, p. 5). He acknowledges how this is somewhat of a confusing concept from a written standpoint. He further defines the differences:

> Two different needs of human beings are involved here. One set of needs can be thought of as stemming from humankind's animal nature—the built-in drive to avoid pain from the environment, plus all the learned drives that become conditioned to the basic biological needs. The other set of needs relates to that unique human characteristic, the ability to achieve and, through achievement, to experience psychological growth; in the industrial setting, they are the job content. Contrariwise, the stimuli inducing pain-avoidance behavior are found in the job environment. (Herzberg, 1968, p. 5)

Table 5 lists the motivator (intrinsic to job) and hygiene (extrinsic to job) factors.

Table 5. Motivator and Hygiene Factors

Motivator Factors	***Hygiene Factors***
Achievement	Company Policy and Administration
Recognition for Achievement	Supervision
The Work Itself	Interpersonal Relationships
Responsibility	Working Conditions
Growth or Advancement	Salary
	Status
	Security

Note. This table has been adapted from Herzberg (2003).

Herzberg provides statistics from his research that show 81% of all events in his survey leading to "extreme satisfaction" come from motivator or intrinsic factors, while 69% of all events in his survey leading to "extreme dissatisfaction" come from hygiene factors (2003). Salary is not listed as either a significant cause or extreme satisfier or dissatisfier. However, since in his survey applications salary was found marginally greater as a dissatisfier than a satisfier (roughly 10% versus 8%), he considered it a dissatisfier—and the conclusion that it is not a motivator (Herzberg, 2003). Herzberg also went to lengths to compartmentalize the first five (by frequency) responses of first level effects as being related to "the job itself" (1959, p. 63). As listed in Table 5, several of those five factors also result in a salary increase or another extrinsic award. It is unclear how this supports decoupling salary from the motivator–concept as he posits. The original study which focused on companies within 30 miles of Pittsburgh, took into effect how an event or series of events caused attitudinal change. This would presumably translate to job performance change according to Herzberg's theories (1959). The short- and long-term effects of attitude and job performance change were also studied. As a component, salary was the sixth-highest rated event for long-term change, while it was the third highest for short-term change. Achievement was the top-rated long-term change and the second-rated short-term change, while recognition was the second-rated long-term change and the top-rated short-term change (Herzberg et al., 1959). Are attitudes in the workplace the same today as they were over 40 years ago, or even 20 years ago? Clearly the answer to that question is no; one would need to go no further than to look at the advances of women in the workplace over the same period of time and see how the entire fabric of the workplace has changed significantly. This is not observed to discount the work of Herzberg; however, the research must be kept in perspective, context, and the understanding of its statistical significance.

The third concept presented by Herzberg pertains to job enrichment. Therein he uses the motivator factors to construct a list based on an experiment he conducted. They are summarized at a high level in Table 6.

Table 6. Job Enrichment Factors

1. Removing controls while keeping accountability
2. Introduce new and more difficult tasks
3. Assign individuals specialized tasks, enabling a new level of experts
4. Making periodic reports direct to employees rather than filter through supervisors
5. Grant additional authority to employees; job freedom

Note. This table has been adapted from Herzberg (2003).

Follow-on research to job enrichment was conducted on five British companies shortly thereafter. While it supported performance improvements in workers in the studies, there was also a positive change in the managers involved even though they were not identified for study purposes. Apparently, there was success associated with the managers involved due to attitude changes: "supervisors now found that they had time available to do more important work…. The enrichment of lower-level jobs seems to set up a chain reaction resulting in the enrichment of supervisors' jobs as well" (Paul, Robertson, & Herzberg, 1968, pp. 61–78).

Money (or) Nothing

Herzberg relied on his studies to make conclusions that many behavioral professionals still point to today for guidance in dealing with the workforce of today. Therefore, salary and extrinsic awards are discounted from being considered as an important component in retaining employees. Organizations conclude that they cannot motivate employees with money, so they put money at the bottom of the list for retention solutions. However, the apparent contrast from survey data from contemporary research to the Herzberg research is that several of the Herzberg hygiene and motivator factors are integrally intertwined and cannot be separated in distinct isolated vacuums as the Herzberg conclusions would seem to indicate.

What is the biggest way that a manager recognizes a person for accomplishing a good job, whether short-term in nature, or longer term such as a year's performance? Verbally acknowledging and recognizing a person is great and should be more than a one-time event. However, if a manager tells a person he or she is doing a great job but the company's actions do not match the words of the manager by giving the person a market's increase to his or wage, or to promote him or her to a position with greater authority or responsibility—also with higher pay, the employee will not be happy, satisfied, or motivated. From a point of view, one could say—so, Herzberg is right. Salary is a dissatisfier. Well, he is partly correct. Stating it in a different way, a pat on the back without money will not make an employee have a long-term motivation, or longer-lasting motivation. It is a start. Further, if there is not an accompanying salary increase or bonus, or some other type of extrinsic award commensurate with the accomplishment being recognized, the employee will find satisfaction, motivation, and employment somewhere else. Similarly, actualization through advancement or growth is important to the satisfaction of the employee. However, if advancement or increased responsibility is not recognized appropriately—meaning, at a decent market rate, the employee will leave. If you compensate an employee and recognize him or her through an appropriate method where he or she is paid or recognized fairly in accordance with the current market, they will be motivated to perform for an organization, and stay. Let compensation fall below the market, and the employee will do what is in the best interest of his or her family unit. They will become a free agent.

An article which had a focus of showing how providing recognition and appreciation can go beyond the value of money to an employee, actually provides support for doing both, instead of providing communication at the expense of extrinsic rewards. If a company eliminates the monetary component of a company-employee relationship, the company does so with great risk. Laabs (1998) refers to studies that show money alone will not motivate employees to perform well, though money is required. It extends that "compensation is a critical element to employee commitment" (Laabs, 1998). Laabs also allows that salary and benefits should be comparable with the market, and that it is an expected right from the employee's perspective of an employment arrangement. A word of caution from the article is that employers should continually seek feedback from employees to see if what the organization is providing to the employee is working well enough to keep them from looking for work elsewhere (1998).

Factors in assessing whether or not an employee is going to leave are the environment, the economy, trends, and available survey data both within the organization and outside the organization. Clear Rock has stated that the satisfaction level of Americans in their jobs is at its lowest rate since the survey started roughly 22 years ago. This is an indicator that employees will look for other employers if the timing of a job changes, and the opportunity (economic and otherwise) is right. Clear Rock goes on to say that an employee should carefully weigh all the pros and cons of changing jobs—that it should not just be a dollars and cents move ("Stay or Change Jobs," 2010).

Towers Watson published very important results in their 2010 Global Talent Management and Rewards Study (2010). While noting that between 25% and 31% of U.S. companies have problems in retaining critical-skill, top-performing (defined as top 10% of performers), and high-potential employees, employers were unable to understand the extent to which job security is a factor in retention. The concern that employees have in determining their own future and retirement has also created an environment that has fostered employees jumping from organization to organization if the employees feel they can get a better compensation or benefits package, or better job security—even if it is only marginally better. According to the survey, employees listed the following six factors, in order, as the most important in influencing them to take an offer from a competing organization: increased compensation, availability of a better pension, greater job security, improved work/life balance, greater career advancement opportunity, and more flexible work hours. The range went from 94% of employees indicating increased compensation to 80% of employees indicating more flexible work hours (Towers Watson, 2010).

Another survey which was applied to a large company, using a random sample methodology, indicated that the number one reason that an employee would leave for another job was compensation. The second reason was for additional opportunity or job engagement (Ramlall, 2003).

The overwhelming evidence from the data compiled in this research and the research from others shows that employees have strong views about extrinsic rewards. The conclusion is that any proposed solution for retention issues must have some degree of extrinsic rewards as part of the solution set.

Potential Solutions

Do Nothing

This is always an option, no matter the issue. Default to what is taking place in the present is what this would result in. If an organization is satisfied with the status quo, no action is necessary. In this case, there is evidence that there is a market-driven problem that needs some type of solution set. Therefore, the option of doing nothing is quickly disposed of as being a viable option. At its worst, doing nothing jeopardizes the ability of an organization to successfully execute mission.

Provide Recognition to Employees

According to Crom (2010), some employees are not necessarily driven by the desire for money, but are satisfied with other recognition. This can be done in a variety of ways from both an individual and team standpoint (Crom, 2010).

Similarly, it is pointed out by Cosack et al., (2010) that there are unique ways to keep employees without allowing salary costs to soar, thereby staying budget-conscious. They suggest it is prudent not only to focus on your star performers but also to look for the employees who are critical for mission execution, but have not achieved star status. Not only would these performers have requisite skills but also discussion by the authors indicates that those employees could have other useful attributes such as work networks. Specifically they say nonfinancial incentives such as "praise from one's manager, attention from leaders, frequent promotions, opportunities to lead projects, and chances to join fast-track management programs are often more effective than cash" (Cosack et al., 2010). To help in the identification of these critical but non-star players, they suggest two strategies. The first is to review the impact of the organization should an employee leave. The second is the likelihood of that employee's departure.

In 2003, Klaff captured some top ideas for recognition when she was interviewing Bob Nelson regarding his theories of rewarding employees. They are listed in Table 7.

Table 7. Nelson's Ten Commandments of Recognition (Summary)
(Klaff as cited in Nelson, 1994)

1. Personally thank employees for doing a good job—early and often.
2. Take the time to listen to employees—as much as they need or want.
3. Provide specific feedback about performance of the employee and organization.
4. Strive to create a work environment that is open, trusting, and fun.
5. Provide information on how the organization operates, and how the person fits into the overall pla
6. Involve employees in decisions, especially as those decisions affect them.
7. Provide employees a sense of ownership in their work and environment.
8. Recognize, reward, and promote people according to their performance; deal with low and marginal performers so that they either improve or leave.
9. Give people a chance to grow and learn new skills.
10. Celebrate successes of the individual. Take time for team and morale building.

Provide Flexibilities

To the extent possible, an organization should try to change or use their flexible work schedules and other flexible benefits to both attract and retain top talent (Charney, 2010).

This could be the difference in successfully retaining your employees if everything else is relatively constant. This is further noted in another reference. While employees are very interested in things that do have costs—and must be considered (e.g., bonuses, health care, and 401k's), flexibility in the area of telecommuting and flexible schedules are things which have an interest for employees across the entire age spectrum (O'Shei, 2010). Telework is an issue that has shown up in some of the survey data from the ACC organizations as part of this research.

Provide Challenging Responsibilities to Employees

Crom (2010) also indicated it would be a good idea if employees were brought in on special projects or challenging assignments to help foster ownership in the project. Once ownership is brought into the picture, employees would tend to be more creative and enthusiastic in solutions provided.

Martin and Schmidt (2010) provided insight into how most companies lose many high-end performers within a year due to under engagement. They state that approximately one in three "emerging stars reported feeling disengaged from his or her company" (2010). Based on significant research, they determined the main reason for employee dissatisfaction is that management does not know how to manage the top performers; they underutilize them. Also, management has the misguided assumption that these top performers are highly engaged. Conclusions from their study are as follows:

1. One in four intends to leave…within the year.
2. One in three admits to not putting all his effort into his (or her) job.
3. One in five believes (his or) her personal aspirations are quite different from what the organization has planned for (him or) her.
4. Four out of 10 have little confidence in their coworkers and even less confidence in the senior team. (Martin & Schmidt, 2010, p. 2)

The two reasons employees are leaving are "outsized expectations and lots of alternatives" (Martin & Schmidt, 2010, p. 2). These top performers have very high expectations of the company and will correspondingly work very hard. However, if they are underutilized, they will become disengaged and look elsewhere for work. They also have a lot of self-confidence in their work skills and their potential to find alternative employers; therefore, they are usually very aggressive in pursuing such alternative work (Martin & Schmidt, 2010).

Martin and Schmidt (2010) also list several other mistakes that organizations make in managing these star performers. First, management sometimes erroneously believes that current high performance will equal future potential. The point is to assimilate the entire data set of information on an employee and not let a single data point drive your decisions. Second, allowing the management of these top performers to be delegated down to the line or first level in an isolated vacuum without senior-level oversight would be problematic. This kind of employee needs higher level visibility to ensure they will get a broader perspective in their development. Third, it is a mistake to keep these stars of the future from having risky assignments. Often the approach here by management is to preclude failure at all costs. There can actually never be a bigger teacher than failure itself, though it is obviously not something to be repeated over and over. Fourth, expecting star performers to share financial pain with the company is not an accurate or reasonable expectation unless the company wants to lose them. The organization should determine a way to differentiate between average or below-average performers and those that excel at very high levels. For some organizations this is a challenge. However, it must be done should they choose to keep the star performers. Fifth, organizations fail to align their star performers with their strategic plan or planning (2010).

Communication

Employees

In a poor economic landscape, a company has to be creative with its employees. Communication has to be at the forefront from management to its employees. Savage (2009) offers several tips, such as talking with employees about potential training or developmental gaps that the company and the employee can identify and close. Additionally, more staff meetings with positive discussions are an absolute requisite.

Another focus for a company is that in tough times, they have to find a way to identify and implement plans for their top performers. Communication must flow to top performers and tell them the organization will do everything possible to create an innovative top-performing unit, and they, as top performers, are going to be a part of it (Greenberg & Sweeney, 2010). Another conclusion of Greenberg and Sweeney is that top performers want to be working with other top performers. This can be used when identifying team members for special projects or mission opportunities, or even having them spend time with a top-performing, more senior staff member who could serve as a mentor to them.

It has also been noted by Denton (2009) that trust is a large issue that employers must address. Lack of trust emanates from an environment where organizations have cut employees from payrolls, in many cases, without the diligent due process of performing analyses of all cost factors and associated impacts. Also, beginning in the 1990s, employers began to cut their pension liabilities for their workforce. The result was that employees had to begin looking out for their own welfare, knowing that employers were not going to do so (Denton, 2009). The impact on trust has been great. Even though federal government workers have been spared the problems associated with the retirement systems, this feeling of distrust has spread nationwide and has included the federal government. Additionally, office politics and favoritism have driven employees to mistrust management. It is noted in some survey data that management is quite surprised by these feelings of distrust. Denton further allows that individual managers may be honest and deal with their employees honestly; however, the news stories that are easily accessible to the U.S. population keep the seeds of distrust afloat. A specific recommendation that Denton (2009) provides to help battle this trust issue is management sharing information with employees and allowing access to information that has been previously guarded.

Allen, Bryant, and Vardaman (2010) address misconceptions about employee turnover and counter it with conclusions from their study. They conclude that management can be very proactive from the very first day the employee walks in the door—and even before. In particular, they suggest giving employees mission-related information before their first day on the job will go a long way in ensuring the new employees become acclimated to what the organization is all about, and to their culture. When they arrive on the job, strong efforts should be made to integrate the new employee into the culture of the new organization (Allen et al., 2010). This last observation relates to the process of “pre-hire embeddedness” found in the Mitigation Up Front section of this paper, in which the more a person is socially tied to people in the organization before they are hired, the greater the likelihood that they will stay (Barrick & Zimmerman, 2009). The social part of an employee is one that clearly will have to be addressed. Regarding the pay issue, Allen et al. (2010) conclude that while employees do leave for more money, their research shows it is not the leading driver.

Labor

There has been a running debate since 1978 about the inclusion of organized labor into affairs of government organizations. Under Title VII of the Civil Service Reform Act of 1978, labor unions were afforded some rights in dealing with management, but those rights were not clear. The one thing that was apparent was that there were certain issues in which management and labor could negotiate if a bargaining unit was present. One of those issues pertains to conditions of employment. If an employee is represented by a labor organization, changes in conditions of employment are negotiable. The definition of conditions of employment could vary from site to site and organization to organization, and would be still dependent on whether there is a formal labor management agreement in place. Moreover, one of the clearly defined rights of management is to retain employees (5 U.S.C. § 71, 1979).

It has been noted over the last ten years that the National Security Personnel System (NSPS) has caused a very prominent and observable rift between labor and management of federal organizations across the DoD. While most of the labor-represented workforce was outside of the NSPS, labor was successful in convincing the executive and legislative branches that it was not a good system, and it was recently repealed. Most of the problems over the issue originated with the nature in which the NSPS was implemented. It appears it was implemented without labor being given a significant opportunity to shape the system. While there were very specific concerns brought up by labor, the root of the problem appears to be the lack of communication between management (in this case the DoD) and labor.

Recently the President created labor-management forums to improve delivery of government services. Therein, "pilot programs would test bargaining over permissive subjects in a small group of agencies. The council would evaluate the programs" (Parker, 2009). It also required agencies to provide to labor pre-decisional information to allow for more communication on workplace issues (Parker, 2009). However, in October 2010, labor indicated they were not satisfied with progress on the labor-management forums and requested more involvement in pre-decisional issues (Swanson, 2010). Further, Swanson reports of new troubles between labor and management in November 2010. This time, the issue is telework; this is something that has been debated for several years. Debating is in stark contrast with discussing the issue.

One can only conclude that if you do not legitimately discuss issues with labor, that contentiousness will result. It does not mean that labor and management have to agree on every issue. That is not a realistic objective. However, discussion and trying to understand the perspective of the other side is good business, whether it is a contract negotiation, a supervisor and employee relationship, or a labor management issue. This is not a section added to this body of work to promote labor management councils. However, if an organization is looking to incorporate some type of novel solution for retention, would it not make sense to have buy-in with employees you have on board? Whether they are represented by labor or not is not the real issue. Gaining employee buy-in is the real issue. It is a fact of life that in many cases employees will be part of a bargaining unit, and by definition represented by labor.

Employee Development

Clear Rock, which is an executive outplacement firm in Boston, has provided information indicating coaching and mentoring are key factors in retaining personnel. However, they additionally note that better compensation and benefits are rated in the top five factors in retaining high-potential and front-line employees (“Employers Using Coaching,” 2007; “Despite Recession,” 2009).

Butler indicates succession planning should be a key objective for many companies in positioning themselves for when the economy picks up and employees start leaving wholesale for greener and potentially more lucrative pastures. A recent Employee Benefits Trends Study has shown that succession planning is again near the top of the list for employers when they were naming their top benefits objectives. It slipped to number two behind controlling health benefit costs; this was the first time since 2006 it was not number one. Nevertheless, the article talks about how investing in key employees in development for succession planning will give those top employees more of a vested interest and make them much less likely to leave the company for competing offers (Butler, 2010).

Increase Leave

The Government Accountability Office (GAO) was the beneficiary of the GAO Human Capital Reform Act of 2004, Public Law 108-271. It was enacted in order to provide the GAO with additional flexibilities to assist them with challenging human resource issues. Of note, Section 6, of the Public Law, allowed “Certain key employees with less than 3 years’ service for purposes of leave accrual may be treated as if they had 3 years of federal service. Therefore, they would earn 160 hours on an annual basis instead of 104 hours” (GAO, 2010). There were several sections in this act. However, there is only one that is being singled out here. Of note, the Conclusion of the report indicated that the contents of the act, Section 6 included, were a success in assisting in both recruiting and retention (GAO, 2010). This is an area where consideration should be extended. In particular, authority should be sought for crediting the1102 employees within ACC five hours of AL per pay period (PP) after one year of service, and six hours of AL per PP after two years of service. Should the employee leave the ACC prior to the end of the three years, leave accrual rate would revert back to four hours per PP. This could gain traction with new ACC employees, much like it has for GAO employees.

Mitigation Up Front

This paper has looked at the time from when an employee is brought on board to an organization, to the time when they leave for another job, with efforts and strategies put forth to try to reduce the chance that an employee leaves. However, there may also be a way to review employees before they are ever selected for employment that could benefit the organization.

Goldsmith states, “one of the defining traits of habitual winners [is] they stack the deck in their favor…. They hire the best candidates for a job rather than settle for an almost-the-best type. They do this when they pay whatever it takes to retain a valuable employee rather than lose him or her to the competition….You’ll discover that their stories are not so much about overcoming enormous obstacles…but rather about avoiding high-risk, low-reward situations and doing everything in their power to increase the odds in their favor” (2007, pp. 180, 181) Krzyzewski (2004), head coach of the Duke men’s basketball team, talks about making sure that the right players get on the train for the long journey in *Leading with the Heart*. Collins (2001) stated his surprise in his similar conclusion:

> We expected that good-to-great leaders would begin by setting a new vision and strategy. We found instead that they first got the right people on the bus, the wrong people off the bus, and the right people in the right seats—and then they figured out where to drive it.... People are not your most important asset. The right people are. (p. 13)

It seems to be a thread of consistency that having the right people on your staff will be a difference maker. More time invested up front on selecting the person with the best skillset can make a difference in both retention and organizational performance.

Sullivan takes it a step further by listing several key factors in recruiting that may be of assistance in improving retention. The focus of this paper is not to look at the recruitment part of the total employee process. By extension, the Sullivan factors will not be discussed in any detail herein, but further research into this area can be fertile grounds for retention improvements.

Table 8. Hiring-Related Factors or Indicators Impacting Future Retention

1. Hiring candidates who are focused on money
2. The source where you found the candidate
3. Their average tenure in other jobs
4. On-boarding and orientation
5. Recruiter involvement after the hire
6. The lack of diversity orientation and retention
7. Manager rewards for great retention
8. Being aware of the most common causes of turnover

Note. This table has been adapted from Sullivan (2007).

Recruitment itself has very significant pressures due to the increasing workload over the years. As reported in the *Government Executive,* the issue began mounting in the decade of the 1990s when the Cold War ended and military drawdowns ensued. When the War on Terror began in the new millennium, staffing was inadequate (Peters, 2010). There is hope that new hiring reforms will address the retention issue. Long (2010) cites the use of new assessment tools which will assist in the review of candidate qualifications. Ensuring the best person gets selected will contribute, to some undetermined degree, to those candidates staying longer in the job due to job enrichment. The reason for that is because there will be a better match of skillset to job requirements (Long, 2010).

Barrick and Zimmerman (2009) show that there are predictive characteristics that can show a strong correlation on whether or not someone is going to voluntarily leave an organization within six months. The testing and data go into some detail, but the “results indicate that [data] measures that assess [deficiencies in] pre-hire embeddedness [personnel connections] in the organization and habitual commitment and pre-hire attitude scales that measure employment motivation, personal confidence, and the traits of conscientiousness and emotional stability” (Barrick & Zimmerman, 2009, p. 200) were predictors of someone leaving the organization within the first six months of work.

Increase Pay

Proficiency Pay (ProPay)

This is a concept that is used in some cases within the DoD to provide additional pay for military members with unique qualifications. Certain health professionals, others with unique foreign language skillsets, some nuclear officers, and other understaffed professionals required skills could have additional pay running from $450/month to $1,000/month or more.

Regarding the 1102 field, there is a shortage of Army civilian Contracting Officers, though the shortage is more pronounced in some localities than others. Army civilian Contracting Officers who are Level III certified should be paid an additional monthly amount as professional or proficiency service pay. This could be either applied as a percentage of salary or a specified amount. This would provide an incentive to those in the contracting professional career field to stay at the Contracting Centers rather than jumping to other organizations such as PEOs for the same or better pay, and less responsibility. There has been some information provided indicating that qualified contracting professionals have either transferred or promoted away from the Contracting Centers to obtain a position in which they did not require a Contracting Officer's warrant. The ACC desperately needs for those who are qualified and have requisite business acumen to use their skills as Contracting Officers.

Additionally, there is a big push within the DoD to build up the pricing corps. Those consist of contract professionals who prefer joining pricing teams within the Contracting profession at the Contracting Centers or Contracting organizations within the ACC. The initiative behind this is to build up the skillset for 1102s to provide cost and price analysis to support contract negotiations. For those 1102s who choose this particular track within the ACC, ProPay is a method or tool that should be used for 1102s who become Pricers within the ACC.

A clarification needs to be provided for discussion purposes. Non-ACC or Contracting Center organizations would be prohibited from having 1102 positions. In great part, this has occurred. However, there are some isolated cases where 1102 positions are found outside the ACC and Contracting Center organizations.

Retention Authorities

5 U.S.C. § 5379 (2010) and 5 Code of Federal Regulations (C.F.R.) § 537 (2010) establish the statutory and regulatory authority for the use of student loan repayment for recruitment and retention purposes. The two conditions associated with this authority call for a federal organization to make a determination based on the qualifications of the employee or the special need of the employee's services by the activity, and an assessment that, in the absence of the loan repayment, the employee would likely leave federal service. This will help a federal organization, which has intense competition from "non-federal" organizations. However, it is not helpful at all if the competition is coming from within the federal government. A written service agreement is a requirement for any employee who takes this benefit; the maximum benefit for an employee is $10,000 per year, or a maximum of $60,000 (5 U.S.C. § 5379, 2010; 5 C.F.R. § 537, 2010).

For the retention incentive program, 5 U.S.C. § 5754 (2010) and 5 C.F.R. § 575 (2010) are the authorities. These incentives are offered to individuals or groups based on the same two conditions listed in the above paragraph. Also, the incentives are offered to individuals or groups based on the organization having a special need for the employee's services due to the organization's mission and the employee's competencies that make it essential to retain the employee in his or her current job during a time before the closure or relocation of the employee's job, and the likelihood the employee would be to leave for a different position in the federal service. For the group, the determination would have to be extended to a narrowly defined group, and the determination would be slightly different based on the specifics of the authority. However, the impact would be the same. These incentives may be up to 25% of the employee's base pay, again based on specifics and guidance on the incentives (5 U.S.C. § 5754, 2010; 5 C.F.R. § 575, 2010).

It is recommended that in both of these previous examples, efforts be applied to have authorities modified to be available for use by an organization, if appropriately justified as to mission requirement and specialization of skillset, to an employee who is likely to leave their job for other federal service, as evidenced by an offer documented in writing. This would be a critical tool that the ACC or other federal organization would have at their disposal.

Job Classification

Additionally, authorities exist to allow for upgrading certain positions based on classification authorities and job complexities. Flexibilities are present to allow for supporting personnel activities to assist in this classification effort. In some cases, this will help an organization accomplish increasing complexities for assigned missions.

Recommendations

Understanding the Entire Problem by Formula

RE = ($*(MD/MS)) + (C + r + J)

Table 9. Retention Formula Translation

Retention Equilibrium = ((Salary and Awards)*(Market Demand of 1102s/Market Supply of 1102s)) + (Corporate Communication to Employees + Recognition of Employees + Job Engagement)

The formula has two parts. Each has an equilibrium point, and there is an overall equilibrium point. The first part contains the drivers of the supply and market of 1102s, which are balanced by extrinsic awards. Simply stated, if MD is greater than MS, an organization will face retention challenges and workforce risk. That is because market demand is outstripping the supply of contracting professionals. An organization should first calculate the scope of the problem that they face. The way to calculate this is by the number of spaces in the market divided by the number of available 1102s in market (e.g., 1000/800 = 1.25). In this example, $ would be represented as the quantum being paid compared to the market rate. If an organization is paying the market rate, the value is represented as 1.0. If the organization is paying less than market rate, the value for "$" is decremented to 0. An organization must proactively bring the extrinsic rewards part of the formula (i.e., $) to equal or greater than 1.0 (greater than 1.0 gives you a higher chance of success) to have traction with retention in a time when MD is greater than MS. In every market this number will change depending on the significance of the demand. The main takeaway on the first part of the formula is getting to 1.0 or greater than 1.0 in $, or extrinsic rewards, when MD is greater than MS will be beneficial to your organization. This is considered equilibrium, and the problem has been mitigated. The preciseness of the increase will also depend on the retention incentives or labor system to which an organization uses for their employees.

The second part of the formula deals with three unique and independent components. Corporate communication to employees, recognition of employees, and job engagement are each calculated on a .33 scale (based on results of a survey). A top score on these three components will result in a score of 1.0. This is considered equilibrium (e.g., .33 + .33 + .33 = 1.0). If the second part of the formula is less than 1.0, it goes out of equilibrium. In this scenario, voluntary departures are minimal.

To reach perfect equilibrium, both parts must equal 1.0, and there can be no part of the formula amiss. Therefore, to reach a perfect equilibrium score for the retention formula, the calculation would be 2.0 (i.e., (1.0 * (1.0/1.0)) + (.33 + .33 + .33) = 2.0).

Continuing with the same example, if the first part, or left side, does not equal 1.0, meaning that there is either a problem with the demand to supply and/or there is a problem in pay, then the right side must be checked and adjusted to ensure that all values are maximized to equal 1.0 to mitigate the risk. It should be noted that, if at any time, the corporate communication, recognition, or job engagement goes below .33 each, that it will serve as a cautionary signal indicating the risk of employees leaving your organization has increased. Therefore, mitigating efforts will have to be used with all factors to bring the workforce retention issue back in balance.

Using the same example as before with demand for 1,000 spaces with only 800 available in the market, add the right side into the mix to show potential improvement areas for the company. 0 * 1000/800 (assumption here is salary and awards are only 95% of the market rate and this triggers 0) + (.20 +.20 + .30) (assumption is the corporate communication, recognition, and engagement are all underutilized). Calculated we see (0 * 1.25) + .70, or 0 + .70 = .70. Neither side is in equilibrium; therefore, retention equilibrium is not reached.

To solve the problem, further analyses is required. An organization can possibly affect the market supply; however, in a large market the organization may not be able to influence it significantly. Therefore, we will keep 1.25 for the market and supply calculation constant. Bringing the salary and awards of the organization in line with the market would be a score of 1.0 for that component. That would yield a score of 1.25 for the first part of the formula. That is the minimum equilibrium score for the organization facing this challenge. As described earlier in the research, there is some evidence that in a very competitive market, having extrinsic awards exceeding to some degree that market, will improve your likelihood of retaining employees. However, it must not be below the market when there are these types of competitive forces in play. Additional efforts to corporate communications, recognition, and engagement will maximize scores for this example. Therefore, the resulting calculation would be (1.0 * 1.25) + (.33 + .33 + 33) = 1.25 + 1.0. For this set of circumstances, this results in an equilibrium of 2.25, though it is not perfect equilibrium. This is called imperfect equilibrium. The fact that imperfect equilibrium totals 2.25 in this case is an indicator that one of the main factors affecting retention needs constant monitoring. The formula is designed to not come into perfect balance or equilibrium if any of the main factors have challenge or risk indicators.

In summary, using the formula will provide you a toolkit for retention. The formula gives you a tool to show that any time it becomes out of perfect equilibrium, you have an indication of a problem. A company should strive for perfect equilibrium and balance or for imperfect equilibrium if that is all that the market will allow. Each of the areas is isolated, but each is also related. By the nature of the research and the discussion surrounding the formula, each part of the formula is very important. If either side of the formula is initially out of balance (i.e., one or both does not equal 1.0), you have a retention issue that needs attention or mitigation. If an organization neglects any of the components, they do so at their own peril. Instead, this should be included in an organization's dashboard metrics—a quick glance will tell you if you are green, or if there are issues that will cause you trouble down the road. It can also provide you the tool to drill into the retention issue to isolate the underlying issue or issues.

Components of the Formula

Recognition

Klum (1994) believes that recognition and gratitude should be provided to employees for a job well done early and often. He also suggests that it is critical for managers to listen to employees; as such, he says to spend as much time as necessary. Crom (2010) states that recognition can be done with a variety of techniques, both from an individual standpoint and that of the team.

Cosack et al., (2010) believe that a strategy should include the ability to focus on star performers, as well as identifying those who are mission critical but who have not achieved star status yet. They further provide that praise, discussions with leaders and mentors, special projects, and opportunities to take special leadership development tracks provide useful tools to allow for recognition (Cosack et al., 2010). Formalized special recognition or award programs support this type of effort; however, it will not take the place of quality time spent with key employees by management or by mentors. The adoption and formalization of a mentoring program for new employees and for organizational employees as they continue to develop is a proven process, and is recommended.

Training for Basic Job Competencies. How does an organization develop its leaders for tomorrow? Currently there are requirements for Defense Acquisition workers to take 40 continuous learning points (equivalent to an hour each) each year. There are few within the workforce who believe that this is all the training that is necessary. However, there is a counterpoint to that. There are many who do not want to pull away from their job requirements to go to training, because they are pressed by so many urgent requirements. Within the DoD, statistics exist showing the workload increasing while the employee number for the contracting workforce has declined (Peters, 2010). This increase in workload has resulted in more pressure on completing more mission products with less time to do it. Continuing, there is also a need to be able to do things smarter; that is where more training comes in. No matter how hot the project, supervisors and managers must show leadership and ensure that their employees have training development plans, and they must have training opportunities planned for their employees' development.

Additionally, various boot camps, or training forums, are currently being employed by the Contracting Centers within the ACC. Both the AMCOM and TACOM Contracting Centers have strong boot camps for training. Recommendation is to continue usage and comparison of the best practices of each for application to each considering the unique missions of the Centers, respectively.

Development for Leadership Skills. Leadership training is different from required training for job competencies. Job competency training for an acquisition professional would be to ensure that an acquisition professional attains the appropriate certification level as required by the Defense Acquisition Workforce Improvement Act (e.g., Contracting Level III). It would also include any specific job-related training necessary to perform the job. Leadership training or development would encompass the leadership skills or experiences necessary to lead a group of people or employees within an organization. It could include leading down (more formal), leading across (with peers), and leading up (to superiors). Clear Rock indicated in two recent studies that coaching and mentoring are key factors in retaining personnel (“Employers Using Coaching,” 2007; “Despite Recession,” 2009). Those are key components of leadership development. It is critical that leadership development integrate into future plans for each employee. They should be tailored to each employee through use of employee IDPs.

Succession Planning. Additionally, it has been shown in a recent Employee Benefits Trends Study that succession planning was near the top for employees when they were naming top benefits objectives. The theory is that in a time of little or no salary growth, investing in key employees in development for succession planning gives those employees more of a vested interest in the organization, and makes them less likely to leave (Butler, 2010). This relates to leadership development. Should a star performer be identified as executive material, their leadership development plan should be augmented to include development or developmental activities for future leadership opportunities.

Communicate

Communication to employees is a key. Without it, you lose employees. There is no substitute.

However, there should also be a structured corporate component to the communication, as well. Greenberg and Sweeney (2010) talk about how this communication must reach the employees and let them know that they are part of the plan for the future. This can be done in several ways.

Allen et al. (2010) relay that corporate communication should start before the new employee walks in the door. Effort should be made to provide useful information, including that about the organization’s mission and what the employee will be doing. It would also include any information about their first six months of work and what type of specific training will be provided. Once on board, a mentor should be assigned to them. For someone new to the organization, effort should be made to find someone who recently (within the last two years) walked in their shoes as a new employee. As an employee gains more experience (1–2 years), they should then be assigned a mentor who is a mid-level to senior-level mentor. This will allow them to gain a broader perspective of the organization’s operations.

Greenberg and Sweeney (2010) also provide that they have found in their research that top performers also like to work with others who are top performers. This can open up another train of thought as to how teams are formulated. These top performers, or even high potential performers, tend to feed off the energy that each other exudes. Understanding this need can be identified by communication with your key employees.

Build Relationships. Additionally, trust is a component of communication. Federal workers have a certain level of distrust for the government as a whole and of management. Some of this is not directly attributable to management; however, it is still a fact, and part of the blame can be assigned to management (Denton, 2009). Denton further allows that management sharing information with employees and allowing access to information that has been previously guarded will help foster trust (Denton, 2009).

Much of the communication to an employee comes from the first line supervisor. Moreover, how the supervisor communicates or treats the employee is a major indicator of whether the person stays (Cascio, 2000). Management should continuously discuss this with first line supervisors, and it should be included in the evaluation of first line supervisors for reinforcement. The first line supervisors are a critical part of the retention solution.

A barrier to effective relationships is one of perception on behalf of management. Management generally believes that they know what the employee is thinking. That is especially erroneous when top performers are concerned. Martin and Schmidt (2010) say that this critical communication breakdown often leads to job underengagement which ultimately leads an employee to seek other opportunities or challenges elsewhere. Extra time and effort needed to communicate with employees about their personal work needs is vital.

Internal Newsletter/Magazine (market Your Organization to Your Employees). An organizational news resource must be provided to the employees. Some of the options for this could be anything from a monthly or weekly email from the front office to a periodic electronic enewsletter to a quarterly hardcopy news sheet. Include successes that have recently occurred. Include pictures of those on high-performing teams. Have firsthand stories about interactions with customers on a test or fielding. Also, the information provided to the workforce should be employee driven. Allow it to be a tool to communicate to the employees, but have employees who have invested in the mission successes and who understand the issues write it. Effectively this provides more job integration with the organization's employees.

Pay

Pay of any employee at the same grade should be at least at the same level of the market. It is even seen in one body of work how the pay is brought to above the level of the market as a recommended practice (Pink, 2009). The question is how to do that if you are limited by personnel system. Currently, there are multiple personnel systems in the DoD (e.g., NSPS, Acquisition Demo, Lab Demo, GS, etc.) While NSPS is ending or transitioning, there still are multiple systems. The different systems which are employed are showing up in the same labor workforce due to the tightly woven and complex fabric of multiple federal organizations within a single metropolitan statistical area such as Washington, DC or Huntsville, AL. This brings rise to organizations with differing missions and goals competing for a defined group of contracting professionals.

An organization must be proactive when there is a strong demand and limited supply of 1102s. This would apply to the recruitment process as well. Several recommendations include increasing the intern program grade levels at graduation to the extent possible. There are instances where DoD organizations will prey on sister DoD organizations for bright talent who were recruited into intern programs. The DoD organizations which had either a different personnel system or deeper budgets were able to lure that bright talent away after the minimum intern period (usually two years) was invested. That was a double loss for the losing organizations. Not only did they lose the bright assets they had trained, but they also lost the time invested in the training and the time it will take to hire new talent. Recently the Administration has ended the Federal Career Intern Program, effective March 1, 2011. It is being replaced by a "Pathways Program." The purpose of the change is to make the intern program "streamlined, transparent, and more uniform"(Brodsky, 2010). There are many details in the program that are yet to be unveiled at this writing. Therefore, the best alternative at this juncture is to watch for developments and eagerly seek any venues to engage as this program policy unfolds. Research concludes, though, that additional time in the intern program will also allow your organization to get the intern invested in your organization and to integrate the new employee into the culture of the organization (Allen et al., 2010). That translates into more time for job engagement.

The introduction and use of ProPay is a critical element and tool of pay. It has shown to be useful in the DoD when applied in targeted fields where shortages exist. This would require coordination within the Department of Army and the office of the Director of the Defense Procurement and Acquisition Policy to get regulatory authority for this. Potential for further coordination beyond this is possible. It is recommended that this be extended to 1102s within the ACC who are Level III certified in Contracting, and either possess a Contracting Officer's Warrant or work in a position for certified Cost or Pricing Analytical support. By extension, the recommendation is made that Army 1102s can only be within ACC, an Army Contracting Center or Organization, or Army Corps of Engineers for better consistency of trained professionals and application of pay procedures.

For retention incentives, we recommend that the incentives be modified to be available for use by an organization, if appropriately justified as to mission requirement and specialization of skillset, to an employee who is likely to leave their job for other federal service, as evidenced by an offer documented in writing. In return, the employee will be required to sign an agreement guaranteeing their service within the DoD (consistent with current law) for a minimum of three years. This will require coordination with DA and DoD officials, as this will need a change in Public Law.

This next item is not a pay element per se; however, the impact of this would be very big for new employees who have just come onboard. As demonstrated in several places in the paper, new employees are at great risk in their first two or three years. As previously discussed, the GAO found a way to coordinate with legislative members to have certain key employees earn six hours of annual leave per pay period prior to those employees attaining three years of federal service (GAO, 2010). After an employee has three years of service, they start accruing six hours of leave per pay period instead of four, which is the amount accrued for an employee during their first three years of service. It is recommended that Series 1102 employees in the Army Contracting Command be granted 5 hours of annual leave per pay period after one year of service, and 6 hours of annual leave per pay period after two years of service. Should they leave the Army Contracting Command before the three year period ends, their leave accrual rate would revert back to four hours per pay period.

Labor Market

A labor market will have a defined number of positions required for mission accomplishment. In the case of the contracting professional community, the same is true. Similarly, there are a defined number of contracting professionals to work those required positions. When the demand exceeds the supply of contracting professionals, the competition increases and the cost for them increases. Conversely, when the supply exceeds the demand, the competition decreases and the cost decreases. That is just basic economic theory. Much to the surprise of many, this applies in today's workforce for the Federal Government or in industry. If there is a shortage of workers, employees for the most part will go where the money is, notwithstanding there are other important tools for retention. Having other federal organizations which can and do pay more than others only exacerbates the issue for those who cannot match their pay. This appears to be especially hard on organizations that use the GS pay system, with their competitors using some type of paybanded personnel system.

Job Engagement

Employees look for work that is meaningful and work that is tied into the success of the organization. That is more so the case for top performers. They have significant drive and expect to be utilized and developed. Organizations should align all assignments of their employees with their strategic initiatives (Martin & Schmidt, 2010). Also they should be identified for work on special projects where they can easily see how the accomplishment of such is tied closely into the mission of the organization (Crom, 2010).

Don't Forget About Labor

An organization needs to embrace the positives that organized labor can bring. Management is bound to stay neutral in affairs dealing with labor as prescribed by Public Law (i.e., if there is a petition to start a labor with a vote, management cannot have a position). However, if there is a bargaining unit represented by labor it would be a good idea to talk to them as much as practicable about issues your organization is currently trying to solve and make them part of the solution. In reference to prior discussion of this point, the DoD may not be experiencing the problems with the different personnel pay systems if the labor unions were brought in as partners up front when NSPS was first being discussed. There is no question that the multitude of pay systems is causing challenges to organizational retention practices. Specifically, those with GS systems are at a disadvantage. Moving forward, labor should be viewed as a partner, and initiatives should be discussed. This dialogue can only enhance the development of solutions pertaining to the area of human resources.

Conclusion/What's Next

A summary of the top 15 recommendations from this research is presented in Table 10.

Table 10. 15 Retention Recommendations for ACC

Can Execute Now
1. Employ formula … RE = ($*(MD/MS)) + (C + r +J)
2. Formalize Mentoring program (include all supervisory personnel at minimum).
3. Culturally integrate communication into manager/supervisor/employee relationships. • Training • Leadership experiences/development • Mission/strategic alignment • 2-way discussions on expectations • Reinforced

4. Corporate communication to employees either initiated or modified to include:
    - Latest Mission news
    - Latest Organizational successes
    - Team Successes
    - Individual Successes
    - Employee driven news product
    - Management will be available to provide information/support
    - News of Mission or Organization changes
    - Customer focus integrated
    - Separate conveyances from Director/Executive Director
5. Begin utilization of stay surveys.
6. Forge understanding with other federal organizations that compete with you (area specific) for 1102s.
7. Establish dialogue and partnership with labor at highest possible levels to gain support for initiatives, both current and prospective.
8. Ensure each IDP of employees is reviewed by senior management.
9. Implement onboarding and recruiter follow-up with new employees.
10. Invest in Succession Planning Development for Key Employees.
11. Continue support of best practices in areas of training (including boot camps) and award programs.

<u>Need Additional Stakeholder Involvement</u>

12. Initiate or expand intern program to the extent possible.
13. Introduction of Proficiency Pay (ProPay) for 1102s in ACC who are Level III certified in Contracting, and either possess a Contracting Officer's Warrant as a job function or work in a position for Cost or Pricing Analysis. By extension, recommendation that Army 1102s can be positioned only within the ACC, a Contracting Center or Organization, or the Corps of Engineers.
14. Modify retention incentive authority to be available for use by an organization, if appropriately justified as to mission requirement and specialization of skillset, to an employee who is likely to leave their job for other federal service, as evidenced by an offer documented in writing.
15. Credit 1102 employees within ACC with 5 hours of AL per pay period (PP) after 1 year of service, and 6 hours of AL per PP after two years of service. Should the employee leave the ACC prior to the end of the three years, leave accrual rate would revert back to four hours per PP.

Several of the listed items will take further coordination between the ACC, the DA, and the DoD. For instance, items 12 through 15 will take coordination, stakeholder involvement, and potentially Congressional action. Items 1 through 11 are ready to execute now. Precedent has been set on most of these issues. These specific recommendations, though, are tailored for the ACC. These recommendations, however, could be applied to other DA or even DoD organizations, for the most part.

The goal of this research has been to take a holistic look at the civilian retention issue. In some cases, there are actions related to hiring that impact the retention of the employee. Accordingly, recruitment was reviewed briefly.

Additionally, there were issues in research and theory that have led management practitioners to conclude some narrow theories as fact. Viewing the issue of retaining an employee or a group of employees requires a macro view of the process due to complexity. Factors such as market demand and personnel authorities impact the retention issue and have to be considered in this analysis. There is no one issue that can be ignored when dealing with retention; by extension, there is no one issue that can receive the sole attention of an organization as a cure for retention issues. To do either extreme will be at the organization's peril and expense. The goal of any organization toward its employees should be the commitment, motivation, and retention of its talent base.

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Outsourcing the Procurement/Acquisition Function of an Operation: Is It a Good Thing or Not?

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Abstract

Outsourcing of the various functions of both the commercial and government world has been occurring for years, but recently, there has been more outsourcing of the procurement/acquisition function than ever before. Although many different functions may be outsourced, the focus of this research analysis will be on outsourcing of the procurement/acquisition function. We will examine the historical reasoning behind the issue of procurement/ acquisition outsourcing, the need for outsourcing, and what drives this need for both government and corporate levels (e.g., shortage of qualified personnel/retiring baby boomers and an inability to hire quickly).

The purpose of this research is to examine ways in which the acquisition leadership can improve the process of recruiting, retaining, and training new acquisition professionals into the career field. Research included scrutiny of government policies, regulations, labor laws, and newspapers citing instances of outsourcing. Research also included interviews of government representatives as well as individuals in the acquisition field who have experience with outsourcing. The outcome will enable the acquisition workforce to understand the government's need for acquisition professionals and their role in enhancing and growing the workforce within the confines that are currently present in the government workplace.

Introduction

Outsourcing of the various functions of both the commercial and government world has been common practice for many years. However, it is in the last 25 years that there has been a notable increase in the outsourcing of the procurement/acquisition function. This change is particularly noteworthy and apparent because it has been the topic of numerous headlines, and the subject of much controversy. In order to discuss outsourcing in-depth, we must define the term, the meaning of which can vary depending on the point of view—government or commercial.

Outsourcing (2011) is "to purchase (goods) or subcontract (services) from an outside supplier or source." *The National Contract Management Association Certified Professional Contracts Manager Study Guide* and the Defense Acquisition University both have similar definitions, which are "a version of the make-or buy decision, commonly used for services, in which a firm elects to purchase an item/service that previously was made/performed in-house" (WIkinson, 2010).

How Did We Get to the Point of Outsourcing?

During the Depression, companies were forced to look for ways to cut costs to stay in business, which led to the beginning of outsourcing in the commercial sector. These companies would conduct an economic analysis to determine if there could be cost savings by hiring another company to perform a certain portion of the work, or to buy goods from a third-party source, rather than performing those functions themselves. The concept caught on in the federal government with the passing of Office of Management and Budget (OMB) Circular A-76, titled *Performance of Commercial Activities*, in 1955. This initiated a process whereby the federal government reviewed which functions it was currently self-performing that could be performed by a commercial source, to provide a cost savings. The OMB A-76 has been revised many times in the last 10 years, and the concept has continued to grow. There are so many areas of the commercial sector and the federal government that can be outsourced; n order to narrow the field, we will focus on the acquisition/procurement function and how that is outsourced, specifically in the government sector.

Acquisition Transformation

The 1990s should have been labeled the "Era of Acquisition Reform" because there were several pieces of legislation passed that changed how the federal government performed contract procurements and administration. The first was the Federal Acquisition Streamlining Act (FASA), enacted in 1994. The passing of this legislation afforded federal government contracting personnel the ability to utilize new procedures for small purchases (those under $100,000). In 1995 and 1996, Congress passed the Federal Acquisition Reform Act (FARA) and the Information Technology Management Reform Act (ITMRA*)*, which was almost a complete re-write of the acquisition rules.[1] These pieces of legislation defined "competition" and established various guidelines for competition, notices, and approvals (Federal Acquisition Reform Act, 1995). The new laws also decentralized the IT world from the General Services Administration down to each specific department or agency. This promoted modular contracting at the various agencies. The government believed that it now had the legislative framework to do better— faster and more efficient—contracting. What was left?

There was one more critical piece of legislation that was passed and that is the final piece of the puzzle: the Defense Workforce Improvement Act, passed in 1990. The purpose of this act was to establish education and training objectives for all of the federal government acquisition professionals. The intent was to set a higher standard and level of professionalism for the contracting profession that was desired, needed, and deserved (DoD, 2011). As a result of this legislation, agencies were established to provide the necessary training for the contracting professionals and to develop the standards/training requirements. Now the government *really* felt that they had the laws in place to provide better, faster contracts and would have the necessary contracting professionals to do it.

Inherently Government Functions

Office of Management and Budget A-76 defines inherently governmental functions in the following:

[1] The Federal Acquisition Reform Act was renamed the Clinger-Cohen Act in 1996.

> These functions include those activities that require either the exercise of discretion in applying government authority or the making of value judgments in making decisions for the Government. Governmental functions normally fall into two categories:
>
> (1) the act of governing, i.e., the discretionary exercise of Governmental authority, and
>
> (2) monetary transactions and entitlement.
>
> An inherently governmental function involves, among other things, the interpretation and execution of the laws of the United States so as to:
>
> (a) bind the United States to take or not to take some action by contract, policy, regulation, authorization, order, or otherwise;
>
> (b) determine, protect, and advance its economic, political, territorial, property, or other interests by military or diplomatic action, civil or criminal judicial proceedings, contract management, or otherwise;
>
> (c) significantly affect the life, liberty, or property of private persons;
>
> (d) commission, appoint, direct, or control officers or employees of the United States; or
>
> (e) exert ultimate control over the acquisition, use, or disposition of the property, real or personal, tangible or intangible, of the United States, including the collection, control, or disbursement of appropriated and other Federal funds. (OMB, 1995)[2]

FAR Part 7.503, which relates to outsourcing work to contractors, specifically states that "contractors shall not do work that is inherently governmental, or work that approaches such manner" (FAR, 2010). So how, or why, does the federal government outsource the federal acquisition process?

The inherently governmental function is subject to interpretation, but most agencies outsource contract administrative tasks, such as contract closeout, price and cost analysis, statement of work development, market research, and the development of the price negotiation memorandum. This allows the government agencies to remain compliant with the above definition, in that only the Government Contracting Officer has signatory authority and only the Government Contracting Officer negotiates or binds the government. So, now we know how the government was getting around the inherently governmental function, as defined by the OMB A-76. The question that remains is why would the government outsource the contract administrative function to a third party?

The answer lies in the numbers: According to the Federal Acquisition Institute's (FAI, 2009) *FY2009 Annual Report on the Federal Acquisition Workforce*, there are 32,925 Contract Specialists (GS-1102 Series); in 2009, 13% of those were eligible to retire. In 2014, 31% will be eligible to retire, and in 2019, 51% of the Contract Specialists will be eligible to retire. We will assume that these numbers maybe on the high side, due to the fact that the poor economy may not allow all personnel eligible to actually retire. Nevertheless, the government will need to replace, or somehow handle, the loss of

[2] There is a proposed memorandum that was issued March 2010 by the OFPP to implement changes to the definition of "inherently governmental function." A final rule has not been published to date.

personnel. So how will the federal government replace the knowledge, skills and abilities of the individuals that will be lost?

Government Intern/Training Program

The government has several types of hiring programs; for example, the Student Temporary Employment Program (STEP), which primarily targets high school students seeking part-time or seasonal work, and the Student Career Employment Program (SCEP), which targets college students. However, there are also a variety of summer job programs, volunteering opportunities, and the Presidential Management Fellows Program, which is aimed toward graduate students. For this paper, we focused exclusively on the Federal Government Intern Program. This program was designed to hire college graduates or individuals who had recently completed a technical certification and to train and keep them in those positions for two years. The positions varied in grade levels but could be a GS-5, GS-7, or GS-9. Although the individuals were not guaranteed a job at the end of the two years, the benefit is that they would have gained knowledge of the federal government, and more importantly, of how the federal government acquisition process works. The intent was that at the end of the two years, the federal government would be able to select the top performers to fill its critical positions (OPM Government Intern Program, n.d.). The reality of the situation began to sink in sometime in the late 1990s, when college graduates were no longer as interested in the positions the federal government was offering. So the idea that the government would get the higher quality employee did not prove fruitful. In *today's* economy, this idea would probably prove to be a very good option, with a few modifications. But still, why were the college graduates no longer interested in the government jobs?

Comments From Current and Former Federal Government Interns

We conducted a survey utilizing various social networks available today to contact federal acquisition professionals who had worked, or were currently working, in the Federal Government Intern Program. These individuals were interviewed to gain their impressions of the program and what they liked or disliked. The results were actually surprising: a distinct line in the sand could be drawn sometime during the 1980s—just about the time that the program changed directions. Most interviewees who had experienced the intern program prior to the mid-1980s (referred to as Group A for discussion purposes) felt that the federal government intern program was very rewarding and one of the "best career moves" that they ever made. This group contained a mix of civilians and military personnel, with the majority belonging to the latter. Group A was asked about the type of projects that they were given to work on, and the type of training they received. Although the projects varied in scope, they all had one thing in common: they brought a sense of purpose to the intern and gave them a challenging and rewarding learning process. The provided training assisted them in performing their job function and helped them learn the process and formalities of the position. Although most members of this group did state that the acquisition process had changed over the years, they felt that the fundamental training they received was key to their learning and their ability to do their job. Group A also had a longer internship—on average, four to five years.

The second group of interns (referred to as Group B) started in the Federal Government Intern Program after the mid-1980s. This group was also comprised of both civilians and military personnel, with the majority belonging to the former. The average internship length was only two years, and when questioned about the types of projects *they* were given to work on, most indicated that they were given administrative contracting tasks, such as contract close-out or post-award contract administration. This group had a mix of individuals who felt that the experience was not rewarding, and they therefore only stayed the two-year minimum period and then moved on to other opportunities. Those in *this* category left with a non-favorable opinion of the program. The *other* portion of Group B, though the tasks they were given in the beginning were *also* administrative in nature, did stick with the program longer than two years and did find the career field rewarding. Generally, Group B felt that the training provided was adequate but that it needed to be enhanced to better prepare them for the tasks that they encountered in this career field.

So what changed during the late 1980s that caused this shift? Of course, we know acquisition reform has caused major changes in how the federal government acquisition professionals operate, but what else has changed? We know that training has changed and the requirements to enter the profession have changed. When both groups were asked about the requirements to enter the field and training, most felt that the requirements were appropriate, but the training received mixed reviews. Some felt that the training was very good; others felt that they needed additional training in the areas of cost analysis, negotiation, joint ventures, and contract administration. What does the training consist of for the acquisition professional?

Acquisition Professional Training

Most of the federal government has similar training programs that mirror the Defense Acquisition University (DAU). The DAU has a certification program that meets the requirements of the Defense Acquisition Workforce Improvement Act (DAWIA). They have certifications in various areas, but the one that would apply to acquisition professionals is the Contracting certification and is usually required to be promoted to the next level in the 1102 contract series. Other federal government agencies have similar training programs to the DAU, but most require the same courses—they are just numbered differently. Tables 1–3 show the three levels in which to obtain certification and the requirements for each.

Table 1. Level 1—Contracting
(DoD, 2011)

Core Certification Standards (required for DAWIA certification)	
Acquisition Training	None required
Functional Training	• **CON 090** Federal Acquisition Regulation (FAR) Fundamentals **(R)** • Personnel serving in a Contracting Coded position on 30 Sep 2010 are exempt from CON 090 through 30 Sep 2012. • **CON 100** Shaping Smart Business Arrangements • **CON 110** Mission-Support Planning • **CON 111** Mission Strategy Execution • **CON 112** Mission-Performance Assessment • **CON 120** Mission-Focused Contracting **(R)** • **CLC 033** Contract Format and Structure for DoD e-Business Environment
Education	• At least 24 semester hours in accounting, law, business, finance, contracts, purchasing, economics, industrial management, marketing, quantitative methods, or organization and management • Baccalaureate degree (Any Field of Study)
Experience	1 year of contracting experience.

Table 2. Level II—Contracting
(DoD, 2011)

Core Certification Standards (required for DAWIA certification)	
Acquisition Training	ACQ 101 Fundamentals of Systems Acquisition Management
Functional Training	• CON 214 Business Decisions for Contracting • CON 215 Intermediate Contracting for Mission Support **(R)** • CON 216 Legal Considerations in Contracting • CON 217 Cost Analysis and Negotiation Techniques **(R)** • CON 218 Advanced Contracting for Mission Support **(R)**
Education	• At least 24 semester hours in accounting, law, business, finance, contracts, purchasing, economics, industrial management, marketing, quantitative methods, or organization and management • Baccalaureate degree (Any Field of Study)
Experience	2 years of contracting experience.

Table 3. Level III—Contracting
(DoD, 2011)

Core Certification Standards (required for DAWIA certification)	
Acquisition Training	ACQ 201A Intermediate Systems Acquisition, Part A
Functional Training	• CON 353 Advanced Business Solutions for Mission Support **(R)** • 1 additional course from the Harvard Business Management Modules
Education	• At least 24 semester hours in accounting, law, business, finance, contracts, purchasing, economics, industrial management, marketing, quantitative methods, or organization and management • Baccalaureate degree (Any Field of Study)
Experience	4 years of contracting experience

One modification that the DAU made to enhance their training was to add a "Core Plus Development Guide," which was drafted in response to the many requests for additional training in areas that many federal government acquisition professionals indicated that they wanted/needed in order to perform their jobs better. The Core Plus Development Guide grouped the acquisition professionals into 10 different categories or areas of assignment in which an acquisition professional might need training, based upon the types of work that they normally perform. The Guide then designed additional courses and on-the-job training that the acquisition professional could take in order to enhance their education/skills in those areas. The 10 categories are broken down as shown in Table 4.

Table 4
(DoD, 2011)

Type of Assignment	Representative Activities
1 - Operational Contracting	Contracting functions in support of post, camp or stations
2 - Res & Dev	Contracting functions in support of research and development
3 - Sys Acq	Contracting functions in support of systems acquisition, to include all ACAT programs
4 - Logistics and Sustainment	Contracting functions performed by the Defense Logistics Agency or by other offices to sustain weapon systems
5 - Construction/ A&E	Contracting functions in support of construction and/or architect and engineering services
6 - Contingency/ Combat Ops	Contracting functions performed in a contingency or combat environment
7 - Contract Admin Office	Contracting function is primarily focused on contract administration
8 - Contract Cost/Price Analyst	Contracting function is primarily focused on advanced cost/price analysis
9 - Small Bus Specialist	Contracting function is primarily focused on advising small businesses or on strategies for maximizing use of small businesses
10 - Other	Contracting functions that perform a variety of assignments or are at a headquarters, secretariat, or OSD

Lists of courses were then recommended based upon the type of assignment and the level of certification that the acquisition professional was assigned. These courses are shown in Tables 5–7.

Table 5. Level I—Contracting
(DoD, 2011)

Core Plus Development Guide (desired training, education, and experience)	Type of Assignment									
Training	1	2	3	4	5	6	7	8	9	10
CLC 003 Sealed Bidding	✔			✔	✔					
CLC 004 Market Research	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
CLC 005 Simplified Acquisition Procedures	✔	✔	✔	✔	✔	✔	✔		✔	✔
CLC 009 Service-Disabled, Veteran-Owned Small Business Program	✔	✔	✔	✔	✔	✔	✔		✔	✔
CLC 020 Commercial Item Determination	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
CLC 024 Basic Math Tutorial	✔	✔	✔	✔	✔	✔	✔	✔		✔
CLC 028 Past Performance Information	✔	✔	✔	✔	✔	✔	✔		✔	✔
CLC 030 Essentials of Interagency Acquisitions/Fair Opportunity	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
CLC 043 Defense Priorities and Allocations System	✔	✔	✔	✔	✔	✔	✔		✔	✔
CLC 045 Partnering	✔	✔	✔	✔	✔	✔	✔			✔
CLC 046 Green Procurement	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
CLC 054 Electronic Subcontracting Reporting System (eSRS)	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
CLC 055 Competition Requirements	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
CLC 060 Time and Materials Contracts	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
CLC 061 Online Representations & Certifications Application (OCRA)	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
CLC 062 Intra-Governmental Transactions	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
CLC 105 DCMA Intern Training							✔			
CLC 113 Procedures, Guidance, and Information	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
CLC 131 Commercial Item Pricing	✔	✔	✔	✔			✔	✔		✔
CLC 132 Organizational Conflicts of Interest	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
CLC 133 Contract Payment Instructions	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
CLG 001 DoD Government Purchase Card	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
CLG 004 DoD Government Purchase Card Refresher Training	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
CLG 005 Purchase Card Online System (PCOLS)	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
CLM 023 Javits-Wagner-O'Day (JWOD) Tutorial	✔	✔	✔	✔	✔	✔	✔		✔	✔
CON 237 Simplified Acquisition Procedures	✔	✔	✔	✔	✔	✔	✔		✔	✔
CON 243 Architect-Engineer Contracting **(R)**					✔					
CON 244 Construction Contracting **(R)**					✔					
FAC 007 Certificate of Competency Program	✔	✔	✔	✔	✔	✔	✔		✔	✔
SPS 101 Standard Procurement System and federal Procurement Data System -- Next Generation User	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔

Table 6. Level II—Contracting
(DoD, 2011)

Core Plus Development Guide (desired training, education, and experience)	Type of Assignment									
Training	1	2	3	4	5	6	7	8	9	10
ACQ 265 Mission-Focused Services Acquisition **(R)**	✔	✔	✔	✔	✔	✔	✔	✔		✔
CLC 001 Defense Subcontract Management	✔	✔	✔	✔	✔	✔	✔		✔	✔
CLC 006 Contract Terminations	✔	✔	✔	✔	✔	✔	✔			✔
CLC 007 Contract Source Selection	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
CLC 008 Indirect Costs		✔	✔				✔	✔		✔
CLC 013 Performance-Based Services Acquisition	✔	✔	✔	✔	✔	✔	✔	✔		✔
CLC 019 Leveraging DCMA for Program Success			✔				✔			✔
CLC 026 Performance-Based Payments Overview	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
CLC 027 Buy American Act	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
CLC 031 Reverse Auctioning	✔			✔						
CLC 035 Other Transaction Authority for Prototype Projects: Comprehensive Coverage		✔	✔				✔			
CLC 036 Other Transaction Authority for Prototype Projects Overview	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
CLC 037 A-76 Competitive Sourcing Overview	✔									✔
CLC 039 Contingency Contracting Simulation: Barda Bridge						✔				
CLC 040 Predictive Analysis and Scheduling			✔				✔			✔
CLC 041 Predictive Analysis and Systems Engineering		✔	✔				✔			✔
CLC 042 Predictive Analysis and Quality Assurance			✔				✔			✔
CLC 044 Alternative Dispute Resolution	✔	✔	✔	✔	✔	✔	✔			✔
CLC 047 Contract Negotiation Techniques	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
CLC 050 Contracting with Canada	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
CLC 102 Administration of Other Transactions		✔	✔				✔			
CLC 103 Facilities Capital Cost of Money	✔	✔	✔	✔	✔	✔	✔	✔		✔
CLC 104 Analyzing Profit or Fee	✔	✔	✔	✔	✔	✔	✔	✔		✔
CLC 107 OPSEC Contract Requirements	✔	✔	✔	✔	✔	✔	✔			✔
CLC 108 Strategic Sourcing Overview	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
CLC 110 Spend Analysis Strategies	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
CLC 112 Contractors Accompanying the Force	✔	✔	✔	✔	✔	✔	✔			✔
CLC 114 Contingency Contracting Officer Refresher						✔				
CLC 120 Utilities Privatization Contract Administration							✔			
CLC 125 Berry Amendment	✔		✔	✔	✔	✔	✔			✔
CLM 013 Work-Breakdown Structure			✔				✔	✔		
CLM 031 Improved Statement of Work	✔	✔	✔	✔	✔	✔				
CLM 032 Evolutionary Acquisition			✔				✔			
CLM 038 Corrosion Prevention and Control Overview	✔	✔	✔	✔	✔	✔	✔			✔
CLM 040 Proper Financial Accounting Treatments for Military Equipment	✔	✔	✔	✔	✔	✔	✔	✔		✔

Education
Graduate studies in business administration or procurement

Experience
Two (2) additional of contracting experience

Table 7. Level II—Contracting
(DoD, 2011)

Core Plus Development Guide (desired training, education, and experience)	Type of Assignment									
Training	1	2	3	4	5	6	7	8	9	10
ACQ 201B Intermediate Systems Acquisition, Part B **(R)**	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
ACQ 370 Acquisition Law **(R)**	✔	✔	✔	✔	✔	✔	✔			✔
BCF 102 Fundamentals of Earned Value Management			✔				✔			
CLB 007 Cost Analysis	✔	✔	✔	✔	✔	✔	✔	✔		✔
CLB 011 Budget Policy			✔							
CLB 016 Introduction to Earned Value Management			✔		✔		✔			
CLC 023 Commercial Item Determination Executive Overview	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
Education										
Masters degree in business administration or procurement										
Experience										
Four (4) additional years of contracting experience										

Since the federal government uses the intern program to recruit for approximately 20% of the vacancies in its acquisition workforce, there are still areas that need to be addressed. Where else does the federal government recruit from to replenish its workforce?

Government Hiring Process

The federal government has modified its recruiting process to reduce the amount of time it takes to hire from the outside—or even to hire from within the federal government. The usual process takes about four months to hire from within the government and about nine months to hire from outside the government. The federal government has streamlined its procedures by eliminating the Standard Form 171 Application for Federal Employment and has advanced to a more commercial application process. Applicants are asked to submit a resume, complete a short application form with basic information (a process usually completed online), and may have to submit supporting documentation to validate qualifications such as a diploma, certifications, etc. The Office of Personnel Management also eliminated the written Knowledge, Skills, and Abilities (KSA) requirement from most job opportunity announcements. Although the applicant is still required to demonstrate these KSAs, they may do so through their resume and not through a separate written document, as was previously required. The elimination of these requirements, and the use of a more streamlined process, results in an increase in the number of applicants to the federal government. However, there still remains the long lead time required to hire acquisition professionals. The hiring process is also encumbered by the fact that due to budget cuts, some open positions are being eliminated. So how does the federal government deal with the increase in federal procurement requirements and the complexity of the requirements becoming more intensive?

Alternatives to Hiring In-House Personnel (Outsourcing)

The federal government is faced with an increase in the number of procurement requirements, the increased complexity of the procurement requirements, and the fact that the contract administrative burden has increased over the last 10 years due to recent legislative issues and the Government Accountability Office audits that have been performed. This leaves contracting agencies with the dilemma of fulfilling procurement requirements for their agency's clients and having the necessary staff that can perform the procurement functions. The intern program was one option and the recruiting of in-house personnel another, but both had drawbacks. Agencies began to look to outside contractors who could perform some of the administrative acquisition functions. At first, this was just the contract close-out actions; then it migrated to the post-award contract administrative function, and now it covers everything except acting and signing on behalf of the federal government. So now that the federal government is outsourcing a portion of the procurement process, what are the true benefits to the government?

Benefits

- Professional Federal Acquisition Contractors are able to hire faster than the federal government and are only subjected to the budgetary constraints of the contract.
- Although these contracts are not personal services, the federal government can usually stipulate the desired skill level of the personnel that are placed on the contract, and if the personnel do not meet the requirements of the contract, the Professional Acquisition Contractor can be requested to provide replacement personnel that do meet the requirements.
- The cost of procurement is lower, when the cost of in-house personnel is compared with the contractual cost of the Professional Acquisition Contractor.
- The federal government headcount numbers are reduced.
- The Professional Acquisition Contractors are able to recruit, train, and retain personnel more quickly and efficiently than the federal government.
- The Professional Acquisition Contractors are able to improve overall procurement pricing and provide better market and supplier intelligence due to their ability to obtain and train a higher skill level of people or to be able to at least have the possibility of reaching those resources that the federal government does not have at its disposal.

However, with the employment of Professional Acquisition Contractors in the workplace, there are also disadvantages that must be reviewed as well.

Disadvantages

- There is a much greater possibility of Organizational Conflict of Interest that will need to be monitored since you have the potential for federal Contractors to oversee the contract administration, pre-award activities, and in some cases, even sit in on the source selection evaluation board as subject matter experts.

- The turnover rate of personnel under the contract may not be conducive to accomplishing the procurement process within the time constraints allowed.
- There may appear to be cost savings in the first few years, but when costs are compared at five years or longer, the cost savings are minimal and in some cases do not exist at all.
- The Procurement Acquisition Contractors still require federal government Contracting Officers to oversee the work that they were contracted to do as well as administer the actual contract that authorizes their work—thereby off-setting some of their benefits by creating additional acquisition workload themselves.

Looking at both the pros and cons, is it beneficial to outsource this portion of the acquisition function to Procurement Acquisition Contractors versus hiring in-house personnel? Each agency must base that decision upon its own procurement requirements, staffing, and budgets. However, one thing that the federal government can do is look at what the Procurement Acquisition Contractors are doing to recruit, train, and retain personnel and try to emulate that model.

Changes That Need to Be Made

The government recruiting procedure still needs to be reviewed and a path forward established to streamline the process to match industry standards. In the commercial environment, a senior-level recruiter typically has 18–20 job requisitions to fill at any given time. Currently, the government does not conduct active recruiting, and therefore, recruiters are not utilized. When comparing a typical government management analyst, who would perform similar functions, they can have anywhere from five to 50 job requisitions at one time. Government management analysts are trained to review resumes; however, they do not pre-screen or pre-interview candidates as recruiters in the commercial environment do. Pre-screening requires the management analyst to know and understand the manager's exact specifications for the position, and that is generally not the case in the government sector. While this is not currently practiced, it may be an area for change. Although the federal government may prefer standardization and adherence to labor laws, the labor laws do allow for a more active recruiting effort, which could prove beneficial to resolve the acquisition professional problem.

The DAU, as well as similar agencies/organizations, has taken a big step to bridging the gap in the required training that is needed with the addition of the Core Plus Development Guide. The DAU has plans to continually review their training curriculum to determine whether it meets the needs of the acquisition professionals. The only foreseeable change in this area, which is not currently being addressed in the commercial environment, is to implement testing for the acquisition professional at the end of each certification level to ensure understanding of all required training. Currently, the DAU and other organizations test at the end of each class, but commercial organizations (e.g., the National Contract Management Association, NCMA, and the Federal Acquisition Institute, FAI) test at each level of certification. After interviewing candidates who have completed both certifications, it appears that most candidates value their commercial certifications over their federal government certifications. The commercial certification test required testing on *all* of their knowledge from the required courses and was closed book. By contrast, most of the tests for individual courses were open book. A test at each level of certification (versus just after each course) ensures that the individual has not merely memorized information from a single session but rather mastered the acquisition concepts presented in all required courses.

Although the federal government offers great benefits and job security, research indicated that acquisition professionals who left the government service for a similar position in the commercial sector had done so based upon salary. Salary in the commercial environment is more competitive than the federal government. This is primarily due to the fact that the federal government is inflexibly structured with specific timing of promotions and step increases, while the commercial environment is not as structured. Other comments indicated that while the federal government prides itself on offering great benefits, the majority of the commercial sector offers similarly competitive benefits, to include vacation and/or sick time, health benefits, retirement plans, short- and long-term disability, bonuses, education reimbursement/tuition assistance, and certification programs similar to the DAU. This presents competition for the federal government. The pay banding system (designed to replace the General Services, GS, schedule), which provided government employees with the ability to negotiate or move within the pay bands depending on individual performance, was implemented to mitigate this situation. However, with the downturn of the economy, the pay banding system is being converted back to the GS schedule. The commercial environment has not made this switch for acquisition professionals. As such, the federal government will continue to be at a disadvantage in the ability to offer overall compensation that is competitive with the private sector and should instead focus on attracting new employees by featuring its strength as a stable job source whenever possible.

What Can We, As Acquisition Leaders, Do?

One of the areas in which young or entry-level acquisition professionals experienced the most frustration concerned the types of work that they were asked to complete. They performed strictly administrative tasks and were not challenged to their full potential. Some felt that performing contract close-out or post-award contract administration was not as rewarding as they hoped and felt that they wanted the opportunity to do more and to grow within the agencies. Agencies *could* implement an acquisition mentoring program where an entry-level acquisition professional is assigned a senior-level (GS-13 or higher) professional who could mentor them along. Specifically, they could work together on the larger, more complex, and more visible procurement acquisitions, in addition to the routine contract administrative functions that they are assigned. This could serve as a win-win scenario for both the junior acquisition person and the senior-level person. The senior-level person has an additional person to share the workload with and would be training the junior person to handle a future large or complex acquisition on his or her own. The mentor should include the junior acquisition individual in all meetings related to the assignment, which in some cases may be multiple assignments, but the end result is that the acquisition leadership needs to challenge and stimulate the younger generation in order to grow the profession.

In the early 1990s, agencies used to sponsor elementary schools and personnel volunteered in a mentor capacity. However, this is no longer as prominent as it used to be. Perhaps the agencies should engage high schools, colleges, and universities to establish mentorships for the potential acquisition professionals that may be learning within the school environment. Another suggestion is for the DAU to grant Continuing Learning Points (CLPs) to senior acquisition professionals who mentor or teach classes in order to foster and grow the federal government acquisition workforce. Most universities are more than willing to work with senior staff members in order to better prepare their students for the business world.

Conclusion

Changes within the federal government occur slowly, but they do happen. They begin with an idea and motivation. With the possibility of 50% of the acquisition professionals in the federal government retiring by 2014, and under current budgetary constraints, the federal government needs to begin making strategic and effective hiring decisions. Some of the required changes will take a significant amount of time and effort to occur, but if each of us mentored one or two junior acquisition professionals, we could develop them into strong, well-trained acquisition professionals. Richard Bach (2011) once said, and it is very appropriate for this situation, "Learning is finding out what we already know. Doing is demonstrating that you know it. Teaching is reminding others that they know just as well as you. You are all learners, doers and teachers." The only way to expand the acquisition profession is for us to act as mentors and teachers and demonstrate to the junior-level acquisition professionals all the great things that this profession has to offer.

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Acknowledgements

I would like to thank all of the people who supported me throughout the process of researching, interviewing, and writing this paper. I first have to thank Mr. Jim Emery, CFO at J. M. Waller Associates, Inc., who prompted and pushed me to submit my ideas for this symposium. Next, I would like to thank all of the NCMA alumni and GS-1102 alumni who responded to my requests for input on their opinions and experiences with the federal government acquisition intern program. I have to thank my staff, who put up with all of the frustrating moments in getting everything pulled together for this, as I think I may have gained a few more gray hairs. I have to thank some very special colleagues who tirelessly reviewed and edited, even down to the wire. They are Ms. Taryn Hermansen, Ms. Kate

Hutson, and Mr. Eric Spillman. I also have to thank Mr. Brian Mitchell, who continued to encourage and support me and review the final paper throughout the entire process. And last but not least, I would be remiss if I did not thank my children for helping laugh throughout the entire process and my parents for reminding me that strength comes from within. If there is anyone that I missed, please accept my sincere apologies, and somehow, someway, I will make it up to you.

Panel 18 – Advances in Acquisition Cost Analysis and Estimation

Thursday, May 12, 2011	
11:15 a.m. – 12:45 p.m.	**Chair: Dr. Daniel Nussbaum,** NPS, former Director, Naval Center for Cost Analysis ***Costing Complex Products, Operations, and Support*** Michael Pryce, Manchester Business School ***A Better Basis for Ship Acquisition Decisions*** Dan Billingsley, Grey Ghost LLC/Siemens ***Back to the Future: The Department of Defense Looks Back at the Should Cost Review to Save Buying Power in the Future*** Martin Sherman, DAU

Dr. Daniel Nussbaum—Professor, Operations Research, NPS. Dr. Nussbaum's expertise is in cost/benefit analyses, life cycle cost estimating and modeling, budget preparation and justification, performance measurement and earned value management (EVM), activity based costing (ABC) and Total Cost of Ownership (TCO) analyses. From December 1999 through June 2004 he was a Principal with Booz Allen Hamilton, providing estimating and analysis services to senior levels of the U.S. federal government. He has been the chief advisor to the Secretary of Navy on all aspects of cost estimating and analysis throughout the Navy, and has held other management and analysis positions with the U.S. Army and Navy, in this country and in Europe. In a prior life, he was a tenured university faculty member.

Dr. Nussbaum has a BA in Mathematics and Economics from Columbia University and a PhD in Mathematics from Michigan State University. He has held postdoctoral positions in Econometrics and Operations Research and in National Security Studies at Washington State University and Harvard University. He is active in professional societies, currently serving as the Past President of the Society of Cost Estimating and Analysis. He has previously been the VP of the Washington chapter of INFORMS, and he has served on the Board of the Military Operations Research Society. He publishes and speaks regularly before professional audiences.

Costing Complex Products, Operations, and Support

Michael Pryce—Research Fellow, Manchester Institute of Innovation Research at Manchester Business School. Mr. Pryce's current research project, *Costing Complex Products, Operations and Support*, is looking at innovative methods of costing future defense equipment. He was previously part of the 10 university Network Enabled Capability Through Innovative Systems Engineering (NECTISE) research teams, exploring organisational aspects of Through Life Systems Management. Mr. Pryce's part of the project looked at availability contracting on the Royal Air Force's Harrier and Typhoon aircraft programmes, and the design of the UK's new CVF aircraft carriers. [Michael.Pryce@mbs.ac.uk]

Abstract

Complex products and systems (CoPS), such as large defense equipment programs, are major capital goods in which customers play a central role from design through disposal (Davies & Hobday, 2005). A central idea of the research that this paper reports on is that the degree of complexity in CoPS may have a significant effect on the range of possible variance of their operations and support (O&S) costs. However, operational use and other factors also have an important part to play in the complexity of CoPS, which simple "parts count" approaches may miss.

The research design presented is one of a pair of detailed case studies, based on the U.S./UK Harrier combat aircraft. In this work paper, the intention is to explore how different approaches in the U.S. and UK to O&S on the Harrier aircraft have impacted some of the key drivers of costs. In addition, initial comparisons are made with more complex (in parts count terms) aircraft.

Introduction

Life cycle costing of defense equipment for long-term operations and support (O&S) is extremely challenging. The estimating of system update costs, changes in the roles and missions that systems are used for, and shifts in the commercial and customer organisations that use and support equipment provide major uncertainties and make predictions of costs highly problematic.

The research that this paper is based on seeks to address these issues by exploring complementary methods to existing costing approaches to help identify the range of variance in O&S costs. It does this through a number of comparative case studies. These are intended to illustrate the feasibility of comparative case studies in identifying the nature and scope of cost variance.

The full report on this research will cover the cases, and other O&S related issues, in greater detail than this paper. However, the introduction of some of the cases in this work is intended to allow discussion of the state of the research at the present time and to guide its future development.

Background

The costing of major defense projects is an area of perennial difficulty. With ever-rising program costs, and constant pressure on budgets, decision-makers are faced with a need for the highest-quality, robust cost estimates at the start of programs in order to allow the best informed decisions to be made.

While much work, over many decades, has been focused on estimating the costs of research and development (R&D), this activity still poses problems, as evinced by recent escalations in the Joint Strike Fighter program's R&D cost estimates. However, an area of even greater challenge is operations and support (O&S), which is frequently where the largest part of overall weapon system life cycle costs reside. The unpredictability of the scope and role for the future use of major weapon systems, the multi-decade duration of their use, the increasing gaps between programs rendering analogous data "stale," the extent and timing of major platform upgrades, etc., add up to a series of major challenges for cost estimators looking at O&S (Kirkpatrick, 1993).

The need to make decisions that ensure that force levels and structures can be sustained over program lifetimes, while still at the early stages in a program, shows how understanding the degree of possible variance in O&S cost estimates matter—they can form the greater part of overall life cycle costs (LCCs). If they turn out greater than their estimated baseline then military force structures and capabilities may suffer, while legislators need to be aware of any potential for Nunn-McCurdy-type breaches that can lead to major re-planning of programs, with attendant delays, etc. All of these factors mean that continued efforts should be made to ensure that the factors affecting O&S costs are understood and captured in estimates.

Currently, the approach used by the U.S. Department of Defense (DoD) is mandated through DoD Directive 5000.4 (USD[AT&L], 2006) and implemented by the Cost Analysis Improvement Group (CAIG). The approach taken is one of analytical cost estimates, using analogies from similar, older programs (where possible) to provide proxy data. A major problem in this is that new technologies (e.g., the move from aluminium to carbon fiber structures) may make it very difficult to "read across" old cost data. For some programs, it is also possible to provide "bottom up" estimates using the composition of more detailed cost estimates for components, sub-systems, etc., to build up an overall system cost (Arena et al., 2008; OSD-CAIG, 2007). However, this approach is often not practical in the early stages of programs, where detailed design data is not available.

The research that this paper reports on seeks to explore a complementary approach to current analytical methodologies in early program stages, in order to add to the robustness of cost estimates. It aims to enable better estimates of overall costs to be made by exploring ways of understanding of the degree of possible cost variance from the baseline provided by analytical techniques.

Research Approach

In the acquisition of complex products and systems (CoPS), such as large defense equipment programs, customers play a central role, from design through disposal. As part of the work undertaken in the CoPS Innovation Centre at the University of Sussex in the United Kingdom, an exploration was undertaken of how civilian firms that create CoPS in fields such as communication and transportation move through the value chain by shifting their "centre of gravity" (Davies & Hobday, 2005). This is typically done to allow them to modify their business model to profit from O&S activities and to ensure that the customer gets a better product and/or better value for his or her money. Implicit in this idea is the ability of organisations undertaking O&S for CoPS to change the way that the activities in O&S are carried out to reduce costs for a given capability, with support for this coming from Gregory (1989) and Hurcombe (1989).

This provides a counter to the notion put forward by Reed (1978) that the O&S costs are effectively "locked in" by fundamental design decisions taken early in a program. Reed suggests that this holds true for all combat aircraft, based on extensive empirical case studies, and that the chances to change maintenance costs are limited by this.

Both of these views have problems. The first is that Davies and Hobday are looking at CoPS that are far more predictable and relatively “static” in their use (e.g., telecoms, construction, railways) compared to the more “dynamic” nature of use that many defense equipment programs face. Second, Reed notes that the O&S lock in of costs may only apply to equipment where system repair is undertaken by replacement (rather than repair) of components.

These two issues mean that there is a need to explore further whether the type of equipment affects O&S costs, as well as whether the nature of O&S activities affects the degree of cost lock in. Is it the case that what can be termed “Dynamic CoPS” —such as combat aircraft, with major issues around operations in many changing situations, with variable levels of use/damage over many years—cannot be predictable enough in use to benefit from different solutions to their O&S needs? Is it also the case that by exploring the way Dynamic CoPS are supported, beyond repair by replacement, lock in of costs can be avoided? If this is the case, how does one design new equipment, or modify old equipment, to benefit from such an approach (for current approaches to such design, see Woodford, 1999)?

The research design to explore these questions is one of a set of detailed case studies, based on the U.S./UK Harrier combat aircraft. This aircraft currently serves with the United States Marine Corps and served with the UK Royal Air Force and Royal Navy until the end of 2010.

The main comparisons in this paper are between UK and U.S. Harrier costs, with the U.S. F/A-18 program and the UK Tornado also featured. The data used has been made available by UK sources. This work will be further extended by using U.S.-originated data and the concepts of other researchers in the field, such as Raman et al. (2003) on the F/A-18, to assist in the findings to be reported at the end of the program of research.

The main idea explored in the cases is that the degree of complexity in a project may have a significant effect on the range of possible variance in O&S costs. An initial assumption, that will be tested using the cases, is that the greater the degree of complexity, the narrower the “room for manoeuvre” in reducing O&S costs. Essentially, the idea tested is that greater complexity brings greater cost lock in. Figure 1 shows an overview of the case studies.

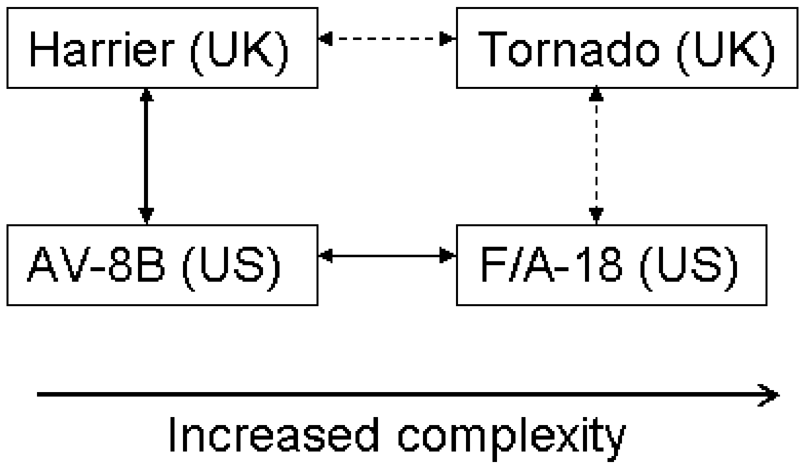

Figure 1. Aircraft Program Comparison Framework

The cases explore the following aspects of O&S:

1. The degrees of variance in O&S requirements between Harriers in the UK and U.S. and other aircraft (F/A-18 and Tornado), to establish how the degree of "designed in" complexity, patterns of operational use, etc., may vary.
2. The UK's Harrier GR.9 upgrade, to explore how design lock in issues were tackled in a system update never imagined by its original designers or users.

It should be noted that it is an assumption in this paper, and in the ongoing research, that factors such as "arisings" and "operational effects," discussed in the next section, have a rough equivalence in cost terms across all users. This is assumed in terms of the idea that they result in rectification actions that lead to maintenance man hours that are charged at nationally equivalent rates, as well as the consumption of spare parts that have similar costs. On this basis, the factors explored are taken to be good proxies for actual costs incurred over time.

Case Study 1: Aircraft O&S, Design, and Use

The approach to estimating the degree of complexity put forward in this research is based on the idea that it is not component count or lines of code that matter, but rather the number of interactions, both between engineered components, the way an aircraft is used, and the organisations undertaking the O&S activities on the aircraft. The assumption is that the overall effect of these interactions would be revealed by comparisons between arisings (e.g., defects) and their related operational effects (e.g., "failures"). An aircraft can still continue to fly a mission with an arising, but an operational effect will mean that a mission cannot continue as planned.

Figure 2 provides an overview of the level of arisings and operational effects on a number of aircraft platforms. The data presented are relatively old (mid-1980s) but have the great value of being for a similar period of use for each platform. Finding data that are comparative on such a basis is essential to allow meaningful comparisons to be made.

Three main points should be noted in relation to the data in Figure 2. First, the selection of three variants of the Harrier family, from two "generations" used by the Royal Air Force (RAF), Royal Navy, and United States Marine Corps (USMC), allows the effects of issues such as different levels of technology, operational use patterns, etc., to be compared. Second, for the AV-8B, F/A-18A/B, and Tornado, the data presented are for early production batches during a period where they were still being introduced into service. Third, and of great significance for this research, is the difficulty in comparing U.S. and UK data, which use different accounting practices.

Type	Arisings	Op Effects
RAF Harrier 1 (A)	2564	61.9
RN Harrier 1 (A)	1449	51.9
Tornado (B)	2122	140.0
AV-8B (A)	1096-1330	24.1-29.8
F/A-18A/B (B)	1265	33.5

Sortie length effects:

Increasing sortie duration by factor 't' increases occurrences by function $\sqrt{t}$ and decreases rates per flying hour by the ratio $1/\sqrt{t}$

Notes: Some AV-8A/C (A) and UK/US Phantom (B) data used for comparison

Sources: MACE/BAES/VAMOSC

Figure 2. Aircraft Reliability and Failure Rates

Note. Figures are per 1,000 flying hours.

The comparison between the three Harrier variants illustrates a number of issues. RAF Harrier sorties were of lower duration than Royal Navy ones, as well as being more punishing on the airframe since they were flown at a lower level. The Harrier is well known for subjecting much of its avionics and airframe systems to a punishing acoustic, thermal, and vibration environment, which is the cause of many system failures and was not amenable to prediction using standard methods, test spectra, etc. (see Beier, 1987). Flight at low level and high throttle settings exacerbate these problems, which the data clearly show. However, the box on the right of Figure 2 illustrates that these differences can be simplified into a general statement on the effect of sortie lengths on the occurrence rates for arisings and operational effects, at least for aircraft of a similar technology level.

The Royal Navy Sea Harriers were of a similar technology level to the RAF aircraft, although built five to ten years later, with more modern avionics and some system improvements incorporated. The AV-8B Harriers of the USMC shown in Figure 2 were of a new generation design, incorporating a new wing made of carbon fiber, new avionics, and substantially revised systems. However, the retention of major parts of the fuselage, made in the UK, that were derived from the first generation Harriers allows a good basis for comparison. The data in Figure 2 illustrate that the newer Harriers were more reliable overall. In part, this is due to the new technology as well as to the aircraft being new in service, although they were about the same age as the Royal Navy Sea Harriers and operated from shore and ship in a similar fashion, although on different mission profiles.

The data show that the AV-8B Harriers had similar, if slightly lower, arising rates to the Sea Harriers but much lower operational effect rates. In part, this was due to environmental factors—the weather in Yuma, Arizona, is much better than at Yeovilton in the UK, while operations from ships in the North Atlantic as well as operations in the South Atlantic had an adverse effect on Sea Harrier rates. The greater fuel capacity, and more efficient wing for cruising flight, of the AV-8B allowed longer sorties than those of the Sea Harrier, helping to give a favourable operational effects figure.

Some of the comparisons between the U.S. and UK Harriers were made possible by some data for the USMC's own first generation Harriers. However, conversion of U.S. figures to UK formats do mean that accounting allocations need to be made that may be slightly wrong, hence the spread of figures of the AV-8B and the F/A-18A/B. Although the main figures presented here relate to comparisons between the Harrier family, data are also provided for the more complex F/A-18A/B and the British PANAVIA Tornado GR.1. In the case of these aircraft, it was thought that the major design differences would make comparison more difficult. However, there was some hope in the fact that they are both twin-engined types, and that the complexity of the "swing wing" on the Tornado may have some equivalent in the added complexity of the "navalization" features for the F/A-18 Hornet.

However, as Figure 2 shows, it is apparent that the differences in the arisings and operational effects figures were very significant. This is explicable in part due to factors mentioned in relation to the Harrier data—different mission profiles, different environmental effects, etc., but the data appear to reveal the fact that the F/A-18A/B was inherently more reliable by design. An attempt at "controlling" UK/U.S. accounting differences using old F-4 Phantom data did not provide any greater insight. Additional data recently acquired, and still being analyzed, do show that later batches of Tornado were significantly more reliable. Indications from this data, as well as from interviews undertaken, are that this is in part explicable due to the RAF failing to support the Tornado using the maintenance strategy for which it was designed. This was later rectified, with a marked improvement in reliability, albeit at great cost.

This data analysis is still progressing and is being associated with analysis of the later F/A-18E/F Super Hornet (e.g., by using insights from Raman et al., 2003). However, it is interesting to note the relative similarities between AV-8B and F/A-18 data in Figure 2, both aircraft originating at the same time from the same design team and sharing some systems. Analysis of these similarities, and their causes, is also ongoing and will be reported more fully at the end of the research.

What theses data are beginning to illustrate is the idea that interactions are not necessarily about the number of components parts but rather are caused by a range of factors. The number of components in the Harrier variants were not greatly different between them, but the figures shown in Figure 2 are. These differences come about through the effect of sortie rates, operational flight profiles, and environmental factors etc., which are the sources of the interactions that the aircraft components and the overall system endure.

To understand the factors that affect O&S more deeply, an example of a part of the aircraft that were largely common to all three variants of the Harrier was required. The main undercarriage (landing gear) units were selected[1]. Data for the share of overall O&S LCC costs of the RAF Harrier I's undercarriage are shown in Figure 3. It can be seen that the

[1] The Harrier has an unusual "bicycle" main undercarriage unit, with wingtip outriggers on the RAF Harrier I/Sea Harrier and mid-wing outriggers of different design on the AV-8B. However, the main units have only minor differences (e.g., some strengthening and lash-down lugs for ship-borne use).

undercarriage's share of the LCC O&S costs can be seen as being "typical" of other major systems (i.e., they are not unusual in their percentage of overall costs). This was seen as making them a good candidate to explore further.

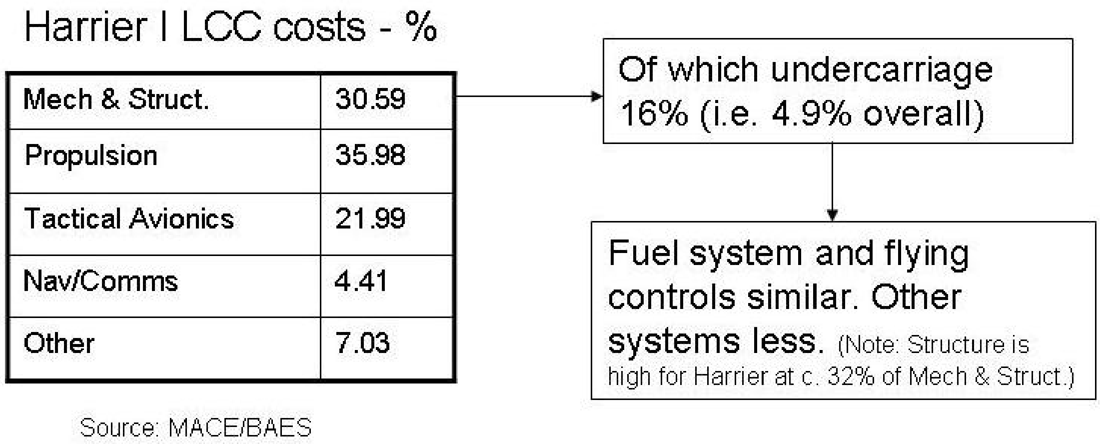

Figure 3. RAF Harrier I Undercarriage (and Other System) LCC O&S Costs

Undercarriage units of combat aircraft are high-value items that are designed to meet an operating life according to a certain assumed spectrum of use. They are built to last and are safety-critical because their failure during takeoff or landing can lead to total loss of the aircraft. Undercarriage units are exposed to heavy stresses throughout their life. These factors can lead to a heavy maintenance burden, with frequent inspections required and repair or replacement often required. For naval aircraft, or STOVL aircraft such as the Harrier, there are many additional sources of fatigue and other damage to the undercarriage, compared to land-based aircraft. One key difference between UK and U.S. undercarriage O&S is that maintenance of such units are a more specialised trade in the U.S., to the extent of personnel specialising down to the level of main or nose gear support.

Operations on the Harrier have led to constant discoveries of undercarriage O&S issues that needed to be addressed. Although the main undercarriage was very robust, being designed to operate off base and to take many unusual loads, such as landing while flying backwards, these discoveries were nearly impossible to predict and meant that the real-world experience of the undercarriage in use differed from the original design spectrum that they were built to meet. For example, as Burton (1996) reports, seemingly minor differences in the build quality of the ski-jump ramps of the UK's Invincible Class light aircraft carriers seriously affected the life of the undercarriage units, depending on which ship the aircraft was being operated from. These build quality differences were not part of the original modelling undertaken for a new ski-jump design and its effect on the aircraft's operating limits and led to cracking in the undercarriage units.

This damage suffered was not particular to the role or mission profile of the aircraft, or to the type of Harrier, but to the particular ship of a class that they were operating from. The damage was expensive to repair but absolutely necessary. This one example is given here to illustrate the peculiarities of the type of incidents that make up the data presented in Figure 2 and to give an idea of how they can emerge unexpectedly. However, the fact that the Harrier's undercarriage was of a robust design meant that there were not any failures—just arisings that were repairable (and are similarly so for the AV-8B; see Hullander & Walling, 2008). The rate and nature of these arisings, however, were not "designed in," although the original characteristics of the undercarriage units were. The arisings were due to the peculiarities of the aircraft's use.

These types of issues have emerged in a range of other examples in the research. Not just the type of operational flight profile but even who is flying the aircraft can have an effect. As one interviewee (ex-Tornado aircrew) put it: "If the same aircraft is flown by the same people every day it doesn't break." Put simply, the fewer times switches, ejector-seat rigging, etc., are adjusted, the fewer interactions and the fewer failures occur. So while it is true that the design stage may well lock in some aspects of O&S—some parts are more liable to break than others and some are easier to fix, depending on how they are designed—this is not the whole story.

Case Study 2. Harrier GR.9 COTS Upgrade

The first case study illustrated how the needs for O&S can be affected by operational use. In the second case, we will explore how the interactions in contracting for O&S and their link to operationally urgent updates can be key drivers of costs. We will also look at how these costs can be contained though the use of COTS technology insertion and the innovative approach taken to it. The case explores the update of the mission computer on the Harrier GR.9 program, undertaken by BAE Systems. As Roark et al. (2008) have noted, it is harder to have visibility of costs when O&S is implemented by a contractor, which means that understanding how contractors undertake such activities will be valuable to understanding the causes of O&S costs.

The Royal Air Force's Harrier GR.9 mission systems update was termed the Harrier Integrated Weapons Programme (IWP), devised to bring together a number of discrete weapon-system enhancement projects. The IWP formed the basis of the GR.9 and T.12 aircraft. Principally, a state-of-the-art MIL-STD-1760 Stores Management System (SMS) was required which, combined with the new High Order Language (Ada) Operational Flight Programme (OFP) software and a new Open System Mission Computer (OSMC), permitted the aircraft to interact with new weapons and sensors.

In April 2002, BAE Systems received an interim contract for the development of the full GR.9 aircraft. A further £150 million contract was signed in January 2003 for non-recurring work, mainly software development and flight testing. The first aircraft flew in May 2003, with an initial batch of aircraft completed by the end of 2003. Operational release occurred in September 2006. The full modification programme had a value of £500 million, including support costs. The update programme was managed through the Future Integrated Support Team (FIST), a joint industry/MoD initiative, with engineering design undertaken at BAE Systems Farnborough and development and flight testing based at BAE Systems' Warton site. The scope of the Harrier GR9 upgrade work covered the following:

1. baseline recovery, re-design, and re-implementation for significant aspects of the avionic system, together with associated sub-system design;
2. procurement, integration, and testing;
3. a complete recovery and rewrite of the software for the central computer controlling the avionic and weapon systems (some 250,000 lines of code);
4. a major airframe change and the rewiring of the aircraft (over five miles of wiring per aircraft was removed or replaced);
5. the selection and integrated management of major international vendors through competitive tender;

6. providing structural and aerodynamic clearances;
7. the management of five instrumented development Harriers to provide test clearance and certification of each capability; and
8. the manufacturing of parts and equipment and their embodiment to upgrade to GR9 standard across the Harrier fleet. (Pryce, 2009)

It was therefore a very extensive program, involving many participants in the industry, government, the RAF, and the Royal Navy (who operated the GR.9 after their own dedicated Sea Harrier fleet was retired in 2006). Matters were further complicated by the need to incorporate unplanned rapid technology insertion (RTI) activities as a result of ongoing UK Harrier operations in Afghanistan. These tested the ability of the technical systems and organisations involved in the update effort to adjust to changing needs.

At the heart of the GR.9 update was the use of a commercial off-the-shelf (COTS) mission computer system. This shared a common chassis and some cards with the OSCAR mission computer that was used by Boeing to update the USMC's fleet of AV-8B Harriers. The OSCAR programme had seen the first major use of COTS computing by a U.S. combat aircraft and was, overall, a success. However, it did reveal that, while Moore's Law may allow a doubling of computer power every eighteen months, the integration and testing cycle on combat aircraft was the key driver of program timescales and associated costs (Adams, 2002; Hoppe & Winter, 1996).

In addition, the timescales during which combat aircraft operate, with the need for ongoing support for decades, is a major issue for COTS insertion—the chips used may well be out of production, and possibly unsupported by their original commercial supplier, many years before the military aircraft they are installed in stop flying. These two timescale issues (testing slowing down COTS insertion, with use ensuring COTS chips' long-term use instead of rapid replacement) have perhaps been behind the apparent lack of delivery of all the early promises of COTS.

With the Harrier, there are additional issues that exacerbate the testing cycle. Vibration levels are not based on a fixed standard to which a system can necessarily be certificated before use on the aircraft (Beier, 1987). Special certification of aircraft systems is therefore required on Harriers, possibly extending the testing cycle and further slowing and/or limiting COTS insertion. In this environment of technical, contractual, organisational, and operational complexity, with a multitude of interactions between different factors affecting O&S, it is very difficult to know how contractors can plan and/or profit from O&S activities without adding cost upfront (or locking it in for later) due to the difficulties of estimation that such uncertainty brings. However, it appears that the Harrier GR.9 case study does highlight that it can be done.

As with the example of the Harrier undercarriage given above, the mission computer is a safety-critical item. This, in part, explains why the testing cycle is so long—it is necessary to ensure that the safety of the system has been proven, and analytical models or bench testing are not adequate to do this. However, the need to incorporate both pre-planned, incremental capability levels to the mission computer operational flight program (OFP), as well as changing OFP software in response to emerging RTI needs in light of urgent operational requirement emerging from Afghan operations, meant that a stable, relatively slow approach to the testing cycle was not possible.

In order to get the required results in the shortest possible time, BAE Systems' Harrier GR.9 team decided to use a number of shortcuts in developing the safety case of the mission computer. These consisted of both simple tools and methods of working that gave visibility and allowed communication to all participants in the company, its suppliers, and customers in the RAF and Royal Navy (Lucas, 2008). This considerably speeded up the insertion of new technology. Central to the ability to do this was BAE Systems' control of the OFP, rather than control residing in the supplier of the computer itself, or in the customer's O&S organisation. Since the OFP was frequently updated, such control was what allowed BAE systems to speed up the process. The OFP was particular to the Harrier GR.9, unlike on the OSCAR program for the AV-8B, where the OFP was developed as part of a modular OFP "family" for a number of aircraft programs (Logan, 2000). In addition, on GR.9 COTS, software languages such as C++ (as used on the OSCAR program) were used less frequently than the older Ada language, which had a well understood development environment.

With the changes to the OFP being unpredictable, an important way to minimise costs on the Harrier GR.9 upgrade, and in ongoing O&S activities such as RTI, was to minimise the time it took to implement them. While this is a simple enough idea, the example of how the UK GR.9 programme was able to implement them much more quickly than on the U.S. OSCAR program, despite the use of a similar computer and airframe, shows that the issue of design lock-in is not as limiting as may be expected. The flexibility that organisational structures can allow to overcome such "hard" technical features as well as accommodate the unpredictable changes to O&S activities that operational service revealed is a key to controlling future O&S costs.

Discussion, Summary, and Conclusions

In this brief paper, we have seen that the causes of operations and support costs are many and varied. In particular, this variance occurs on platforms such as the Harrier family of aircraft, which are notionally quite similar.

This finding in itself calls into question the idea of using past data to project future costs of new systems. If there are significant differences in the O&S costs and the causes of the costs between similar platforms then it is essential that they are understood in detail before being applied to future designs. It may be that the future design is particularly susceptible to some particular issue that is "lost in the noise" of aggregated data.

A case in point given in this paper is the operation of UK Sea Harrier aircraft from ski-jump-equipped aircraft carriers. The fact that one of these ships caused damage to aircraft undercarriage units was not catastrophic in this case, but in large part, it was due to the undercarriage being of robust design, thanks to very different original requirements. If the undercarriage had been designed by the assumed loads for the ski-jump, modelled as part of the design and clearance programme, it could well have failed in service use, leading to expensive redesign, remanufacture, and modification work.

Similarly, the Harrier GR.9 case illustrates how, despite minor overt differences from the AV-8B, the mission system upgrade was carried out via quicker testing cycles, leading to lower costs than might otherwise have been incurred. Such specific differences between two apparently similar cases would need to be understood before planning and costing the system architecture, O&S infrastructure, and update roadmap of a new platform based on data from them.

Regarding the basic question of technological lock in of costs, it appears that Reed (1978) and others who advocate this view are not correct. Clearly, patterns of operational use, approaches to O&S, and relatively minor differences between successive versions of an aircraft can have a significant impact on O&S activities and, thereby, on associated costs. In the case of related, relatively simple aircraft, as with the Harrier family, this still allows useful data to be gathered on the effects of complexity factors over and above "parts count"–type estimates. Their relative similarity allows for this.

With more technically complex, higher parts count aircraft that are unrelated, it appears that it is not possible to use data from one to predict the O&S costs of another — the Tornado and F/A-18 comparison shows that similarly complex (in parts count terms) aircraft can have very different O&S figures.

Regarding the idea that Dynamic CoPS can benefit contractors through O&S contracting arrangements, despite their much higher levels of unpredictability, compared to static CoPS, the cases drawn from Harrier, at least, show that this may be possible. As such, Davies and Hobday's (2005) work may be applicable. However, it may not be directly applied in an easy form, since using the "solutions" approach they propose to O&S support of combat aircraft would require a detailed, in-depth knowledge of the nature and degree of the variance of possible O&S effects and of the wide range of factors that cause them. These seem much wider, and more unpredictable, than in static CoPS.

Building on these interim findings lies at the heart of the ongoing research program that this paper derives from. With a clear idea of the effect of all the factors, and their interactions, that cause O&S issues and their related costs, it is thought that a more useful method of applying data from existing programs to future ones can be developed. This work is due to be reported by September 2011.

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Acknowledgements

Professor David Kirkpatrick of University College London, Professor Eric Grove of Salford University, and Alistair Forbes of Manchester Business School kindly undertook to review the research that led to this paper. Staff from the BAE Systems' Harrier team are to be especially thanked for allowing me to interview them at a time of great turmoil within the team, with the recent cancellation of the UK Harrier fleet. In addition, staff at Boeing, St. Louis, provided useful information and feedback.

The material in this paper is based upon work supported by the Naval Postgraduate School Acquisition Research Program under Grant No. N00244-10-1-0072.

A Better Basis for Ship Acquisition Decisions[1]

Dan Billingsley—Senior Partner, Grey Ghost LLC. Grey Ghost is an Annapolis, MD, firm that provides confidential analysis and assessment of information systems for the marine industry. Mr. Billingsley formed Grey Ghost in April 2007, following 38 years of government service. After graduation in 1969 with a BS in Engineering Science from Louisiana State University, most of Mr. Billingsley's early career was in ship structural design and engineering at Puget Sound Naval Shipyard, the Naval Ship Engineering Center, and in structural safety policy development at the Coast Guard Office of Merchant Marine Safety. After joining the Naval Sea Systems Command in 1982, most of his career involved the development, implementation, and application of computer tools for ship design. Mr. Billingsley played a key role in initiation of the Navy/Industry Digital Data Exchange Standards Committee in 1986, which led to the current ISO 10303 Industry Standards for the Exchange of Ship Product Model Data (the STEP standards). He served as Head of NAVSEA's Computer Aided Engineering Division from 1988 to 1997, as CAE Program Manager from 1999 to 2001, and as the Technical Warrant Holder for Product Data Integration and Exchange from 2002 to 2004. His last assignment was as the Navy Program Manager for the National Shipbuilding Research Program from 2004 to 2007. He transitioned NSRP from an OPNAV-funded program headed for termination in FY 2005, to a PEO- and Congressionally funded program with ~$40 million in Federal and industry matching funds in FY 2007. While at NAVSEA, Mr. Billingsley won the Meritorious Civilian Service Award in 1991 and the Superior Civilian Service Award in 2007. [dwbillingsley@gmail.com]

Abstract

Naval ship acquisition is widely thought to be too expensive, too long, too uncertain, and too risky.

Throughout the ship development process, decision makers at all levels are afflicted by unreliable estimates and projections of *cost, performance, schedule, and risk* of competing alternatives. In this context, "decision makers" includes senior Navy leadership, program officers, and ship design managers, all of whom make decisions affecting the eventual product.

How can estimates and projections of *cost, performance, schedule, and risk* be improved? To some extent, decision making in the face of uncertainty is an inescapable part of the development of naval warships due to their unrivaled complexity. This is especially true in the early stages of ship development. However, analysis indicates that the quality of *cost, performance, schedule, and risk* estimates could be substantially improved by actions addressing the root causes of poor estimates.

This paper examines four root causes of poor *cost, performance, schedule, and risk* estimates and projections in the context of ship information development and flow. Eight solution vectors are identified that can provide higher quality estimates and projections earlier in the design process, reducing the uncertainties faced by decision makers, saving expensive engineering labor, and increasing assurance that the delivered ship will satisfy requirements. The relationship of particular solution vectors to the particular root causes is provided in tabular and discussion form.

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[1] Originally published as Billingsley (2010). Reprinted with permission.

Ship Acquisition Woes

Naval ship acquisition is widely thought to be too expensive, too long, too uncertain, and too risky. In the eyes of Congress,[2] "Our ships are simply too expensive"; and "I believe the Navy needs to look very hard at their requirements process to determine if marginal extra capability is worth significant construction or integration costs." In the eyes of the Navy,[3]

> Inarguably the underlying challenge—indeed, the pressing requirement—before us today in shipbuilding is affordability.
>
> The fact is that ship costs are rising faster than our topline….To this list I need also add performance, for on even our most mature programs, we have experienced cost growth as a result of performance shortfalls and quality escapes.
>
> The reality is that there is no single fix to turn around this trend, but rather a large number of initiatives, practices, and standards that we need to attack across the board….
>
> We need to ensure that our requirements are balanced by our resources....The key here is to inform the process with realistic cost estimates and realistic risk assessments at the front end. This drives the difficult decisions early, where there are true choices, and true opportunities….
>
> To meet these objectives, we must be smart buyers. The acquisition workforce has been downsized over the past decade and a half to the extent that our professional corps has been stretched too thin and we have outsourced too much of our core competencies. Accordingly, we must rebuild our Navy acquisition workforce.

In the eyes of the Defense Department,[4]

- "Many weapons systems are over-budget, late, and don't meet performance goals" (e.g., GAO-06-391[March 2006]).
- "Lengthy and rigid acquisition process degrades ability to address rapidly changing irregular, catastrophic and disruptive threats."
- "Many of these problems can be traced to an ineffective design process."
- "Our present design tools are inadequate to produce an integrated design with few flaws."

Cost overruns and schedule slips would perhaps be more tolerable if the results were unquestionably world class. Instead, recent years have seen the emergence of

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[2] The Honorable Gene Taylor (D-MS), Chairman of the Subcommittee on Seapower and Expeditionary Forces of the House Armed Services Committee on Shipbuilding Effectiveness, in his opening statement for hearings on July 30, 2009.

[3] The Honorable Sean J. Stackley, Assistant Secretary of the Navy (Research, Development and Acquisition), and Vice Admiral Kevin M. McCoy, Commander, Naval Sea Systems Command, in prepared testimony for the Subcommittee on Seapower and Expeditionary Forces of the House Armed Services Committee on Shipbuilding Effectiveness on July 30, 2009.

[4] Mr. Al Shaffer, Principal Deputy, Defense Research and Engineering, at the 2009 High Performance Computing (HPC) Modernization Program Users Group Conference, June 17, 2009.

unbalanced ship designs, designs so optimized for a particular characteristic (e.g., stealth or high speed) that their general suitability has been questioned.

Clearly, ship acquisition is not working out as planned. To face the challenges of the coming decades, we need an acquisition process that is swifter, more efficient, and more credible.

The Culprit—Poor Decision Support Information

No doubt if past decision makers[5] had understood how things would work out (the *cost, performance, schedule, and risk* implications of their decisions), they would have chosen alternate courses of action. In fact, decision makers must currently rely on poor quality *cost, performance, schedule, and risk* estimates, especially in the very early stages of ship acquisition—when the opportunity to excel and the opportunity to err are greatest.

To some extent, decision making in the face of uncertainty is an inescapable part of the development of naval warships due to their unrivaled complexity. This is especially true in the early stages of ship development. However, it is clear that decision makers are operating with far more uncertainty than necessary, due to being served by inexperienced ship design organizations, frequently staffed by inexperienced ship design engineers. In turn, these organizations and engineers must frequently rely on missing or inaccurate analysis tools and must apply these tools with missing or late analysis inputs.

Root Cause #1—Inexperienced Ship Design Organizations

Successive generations of Navy leaders have underestimated the difficulty of naval warship development. They begin with the notion that management and analysis techniques that have worked well for simpler products will suffice for a task with the complexity, scale, and scope of a naval ship acquisition. As they learn otherwise, their tenure in office comes to an end, and the cycle is repeated.

The challenges of warship development have humbled otherwise highly competent organizations and corporations. To fully appreciate the difficulties they face, it is necessary to understand certain aspects of naval warship design development. This process is in many ways different from the acquisition and/or development of other DoD military items. Key differences are as follows:

- Product Complexity—The typical ship is comprised of hundreds of times as many parts (and more kinds of parts) as the typical aircraft, thousands of times as many parts as the typical power plant, and ten thousands of times as many parts as the typical vehicle. Indeed, our more complex ships fly aircraft off the roof, have vehicles running around inside, and have a couple of power plants in the basement—all incorporated in a floating city capable of moving at high speeds around the oceans of the world.
- Process Complexity—As illustrated in Figure 1, the process of ship development is likewise complex, particularly for naval warships. It involves thousands of individuals in hundreds of corporations, and governmental and regulatory bodies operating throughout the world. Each ship is in some ways unique. A ship may have a conception-to-retirement lifespan of 50 years,

[5] In this paper, "decision maker" is intended to refer to decision makers at all levels, including senior Navy leaders, Program Managers, and Ship Design Managers.

involving both those not-yet-born when it was launched, and those who will retire before it retires. Certainly today's ship will outlive several generations of information technology applied to its development, construction, and service life support.

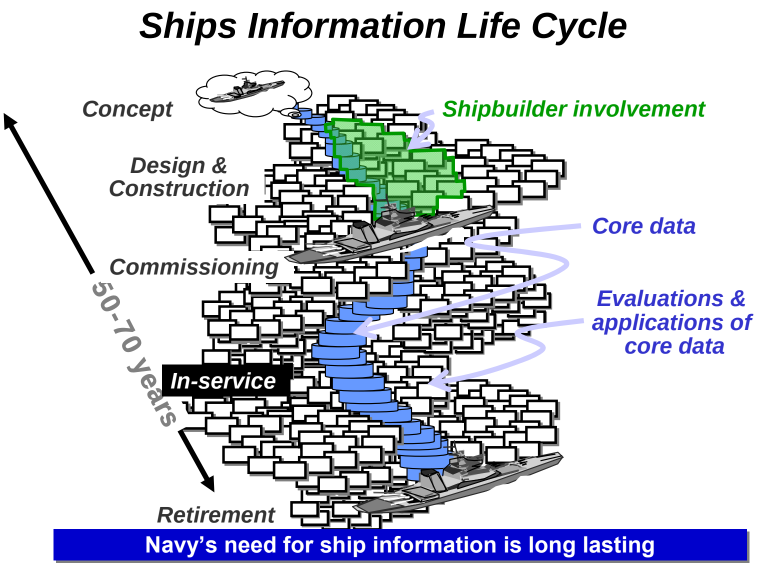


Figure 1. A Long Process With Many Participants

- System of Systems—As illustrated by Figure 2, the fluid-supported, self-contained, self-propelled, multi-mission, and self-sustained nature of ships necessitates tradeoffs between competing requirements. The optimal total ship design will be comprised of many sub-optimized elements. Conversely, a collection of optimized elements will not work as a total ship. Solution of these conflicts is an intrinsically iterative process.

Figure 2. Warship Designers Must Trade-off Conflicting Requirement for Scarce Resources

- Slow Development of Definition—As illustrated in Figure 3, physical detail emerges as the design matures, typically over the course of several years.

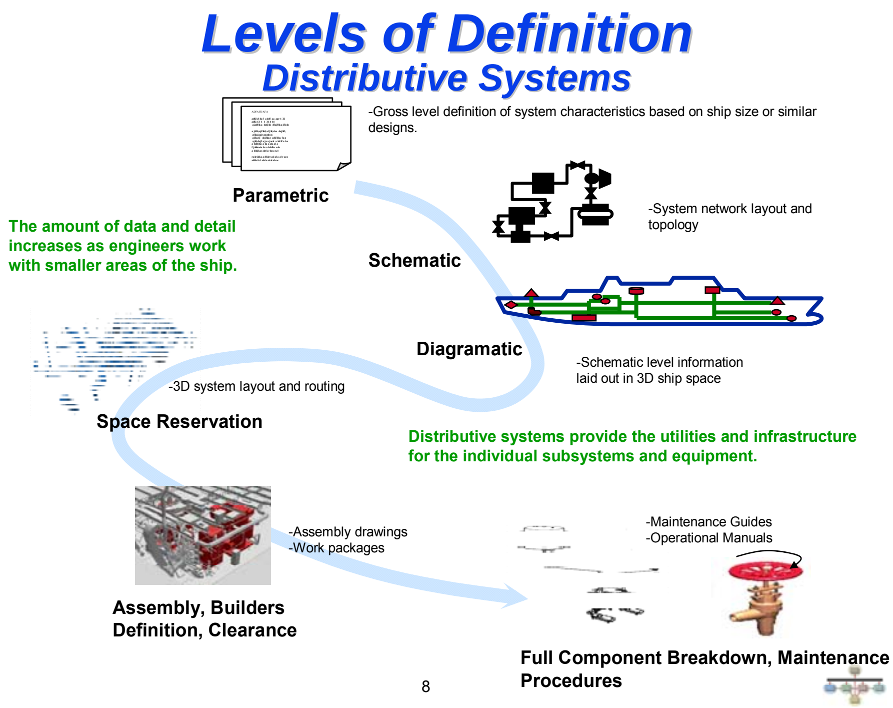


Figure 3. Physical Detail Emerges as the Design Matures

Early Stage Focus—The essence of early stage design is the ability to correctly predict the cost and behavior of the millions of parts that will comprise the completed ship—and to do so years before most of those parts have been identified. Critical decisions must frequently be made based on inadequate information. The emphasis is on total ship behavior, swift iteration through multiple options, lightweight definition with accurate allowance for "known unknowns," and identification and reduction of total ship system risks.

Later Stage Focus—The essence of later stage design is to prepare instructions for the manufacture and assembly of the ship. The emphasis is on local fit, assurance of system function, avoidance of configuration changes with widespread impact, and detailed manufacturing definition—detailing or accounting for every part. We have discovered that individual or organizational skill in the later stage domain does not engender skill in the early stage domain and vice versa.

A mature, experienced design organization must have in place the organizational structures, procedures, and margin policies to deal effectively with the multiple creative tensions and uncertainties within early stage design. Prior to the 1990s, early stage design was the domain of NAVSEA and predecessor organizations. By accomplishing several designs per year and with an institutional culture of continuous process improvement, NAVSEA successfully completed development of designs for virtually all of today's U.S. Naval force.

It is ironic that an organization which understands and embraces so completely the need to approach the chaos of war with sound experience, training, organization, and doctrine takes such a casual, ad-hoc approach to the chaos of naval ship acquisition. Since the advent of Acquisition Reform in the early 1990s, every new ship design effort has been undertaken by a design team formed specifically for that effort. It is no wonder that results have been less than satisfactory. Nor should we expect better results by repeating this approach.

Root Cause #2—Inexperienced Ship Design Engineers

It takes about five years of experience with the unique characteristics of the marine environment and the challenges of ship operations, before the typical engineer has acquired the experience necessary to effectively support ship design. Consider, for example, an experienced structural engineer new to ship design. He discovers that the basic structural element, the stiffened plate panel, is unlike anything found in civil structures. Rather than a fixed foundation to which loads can be reconciled, he finds a distributed foundation which is *in motion* (somewhat analogous to a continuous earthquake). He also discovers that, despite decades of research, real-world loads are somewhat indeterminate and that a certain amount of buckling/panting is permissible to achieve structural weight targets.

In recent years, engineers charged with developing key elements of front-line warships are all too often "rookies," in terms of early stage ship design experience. And hard-learned lessons are not systematically captured in a form that new ship designers can use.

Ad-hoc, single-project design organizations are not incentivized to attract, and certainly not to retain, engineers with the requisite experience. In coming decades, this situation will be worsened by the severe shortage of science, technical, engineering, and math (STEM) workers forecast for the U.S.

It is encouraging to see a number of initiatives aimed at filling the pipeline of STEM workers available for naval ship design, including the following:

> The Science, Mathematics And Research for Transformation (SMART) Scholarship for Service Program established by the DoD to support undergraduate and graduate students pursuing degrees in STEM disciplines. The program aims to increase the number of civilian scientists and engineers working at DoD laboratories. Recipients receive a cash award, full tuition, and related educational expenses, health insurance, summer internships, and post-graduation career opportunities.
>
> The ONR Naval Research Enterprise Intern Program (NREIP) provides an opportunity for students to participate in research at a Navy lab during the summer. Recipients receive a stipend for a 10-week summer internship.
>
> The ONR National Naval Responsibility for Naval Engineering (NNRNE) Program has initiatives aimed at students from middle school to graduate school. One of those initiatives, in partnership with NAVSEA and NSWC, is the Center for Innovation in Ship Design (CISD) at Carderock (Naval Surface Warfare Center, n.d.). CISD conducts both summer projects with NREIP interns, and longer term (3–6 months) projects in collaboration with government, academia, and industry.
>
> Through NSRP, NAVSEA sponsored the Shipbuilding Engineering Education Consortium (SEEC) working group (comprised of representatives from government, academia, and industry) in 2009 to develop an overarching strategy for educating engineers across the spectrum needed by NAVSEA and the

shipyards. NAVSEA issued a solicitation based on the recommendations of the group and is now evaluating proposals.

NAVSEA's Naval Acquisition Intern Program is hiring engineers and other professionals and providing a rotational training to equip them for careers in NAVSEA.

The collective success of these programs is increasing the pool of talent from which experienced ship designers can be developed.

Root Cause #3—Missing or Inaccurate Analysis Software

Software used by ship design engineers are of two primary types:

- definition software (e.g., Computer Aided Design, CAD) to reflect and communicate the developing design, and
- analysis software (e.g., spreadsheets, Computer Aided Engineering [CAE], Modeling and Simulation [M&S]) to estimate the characteristics and predict the performance of the developing design.

Shortcomings in this latter category of software account for many of the uncertainties of *cost, performance, schedule, and risk* with which decision makers must contend.

The complexity of ships demands a wide variety of analysis tools and, for many design disciplines, different tools at different stages to be compatible with definition information available at that stage. Surveys have shown that availability and quality varies widely across disciplines from "very good" to "non-existent." Overall, the availability and quality of analysis software has eroded with the passage of time. There has been inadequate investment to keep pace with changes in computer technology, weapon systems technology, and ship technology (materials, hull configurations, power density, etc.).

Analysis software is, of course, one of many estimation or evaluation methodologies that can be brought to bear on an engineering problem. Methods are as follows (in rough order of accuracy):

- Engineering judgment,
- Hand calculations,
- Class rules,
- Spreadsheets,
- Adapted commercial off-the-shelf (COTS) CAE software,
- Special purpose COTS CAE software,
- Custom CAE software,
- Modeling and simulation,
- Model testing, and
- Full scale trials.

Currently, tool investment shortfalls are causing increasing reliance on engineering judgment at a time when an increasing number of engineers who have that judgment are retiring from the ship acquisition workforce.

Sources of Ship Design Software

The preferred source for analysis tools is COTS. Where ship design needs are similar to general design needs (e.g., pipe flow analysis, electric load analysis, structural response), COTS provides economical, well supported, and generally well-verified analysis software. Unfortunately, only 25%–30% of ship design software needs can be satisfied by COTS. The rest is so ship-specific that there is an inadequate market to attract COTS providers, and/or it is too military-specific for an open-market solution.

Non-COTS sources of analysis software include ONR-sponsored research software, ship acquisition program office sponsored software, and the CREATE Program (Post et al., 2008, p. 12090).

ONR has been a substantial provider of software for ship design. ONR-sponsored software is frequently a by-product of research in disciplines of interest to ONR programs. These may or may not align with ship design needs. The user interface of research software is typically barely adequate for the needs of research scientists and can be incomprehensible to a ship design engineer. Additionally, much of the software developed under ONR grants ends up not belonging to the Navy. Lastly, research software rarely has the validation or assured range of applicability one would desire for acquisition design.

Ship acquisition program offices have been substantial sponsors of software for ship design. Focus is usually on technical problems unique to the specific acquisition program. Timing is frequently an issue. By the time an acquisition program is established and funded, and the software need is identified, there is frequently inadequate time remaining for software development to take place.

The CREATE program was established in 2008 to leverage and apply the availability of high-performance computing to defense needs. CREATE is making substantial investments in scalable design and analysis software for ship hydrodynamics, shock, and rapid design. The ship design community looks forward to the availability of CREATE-developed software in the years to come.

The naval ship engineering community was an early adopter of computer technology to assist with the problems of ship design. Much of the software used to support ship design decisions today originated at NAVSEA in the 1970s, 1980s, and early 1990s. Throughout this period NAVSEA maintained an office or program focused on design process improvement including the following:

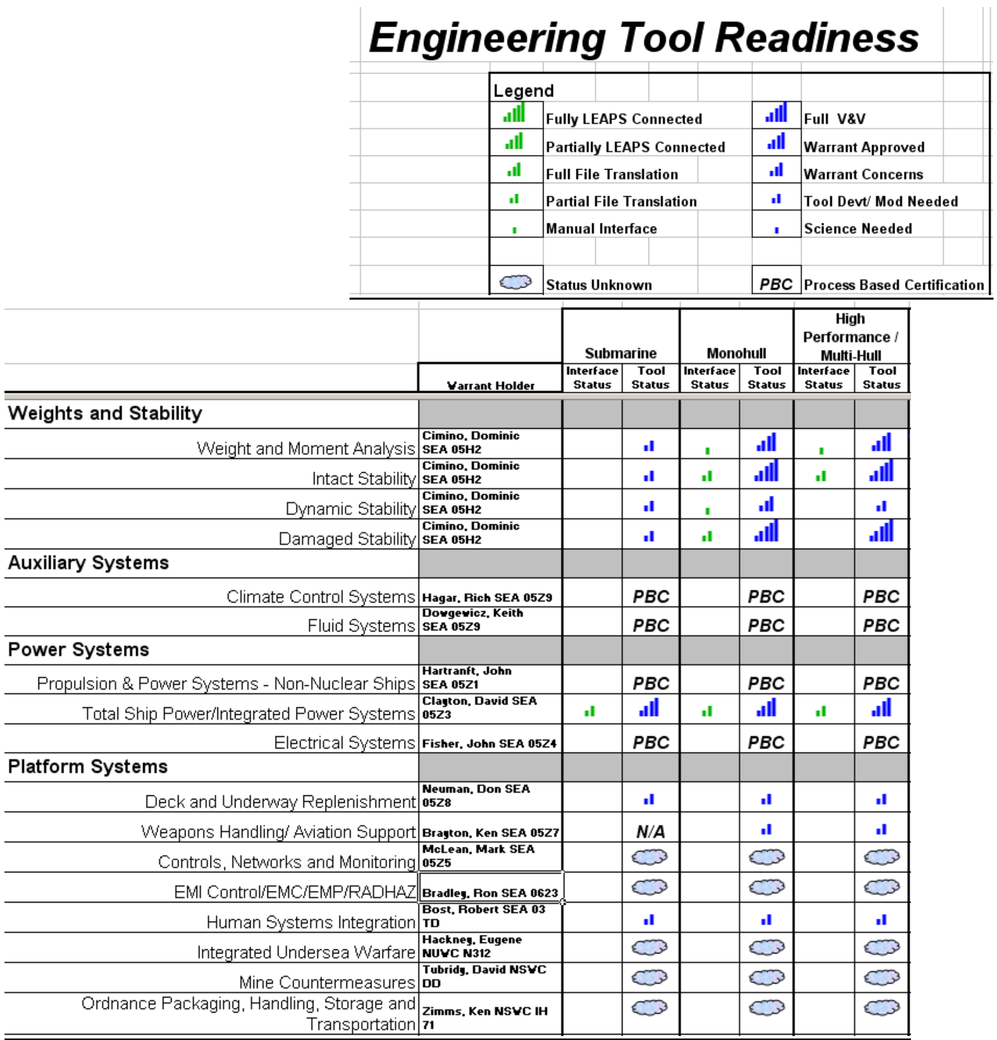
- Computer Aided Ship Design and Construction (CASDAC) Program,
- Computer Supported Design Program,
- Computer Aided Engineering Division,
- Ship Design, Acquisition and Construction (DAC) Process Improvement Program, and
- Computer Aided Engineering Program.

These programs provided system architecture, definition software, and software interfaces to permit available software to function as an integrated design system. Additionally, these programs provided “infill” funding for critical software (e.g., weight engineering) that did not have the glamour or program-specific focus to attract sponsorship from the sources mentioned above. Since the demise of the CAE program in 2000, there has been virtually no source of architectural leadership or integration and infill funding for early stage design computer software.

Design Software Plans and Surveys

NAVSEA periodically developed a blueprint or roadmap to provide a comprehensive vision of ship design and integration software status, needs, and future direction, including the following:

- **Simulation Based Design for Ships Master Plan** (NAVSEA, 1995) characterized the investment needed to realize the potential of newly available design technologies as $80 million over the FYDP and proposed a cost-sharing arrangement among NAVSEA, ONR, and OPNAV.
- **Certification Scorecard—An Investment In Seapower** (NAVSEA, 2000) laid out a system of metrics for the quality of ship certification software and updated the development cost projections from the SBD plan to include support cost.
- **Engineering Tools Survey** (2004; NAVEA, 2005) used a system of metrics to roll up a numerical summary estimate of the readiness of NAVSEA engineering software. An excerpt is provided in Figure 4. Resources limited this survey to approximately half the design disciplines of interest.



Engineering Tool Readiness

Legend

	Fully LEAPS Connected		Full V&V
	Partially LEAPS Connected		Warrant Approved
	Full File Translation		Warrant Concerns
	Partial File Translation		Tool Devt/ Mod Needed
	Manual Interface		Science Needed
	Status Unknown	PBC	Process Based Certification

	Warrant Holder	Submarine Interface Status	Submarine Tool Status	Monohull Interface Status	Monohull Tool Status	High Performance / Multi-Hull Interface Status	High Performance / Multi-Hull Tool Status
Weights and Stability							
Weight and Moment Analysis	Cimino, Dominic SEA 05H2						
Intact Stability	Cimino, Dominic SEA 05H2						
Dynamic Stability	Cimino, Dominic SEA 05H2						
Damaged Stability	Cimino, Dominic SEA 05H2						
Auxiliary Systems							
Climate Control Systems	Hagar, Rich SEA 05Z9		PBC		PBC		PBC
Fluid Systems	Dowgewicz, Keith SEA 05Z9		PBC		PBC		PBC
Power Systems							
Propulsion & Power Systems - Non-Nuclear Ships	Hartranft, John SEA 05Z1		PBC		PBC		PBC
Total Ship Power/Integrated Power Systems	Clayton, David SEA 05Z3						
Electrical Systems	Fisher, John SEA 05Z4		PBC		PBC		PBC
Platform Systems							
Deck and Underway Replenishment	Neuman, Don SEA 05Z8						
Weapons Handling/ Aviation Support	Brayton, Ken SEA 05Z7		N/A				
Controls, Networks and Monitoring	McLean, Mark SEA 05Z5						
EMI Control/EMC/EMP/RADHAZ	Bradley, Ron SEA 0623						
Human Systems Integration	Bost, Robert SEA 03 TD						
Integrated Undersea Warfare	Hackney, Eugene NUWC N312						
Mine Countermeasures	Tubridy, David NSWC DD						
Ordnance Packaging, Handling, Storage and Transportation	Zimms, Ken NSWC IH 71						

Figure 4. Excerpt From Phase I Engineering Tool Survey Final Report

- **Naval Ship Engineering Process Issues and Opportunities** (2006; NAVSEA, 2008) is an exposition of the cost and benefits associated with coordinated investment in each of four broad areas, as follows:
    - Product Data Interoperability,
    - Concept and Feasibility Design Tools,
    - TWH Tools for Certification of Design, and
    - Design Community Tools Coordination.
- **Design Tools Roadmap** (in progress) employs more intensive interviews of technical warrant holders and development of a design process model to pinpoint the most cost-effective areas for investment. Progress has been fitful due to funding limitations.

Investments in the 1990s and Early 2000s

During the late 1990s and early 2000s, program offices made independent investments in program-specific and shipyard-specific Integrated Product Data Environments (IPDEs; also known as IDEs and other names). Primary focus was on CAD systems for manufacturing definition, coupled with Product Data Management (PDM) systems for configuration management. The net result is a number of partially complete, detail design, and construction-oriented systems that are not interoperable with each other.

The NAVSEA engineering community was able to afford very little for early stage software development and support during this period and was unable to afford the effort involved to maintain a comprehensive picture of the status of its engineering tools. However, the efforts listed above sustained a collective awareness adequate to discern particularly glaring needs. 60–70% of ship design analysis areas have one or more of the following problems:

Evaluation software is of poor quality:

- poor algorithms inadequately represent underlying physical phenomena,
- misleading user interface,
- poor verification and/or validation, and
- application outside valid range.

Evaluation software is unavailable:

- new warfighting threats and/or technologies have emerged,
- fundamental understanding of the physical phenomena involved is inadequate,
- unconventional materials (e.g., composites) have been introduced, and
- unconventional configurations (e.g., multi-hulls, unprecedented electric power densities).

These shortcomings have been addressed in the past as problems for the ship design community, which they are. Of more national importance, however, is that these poor quality and/or missing software are the source of cost, performance, schedule, and risk estimates relied upon by decision makers when making expensive and far-reaching decisions. Good software is cheap, compared to the cost of compensating for failed systems in service.

Root Cause #4—Missing or Late Analysis Inputs

Even if quality analysis software is available, it does little good if timely and accurate input is not available. For example, the most commonly used software to evaluate ship vulnerability to weapons impact requires the following:

- Adequate definition of ship structure (thickness of plating and stiffener size and spacing for bulkheads, decks, and shell) to model blast penetration, and
- Adequate definition of component placement and distributive system routing (diagrammatic level of definition) to model system failures resulting from blast penetration.

At present, lack of adequate definition and inefficient data transfer into vulnerability analysis tools delay the availability of vulnerability estimates well beyond the point where they could most effectively influence design development. There are similar examples in other disciplines suggesting the need for the following:

- More rapid development of candidate definition information,
- More rapid transfer of definition information to analysis programs,[6] and
- Surrogate definition from previous design efforts similar enough to the intended definition to support at least a rough estimate.

The problem of data availability can be especially challenging when analysis is required to respond to an emergency involving a ship in service.

The NAVSEA engineering community is developing Leading Edge Architecture for Prototyping Systems (LEAPS) as a design product model to address this problem. LEAPS provides unique capabilities not available commercially. Some tools are tightly coupled to LEAPS. Others use LEAPS data via translators. LEAPS serves as somewhat of a Rosetta Stone, capable of accepting configuration/definition information from a variety of sources, such as commercial CAD systems, and transforming them into inputs for analysis programs. LEAPS also provides a seamless mechanism for sharing analytical results between different disciplines. Additionally, LEAPS maintains a trace between definition source information and analysis results based on it—a "pedigree" of analysis results.

LEAPS has yet to be implemented as the core data exchange mechanism for an ongoing design project. This is partially due to system maturity, partially due to less-than-comprehensive coverage of all disciplines, but mostly due to the lack of a NAVSEA-led design effort in recent years.

The CREATE Program is sponsoring further development of LEAPS as part of its Rapid Design Integration/Ships Project aimed at streamlining the Concept Design phase.

Solution Vectors

Clearly, inexperienced ship design organizations, inexperienced ship design engineers, missing or inaccurate analysis software, and missing or late analysis input are introducing substantial uncertainty about the *cost, performance, schedule, and risk* of acquisition alternatives. These root causes are contributing to poor decisions, leading to cost overruns, schedule slips, performance shortfalls, and inadequate and untimely

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[6] The data transfer mechanism most frequently cited in recent surveys is "look and enter"—the designer looks at hard copy products of previous design efforts and keys input data for the next analysis.

response to emerging threats and requirements. Following are eight solution vectors that will tackle the root causes discussed. Figure 5 depicts the relationship of these solution vectors to the root causes, that is, which root causes will be mitigated by which solution vectors.

	Solution Vectors	Root Cause #1 – Inexperienced Ship Design Organizations	Root Cause #2 – Inexperienced Ship Design Engineers	Root Cause #3 – Missing or Inaccurate Analysis Software	Root Cause #4 – Missing or Late Analysis Input
A	National Design Organization	O	O	O	O
B	Development of Design Engineers		O		
C	Mature Interim Design Products	O	O		O
D	Standard Components / Product Standards	O	O		O
E	Design Exercises	O	O		
F	Design Software Demand Signal			O	O
G	Integration and In-fill Software		O	O	O
H	Expedite Data Transfer	O			O

Figure 5. Relationship of Solution Vectors to Root Causes

Solution Vector A—Build and Sustain a National Design Organization (NDO)

The country needs a national organization that is experienced, practiced, and prepared in the organizational art of naval ship design—one able to provide quality *cost, performance, schedule, and risk* estimates for decision makers and one able to provide sound designs swiftly in response to emerging needs.

This organization must be focused on the Navy as its customer and provide an enterprise resource for ship acquisition. Roles of the NDO would include leadership of early stage design, establishment of design and engineering standards, and providing of a focal point for fleet feedback. A robust NDO would naturally pursue the other seven solution vectors identified below. These vectors have value in the absence of an NDO, but there would be significant synergism were they coordinated.

Continuity is the key for an NDO. It must be line funded by a sponsor who is able to annually rise above the program-centric nature of the Navy and the DoD. It must efficiently provide a service needed by all. There is likely to be no increase in net cost compared to the multiple, independent design organizations now being supported by various program offices.

The NDO must be process focused and oriented to continual process improvement. Analysis (NAVSEA, 2008) has revealed that 33% of the combined budget of NAVSEA, PEO Ships, PEO Subs, and PEO Carriers is spent on knowledge work—work intimately related to information development and flow during ships' life cycles. In contrast to extremely sophisticated *product* analysis methodologies applied to the ships themselves, *process* analysis methodologies are rudimentary. Examples abound of duplicate development of information. NAVSEA's Design Tools Roadmap Project (proceeding in fits and starts, due to limited funding) has discovered a number of powerful process analysis tools used in other industries, but virtually unknown within the Navy.

An important product of the NDO would be design process guidelines and documentation. These are important for training staff replacements and as baseline references for continuous process improvement. Currently, little process documentation can be found, and what there is, dates from the 1970s and early 1980s. It can usually only be found in personal collections, rather than in a central repository.

There are various organizational constructs for an NDO.

The top candidate is a government-led organization with support as required from contractors. This option is intrinsically aligned with the Navy's interests and would provide natural channels for fleet feedback. The Navy-wide demand for designs would naturally maintain the experience level of the organization and its staff. This approach would reinstate the successful approach that provided designs for virtually all of today's U.S. Naval force.

A second candidate is an independent Federally Funded Research and Development Center (FFRDC). This organization might enjoy more freedom of action than a government activity and would be buffered somewhat from acquisition politics. Conversely, communication with Navy leadership and the fleet could be more constrained and formal.

A third candidate would be a consortium of shipbuilders and the Navy, with similar advantages and disadvantages as an FFRDC. The many near-death experiences of the National Shipbuilding Research Program (NSRP) have illustrated the vulnerability of this construct to uncertain sponsorship. More of the Board of Directors' time and energy would likely be dedicated to efforts to maintain sponsorship than to providing oversight and direction. The consensus nature of this model would likely result in a less tightly-integrated design approach than the previous candidates.

A fourth candidate is separate design organizations for the two corporations (General Dynamics and Northrop Grumman) controlling the nation's largest shipbuilders. This might provide some competition, while at the same time, ensuring some duplication of effort and expense. There would be demand for fewer designs than for a single NDO, resulting in less experienced organizations and staffs. Fleet feedback and commonality of equipments for the future fleet would be harder to achieve. Additionally, the needs of smaller shipbuilders now producing significant numbers of fleet units would not be served. Lastly, early stage design organizations within the shipbuilders would be subject to continual pressure due to being outside the mainstream business of their respective companies.

Absent a decision in favor of an NDO, Option 4 is the most likely outgrowth of the status quo.

Solution Vector B—Development of Design Engineers

Experienced staff is a key component of any solution to ship acquisition woes. Engineering judgment is the ultimate fallback for *cost, performance, schedule, and risk* estimates in the absence of any more sophisticated methods. It is generally acknowledged that an experienced ship designer with poor tools will provide better *cost, performance, schedule, and risk* estimates than a novice ship designer with sophisticated tools.

As noted in the "root problem" discussion, there are several initiatives oriented toward increasing the supply of STEM workers for the Navy and the DoD. It is important that those individuals with particular aptitude and inclination toward early stage ship design have a "landing pad" (e.g., the NDO), lest they be dispersed to other parts of the DoD or industry and be unavailable to the Navy.

Solution Vector C—Mature Interim Design Products

"Mature interim design products" refers to systems and/or subsystems that have been designed to near-production level of definition and evaluated in detail. Because of this refinement, the *cost, performance, schedule, and risk* of incorporating these interim products into a ship design is much more certain than for an ad-hoc system design developed at a lesser level of definition in the course of early stage design.

Interim design products can be developed for a range of requirements, for example, shipboard electric plants for a range of power levels. Development of mature interim design products provides an excellent training opportunity for engineering staff.

This approach was used in the Mid-term Sealift Technology Development Program's Engine Room Arrangement Modeling (ERAM) project to develop, in advance, and in collaboration with shipbuilders, a range of engine room options that were later incorporated in various Sealift designs (Keane, Fireman, & Billingsley, 2005).

An alternate means of acquiring mature interim design products is to extract them from ships in service. This can be difficult, because they may be "hidden" within proprietary CAD models structured for assembly rather than systems review. Data transfer technology has matured to make this type of extraction and data transfer feasible for cooperating engineering organizations. The effort of separating system information and measuring as-built performance provides an excellent training opportunity and provides very high quality *cost, performance, schedule, and risk* estimates for the interim design product.

A library of mature interim design products would enable faster ship design development in the face of emerging threats or requirements. It would allow us to emulate the 21st century auto industry's ability to quickly configure and bring to market, vehicles engineered to suit particular needs, but comprised largely of previously developed and tested components (engines, brakes, seating, navigation, etc.).

This contrasts with ship standardization, which emulates Henry Ford's one-product-fits-all Model T approach.

Solution Vector D—Standard Components and Product Standards

A number of studies and projects[7] over the years have highlighted the benefits of reducing the proliferation of similar parts in the fleet. The most notable benefit is reducing the substantial logistics cost of maintaining inventory for redundant functions. NSRP's Common Parts Catalog has also identified acquisition cost savings by reducing the number of parts used by various shipbuilders in various new designs.

An ancillary benefit of these commonality efforts is the increased certainty about *cost, performance, schedule, and risk* by using familiar parts in new designs. Existing programs along this vector should be supported and consideration given to opportunities for synergy among them.

Solution Vector E—Design Exercises

Periodically, at least annually, a team should be assigned design of a major interim product or an entire ship as an exercise (just as warriors frequently participate in various exercises). These exercises would have three objectives, as follows:

- Training for individual designers and the design organization,
- Experimentation with new design processes such as set-based design and LEAPS-centered design, and
- Putting design products "on-the-shelf," both to reduce uncertainty in *cost, performance, schedule, and risk* estimates for similar projects, and to allow more rapid response to emerging threats.

Similar exercises are being conducted currently by CISD with the main focus being training and introduction to the naval ship design community for students. To achieve the organizational training goals, these design exercises should be conducted by the NDO, if one is established. If not, they could be conducted by CISD as a more intense version of their present practice.

Solution Vector F—Design Software Demand Signal

As discussed in Root Cause #3—Missing or Inaccurate Analysis Software, ship design software comes from a variety of sources, indeed, from wherever it can be obtained. However, these sources are, in general, not well informed about the needs of the ship design community. Annually, the design community should report the status of design tools currently available. The report should be in consistent terms, year to year, and should address accuracy, verification, user confidence, usability, and range of applicability from the perspective of subject-matter experts and technical warrant holders.

This demand signal would serve several functions, as follows:

- An annual checkup using consistent metrics on the health of ship design software. Are we getting better or getting worse?
- Focus leadership attention on areas where tool defects are contributing to uncertainty regarding *cost, performance, schedule, and risk*.
- Provide a guide for potential sponsors of physical research and software development—yielding an additional criterion for project selection.

[7] For example, the Affordability Through Commonality Program.

Experience has shown that it is initially difficult to formulate such a status report. Once the baseline is in place, however, and the structure, terminology, and metrics are established, the annual updates should not be so onerous.

Ideally, the demand signal would be formulated by the NDO. If not, it could be assembled by an independent consultant or other third party.

Solution Vector G—Integration and In-Fill Software

As discussed in Root Cause #3—Missing or Inaccurate Analysis Software, sources such as COTS, ONR, ship acquisition programs, and CREATE provide significant software to the ship design community. However, there is a need for architectural leadership, definition software, and software interfaces to permit the collection of available software to function as an integrated design system. Additionally, there is a need to provide "infill" funding for critical software (e.g., weight engineering) that does not have the glamour or program-specific focus to attract sponsorship from the sources mentioned above.

Based on comprehensive estimates from the 1990s, adjusted for inflation, the annual requirement is for about $25 million to address these needs with a coordinated approach. It is not known how much is currently being spent to address these needs in ad-hoc, program-specific efforts.

Integration of tools directly bears on the issue of streamlining knowledge work—work intimately related to information development and flow during ships' life cycles. As noted earlier, approximately 33% (perhaps $10 billion) of the combined budget of NAVSEA, PEO Ships, PEO Subs, and PEO Carriers is spent on knowledge work.

Provision of these design tools permits more rapid development of design options, addressing the Root Causes of "Missing or Late Analysis Inputs" and "Missing or Inaccurate Analysis Software," and providing better *cost, performance, schedule, and risk* estimates for decision makers. Additionally, streamlining design processes, better tools, and better integration reduce the numbers of experienced staff required to complete design development. Lastly, the more rapid feedback provided by efficient design tools will speed the maturation of inexperienced staff.

Pursuing this vector would be an intrinsic activity of an NDO. If an NDO does not exist, then a consortium is the preferred approach (Transportation Research Board, 2002) to fulfilling this need.

Solution Vector H—Expedite Data Transfer

This solution vector has two parts:

- Implement data transfer standards that have been developed for ship definition, and
- Develop data transfer capability for information relating to operating plans, production plans, and support plans.

As discussed previously, ship design engineers have been primarily concerned with definition and analysis, and with systems and software to facilitate these processes. The Navy and the shipbuilding community have developed implementable standards[8] and

[8] ISO 10303 Standard for the Exchange of Product Model Data/Shipbuilding Application Protocols.

contract requirements[9] to achieve interoperability of definition data across programs, between organizations, and across time (archiving and retrieval). The shipbuilders believe the implementation of NPDI will lower costs, improve design-build cycle time, and reduce the cost of changes. Navy leadership needs to ensure that NPDI specifications are incorporated into acquisition specifications for all future ships.

However, there are more factors impacting the *cost, performance, schedule, and risk* of a ship than its physical configuration (definition). The way it is operated, the way it is manufactured and assembled, and the way it is supported in service can all affect *cost, performance, schedule, and risk* without a change to the physical product. Figure 6 illustrates the categories of knowledge work, information, and software involved in ship development and service life support.

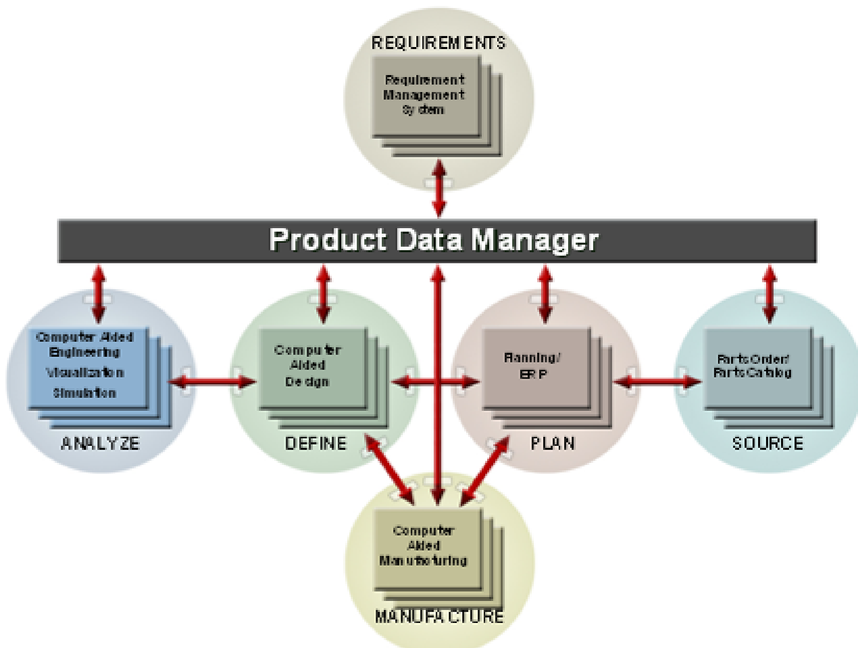

Figure 6. Categories of Knowledge Work, Information and Software for Ship Development, Construction, and Service-Life Support

The Navy and the industry initially focused on the capability to transfer DEFINITION information. Having developed content standards, format standards, acquisition policy, and contract terms, complete success is at hand.

By contrast, information about operational plans, production plans, and support plans are inferred, perhaps inconsistently, when developing *cost, performance, schedule, and risk* estimates. No means of sharing this information in computer-sensible form is available. The Navy and the industry need to focus on developing the capability to transfer PLANNING information with equal facility as DEFINITION information.

[9] NSRP/Navy Product Data Initiative (NPDI)—Integrated Product Data Environment (IPDE) Specification, June 30, 2008.

Conclusion

Proposals to improve ship design capability, as an end unto itself, have not gained much traction with senior Navy leadership. The issues are complex and improvements can be hard and expensive to obtain. However, if these same proposals are viewed in the context of critical ship acquisition decisions impacting the nation's security and committing billions of dollars, then reducing uncertainty about the *cost, performance, schedule, and risk* of alternatives seems very worthwhile indeed. Quality engineering may be expensive, but mistakes in ship acquisition are horrifically expensive (and may not be recoverable).

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Back to the Future: The Department of Defense Looks Back at the Should Cost Review to Save Buying Power in the Future

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Abstract

In September 2010 the Under Secretary of Defense (Acquisition, Technology, & Logistics[AT&L]), Dr. Ashton Carter, delivered a mandate for improved productivity and efficiencies to achieve better buying power with the $400 billion the Department of Defense (DoD) spends each year on goods and services. Dr. Carter directed a "Should Cost" be determined, in addition to the statutorily required Independent Cost Estimate (ICE). This paper will discuss the processes employed, with a focus on lessons learned and best practices identified, during the Secretary of the Air Force–directed Evolved Expendable Launch Vehicle (EELV) Should Cost Review (SCR). Conducted to address escalating contract prices and better inform contract negotiations, the EELV SCR was the first on an MDAP since the C-17 in 1995. Since there was little documentation on the SCR process and a dearth of experienced persons, the EELV SCR Team "wrote the book" as they worked their way through the process.

Actual outcomes will be discussed in a general nature, since specifics are not yet releasable as they contain proprietary and negotiation sensitive information.

Introduction

Is the latest mandate for greater affordability, productivity, and efficiencies in DoD acquisition processes more rhetoric to appease Congress and the American public? Initially, for many in the Defense Acquisition Workforce (DAW), the call by the Under Secretary of Defense for Acquisition, Logistics, and Technology (USD[AT&L]), Dr. Aston Carter, to "do more without more" sounded like the broken record so often heard as we make repeated attempts at acquisition reform. As greater definition of the expectations and the processes to be applied in achieving these initiatives is detailed to the DAW, confidence increases that real change is afoot. The FAR-based EELV SCR is well aligned with these initiatives and an outstanding example of action oriented implementation.

The conduct of an SCR is not a novel idea; in fact, they were very popular in the 80s and early 90s. However, the most recent one on a Major Defense Acquisition Program (MDAP) was the one completed in 1995 on the C-17, and over time, documentation and experienced persons dwindled. The EELV SCR team, leveraging what information they could find through research, embarked on a seven-month, $6 million journey to satisfy Secretary of the Air Force tasking. The outcomes of this review, as noted in Figure 1, both in terms of potential savings to the EELV program and broadened knowledge of the SCR process, indicate it was well worth conducting.

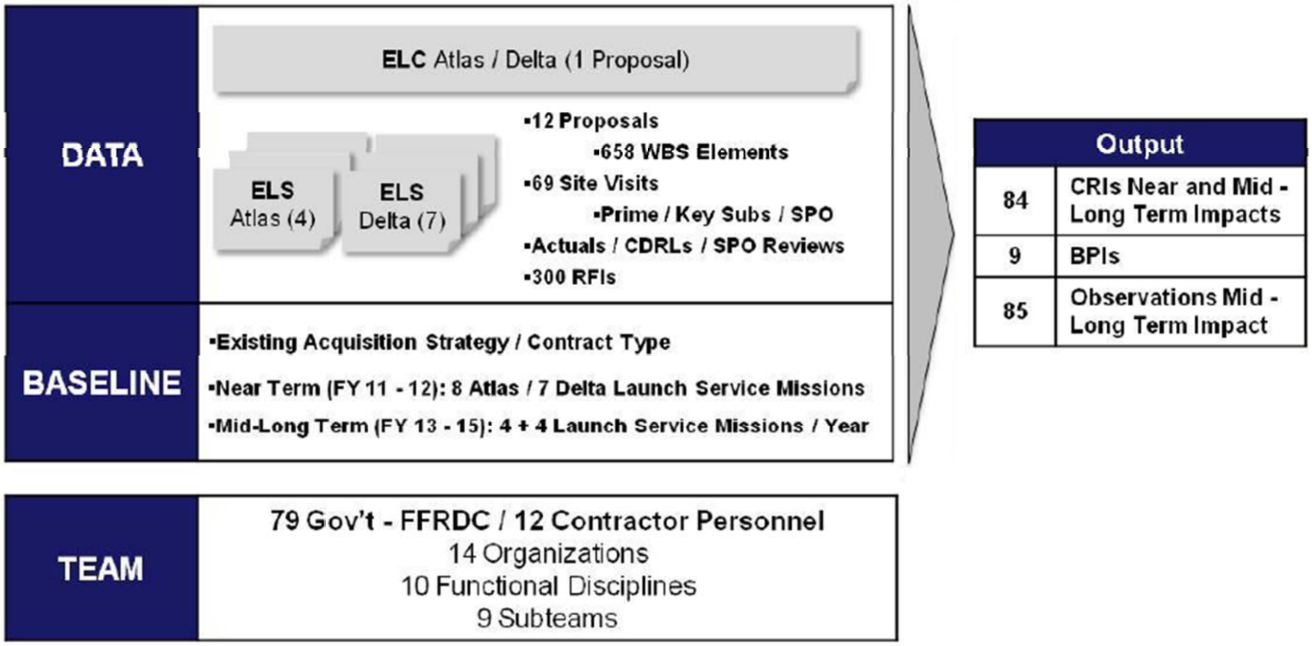

Figure 1

Affordability: The New Imperative

President Obama (2009) stated, "We can no longer afford to spend as if deficits don't matter and waste is not our problem." Secretary of Defense Robert Gates followed this up with his own words:

> To sustain necessary investment levels…we must significantly improve the effectiveness and efficiency of our business operations. Doing so will increase funding…for our mission functions from savings in overhead, support, and non-mission areas.
>
> First, is this [DoD inefficiency] respectful of the American taxpayer at a time of economic and fiscal duress? And second, is this activity or arrangement the best use of limited dollars given the pressing needs to take care of our people, win the wars we are in, and invest in the capabilities necessary to deal with the most likely and lethal future threats? (DoD, 2010)

The intent was not to reduce the DoD's budget top line, but to realize $100 billion in savings over the next five years that could be reinvested to recapitalize aging weapons systems, or fund additional process improvements to yield further savings. The emphasis is on improving efficiency and reducing costs in the contracting arena in order to get better buying power in goods and services.

Fully supportive of the Secretary, Dr. Carter (2010a) outlined five areas and 23 specific initiatives, by way of implementing his September 14, 2010, memorandum to acquisition professionals, *Better Buying Power: Guidance for Obtaining Greater Efficiency and Productivity in Defense Spending*. The five areas specifically outlined in Dr. Carter's guidance are as follows:

- Target Affordability and Control Cost Growth,

- Incentivize Productivity and Innovation in Industry,
- Promote Real Competition,
- Improve Tradecraft in Services Acquisition, and
- Reduce Non-productive Processes and Bureaucracy.

Whether we look to improve the “back-end” to front-end ratio in acquisition, increase our “bang for the buck” in production, or convert overhead to warfighter readiness, the DoD, enabled by Congress, needs to modify “business as usual” and institutionalize a culture of savings.

Included under the first area are five specific initiatives, one of which is to drive productivity growth through Will-Cost/Should-Cost management. Dr. Carter (2010a) detailed this initiative:

> During contract negotiation and program execution, our managers should be driving productivity improvement in their programs. They should be scrutinizing every element of program cost, assessing whether each element can be reduced relative to the year before, challenging learning curves, dissecting overheads and indirect costs, and targeting cost reduction with profit incentive—in short, executing to what the program *should cost.*
>
> The Department's decision makers and Congress use independent cost estimates (ICE)—forecasts of what a program will cost based upon reasonable extrapolations from historical experience—to support budgeting and programming. While ICE Will-Cost analysis is valuable and credible, it does not help the program manager to drive leanness into the program. In fact, just the opposite can occur: the ICE, reflecting business-as-usual management in past programs, becomes a self-fulfilling prophesy. The forecast budget is expected, even required, to be fully obligated and expended.
>
> To interrupt this vicious cycle and give program managers and contracting officers and their industry counterparts a tool to drive productivity improvement into programs, I will require the manager of each major program to conduct a Should-Cost analysis justifying each element of program cost and showing how it is improving year by year or meeting other relevant benchmarks or value. Meanwhile, the Department will continue to set the program budget baseline using an ICE. (Carter, 2010a)

After years of exhortations to the acquisition workforce to do a better job of buying our weapons systems and multiple attempts at acquisition reform, this is something new. A push to identification and reporting of two costs is a fundamental shift in the way we perceive things and manage our budgets. The will-cost figure now essentially shifts from being a floor, from which actual cost would rise, to being a ceiling, from which actual cost is expected to come in under. An Office of the Secretary of Defense (OSD) working group is drafting additional guidance to explain the difference between Should Cost/Will Cost management and a full blown FAR-based SCR to prevent program offices from embarking on unnecessary efforts. The should-cost management baseline is the program execution baseline, and as such, differs from the contract level should cost as defined in the FAR. The program level should-cost estimate is based on realistic technical and schedule baselines and assumes success oriented outcomes from the implementation of efficiencies, lessons learned, and best practices with a level of margin considered for successful program execution.

The should-cost estimate is developed by the program office through one of three approaches. The first is to use the will-cost estimate as a baseline and identify discrete, measurable near-term and long-term initiatives for savings against that base. The second method is a bottoms-up approach detailing items from a program level. The third approach is to conduct a FAR-based SCR. The third approach is the avenue the Air Force took in directing the EELV SCR.

Figure 2

Why a FAR-Based Should Cost Review?

The Secretary of the Air Force (SECAF; 2010) tasked the Director of the National Reconnaissance Office (DNRO) and the Commander of Air Force Space Command (AFSPC/CC) to conduct an SCR per FAR 15.407-4 (2005). The application of the FAR-based SCR process to the EELV program was not just about putting checks in the block. There is no question as to the success of the EELV program, in terms of its ability to provide outstanding support to the DoD’s commitment to assured access to space. It has delivered 35 successful launches, placing critical national security space payloads into orbit. Unfortunately, the program also faces the following significant challenges: projected price increases ranging from 30–60%, supplier readiness concerns, and unresolved Defense Contract Audit Agency (DCAA) audit issues. The actual and projected contract price growth, coupled with questioned price reasonableness, was cause for interest from the Air Force, the OSD, and Congress. The stated goals of the SCR were as follows:

- Establish an authoritative baseline for current launch capacity and requirements,
- Identify programmatic requirements specifically for EELV, and
- Determine the most probable EELV costs and the factors affecting EELV costs/availability.

Subsequent to the SECAF letter, the DNRO and the AFSPC/CC (2010) issued a joint Terms of Reference (TOR) with four SCR objectives and eight desired outcomes. The TOR stated objectives were as follows:

- Identify lowest executable most probable cost, without adversely impacting mission success;

- Promote short- and long-range economy and efficiency improvements;
- Provide recommendations with cost quantification for negotiation objectives; and
- Enable "bottom up" cost baseline, provide program cost transparency and credibility, support launch vehicle and launch capability negotiation positions, enable contractor operations insight, and assist in justifying future funding requirements.

The TOR desired outcomes included the following:

- Evaluate economy and efficiency of contractor operations to reduce costs;
- Baseline program for affordability—determine accurate, verifiable program costs;
- Obtain "in-process" buy-in from the DoD and the Director of National Intelligence (DNI) cost communities;
- Document supplier base/readiness issues and cost projections;
- Support government's FY2011/2012 ELS and ELC negotiation positions; and
- Provide additional FY2012 POM justification.

The FAR section 15.407-4 describes a should-cost review as follows:

> Should-cost reviews are a specialized form of cost analysis. Should-cost reviews differ from traditional evaluation methods because they do not assume that a contractor's historical costs reflect efficient and economical operation. Instead, these reviews evaluate the economy and efficiency of the contractor's existing work force, methods, materials, equipment, real property, operating systems, and management. These reviews are accomplished by a multi-functional team of Government contracting, contract administration, pricing, audit, and engineering representatives. The objective of should-cost reviews is to promote both short and long-range improvements in the contractor's economy and efficiency in order to reduce the cost of performance of Government contracts. In addition, by providing rationale for any recommendations and quantifying their impact on cost, the Government will be better able to develop realistic objectives for negotiation (FAR, 2005).

The FAR further categorizes SCRs into two types: Program SCR and Overhead SCR, which can be performed together or independently. These reviews are scalable and can range from comprehensive (the contractor's entire operation, to include major subcontractors) to focused (targeting specific areas of the contractor's operation). A Program SCR looks at "significant" elements of direct costs, such as material and labor, and associated indirect costs, as they relate to major production efforts. An Overhead SCR focuses on indirect costs (i.e., general and administrative activities, taxes, infrastructure and security, fringe benefits, and shipping and receiving) and normally includes a Forward Pricing Rate Agreement (FPRA) evaluation. The EELV Program met all the criteria for both types of SCR as described in Table 1.

Table 1

Program Should Cost Review	Overhead Should Cost Review
▪ Some initial production has already taken place ▪ The contract will be awarded on a sole source basis ▪ There are future year production requirements for substantial quantities of like items ▪ The items being acquired have a history of increasing costs ▪ The work is sufficiently defined to permit an effective analysis, and major changes are unlikely ▪ Sufficient time is available to plan and adequately conduct the should-cost review ▪ Personnel with the required skills are available or can be assigned for the duration of the should-cost review	▪ Dollar amount of Government business (DFAR—Projected annual sales to DoD exceed $1 billion) ▪ Level of Government participation (DFAR—Projected DoD versus total business exceeds 30%) ▪ Level of noncompetitive Government contracts (DFAR—Level of sole-source DoD contracts is high) ▪ Volume of proposal activity (DFAR—Significant volume of proposal activity anticipated) ▪ Major system or program (DFAR—Production or development of a major weapon system or program is anticipated) ▪ Corporate reorganizations, mergers, acquisitions, or takeovers ▪ Other conditions (e.g., changes in accounting systems, management, or business activity)

EELV Background

As noted in the EELV Final Report (2010), in 1998, the Air Force awarded cost sharing development and commercial launch service contracts to Lockheed Martin and Boeing. It was believed at the time that the commercial satellite forecast would drive a significant demand for launch services. The expected volume allowed the government to obtain contracts at a significantly lower cost than previously experienced. The commercial market boom never materialized, rendering the assumptions for the business case moot. This left Lockheed Martin and Boeing in a very difficult financial position relative to the contracts, and left the government as the primary, and practically only, customer. The small volume undercut any reasonable belief that two companies could survive, let alone have sustainable competition. As a result, in 2005, the two providers proposed combining their launch services resources and forming United Launch Alliance (ULA) as a joint venture. In 2006 the formation of ULA was approved, and the government's business and contracting approach was adjusted to fit this "sole source" construct. Today the agreements are structured to accommodate up to four Atlas and four Delta launches per year. This is done through two types of contracts. There is an EELV Launch Capability (ELC) Cost-Plus Award Fee contract covering all launch related costs such as systems engineering, program management, mission integration/assurance, supplier readiness, transportation, and launch operations and base support. There is also an EELV Launch Services (ELS) Firm Fixed Price contract to pay for flight hardware, factory touch labor, materials, quality inspections, and tools for each of the Atlas or Delta rockets on a mission-by-mission basis. There are significant supply chains associated with both contracts.

The following is stated in the EELV SCR Concept of Operations (2010):

> The overall objective of the SCR will be to promote both short and long-range improvements in the contractor's economy and efficiency to assess affordability and reduce the cost of performance. The improvements must not have an adverse impact on mission success and meeting ORD requirements. In addition, by providing rationale for any recommendations and quantifying their impact on cost, the government will be better able to develop realistic objectives for negotiation. This SCR will provide desired outcomes to enable a defensible "bottom up" cost baseline, provide program cost transparency and credibility, support launch vehicle and launch capability negotiation positions, enable insight into contractor operations, and assist in justifying future funding requirements.

Team Structure

In his letter, the SECAF (2010) named Mr. Ron Poussard, the Director of Air Force Office of Small Business Programs, to be the Director of the EELV SCR. The SCR Director was faced with the difficult task of building a team possessed with the unique skills necessary to conduct an SCR, the likes of which had not been conducted in over fifteen years. He first went to the primary stakeholders, which consisted of the Air Force Space Command, NRO, NASA, and Defense Contract Management Agency (DCMA), as resource pools, and got a significant portion of his manning from them. Recognizing there were still some skill/knowledge gaps, he then looked to alternative sources of expertise and filled his specific personnel needs through the Navy Price Fighter$, the Federally Funded Research and Development Center (FFRDCs), contractor support, and the Defense Acquisition University (DAU). The requisite team attributes spanned knowledge and experience in the following: acquisition, contracting, aerospace engineering, software, cost analysis, manufacturing and industrial engineering, process improvement, and supply chain management. Conspicuously absent from much of the EELV SCR was the EELV Program Office itself. The program office participation was primarily seen during the review of initiatives and drafting of the final report. While they were not active participants on any of the teams, they did respond to queries from the teams.

As can be seen in Figure 3, which shows the represented organizations, this was a multi-agency, multi-service, multi-functional team.

Figure 3

The EELV SCR Team was comprised of three teams organized to allow for focus on commodities/functions and ensure both types of FAR-based SCRs were complete. There were ELC and ELS Teams to address the processes associated with these products and services, and further sub-divided to allow for concentration on the larger cost centers. The Overhead Team was chartered to investigate and analyze cost elements for indirect rate pools and the base used as a foundation for the rates. Each team documented unique processes and identified the specific CRIs, Business Process Initiatives (BPI), Observations, and Recommendations. Given the complexity of the contracts and the interdependent nature of the teams, it was realized there was a need for an overarching, integrated view, thus the Integration Group. This structure is laid out in Figure 4.

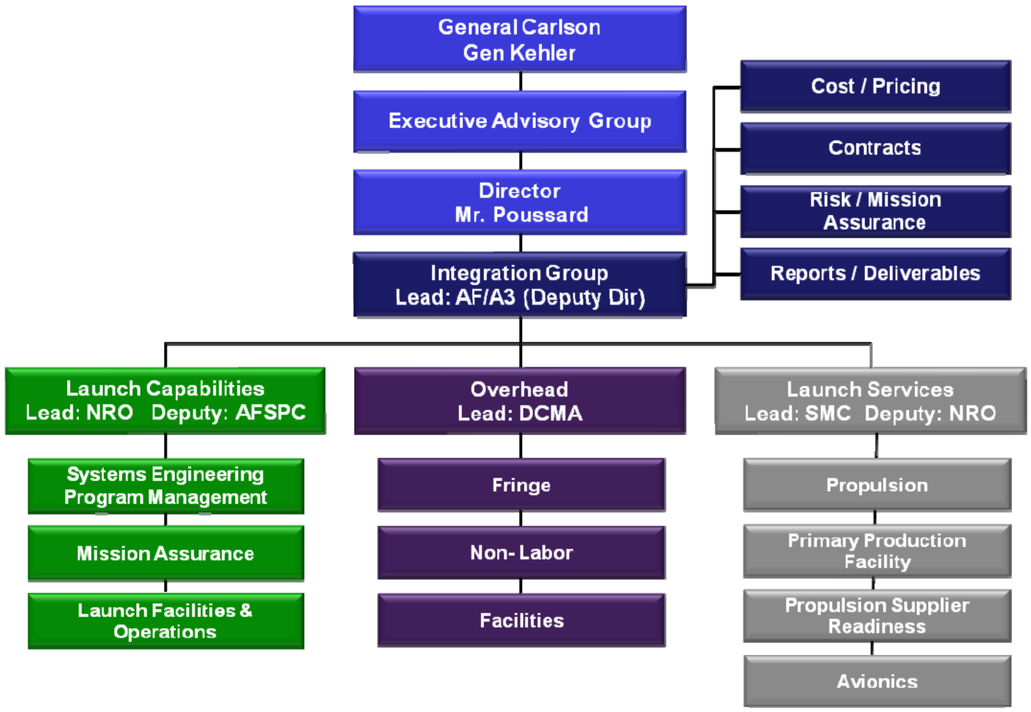

Figure 4

The EELV SCR Methodology

As stated in their charter, the Vision for the team was as follows:

> The SCR Team will identify realistic initiatives that can be implemented by the EELV System Program Office (SPO), United Launch Alliance (ULA), and/or subcontractors to affect increased efficiency and lower costs without adversely impacting EELV mission success. We will do this by operating with transparency, credibility, and integrity with participation of all stakeholders, in an open, collaborative environment.

In order to achieve this vision, elements of the SCR Team paid numerous site visits to the EELV contractor, subcontractors, and SPO facilities to gather facts relevant to technical, management, and manufacturing processes. Standardized Requests for Information (RFIs), checklists, and interview guides were used for data collection. Focus areas for data collection were determined through the application of the Pareto Principle to work breakdown structure (WBS) elements sorted by associated cost. The data/information was assessed to develop potential cost reduction initiatives (CRI). Proposed CRIs were then run through a risk analysis and assessed by the Integration Group. Validated CRIs were then applied to the model to determine cost savings impact.

The EELV SCR was stood up in March 2010, with the senior leadership reviewing two documents for basic information and framework development: the 1972 Army Materiel Command pamphlet on Procurement Should-Cost Analysis and the 1995 documentation/reports from the C-17 SCR. Leveraging this information, they set about building the plan for the EELV SCR. They settled on the phased approach, depicted in Figure 5, to conduct the SCR, with the first four phases being completed by the team, and the fifth phase then being under the purview of the program office and their senior leadership.

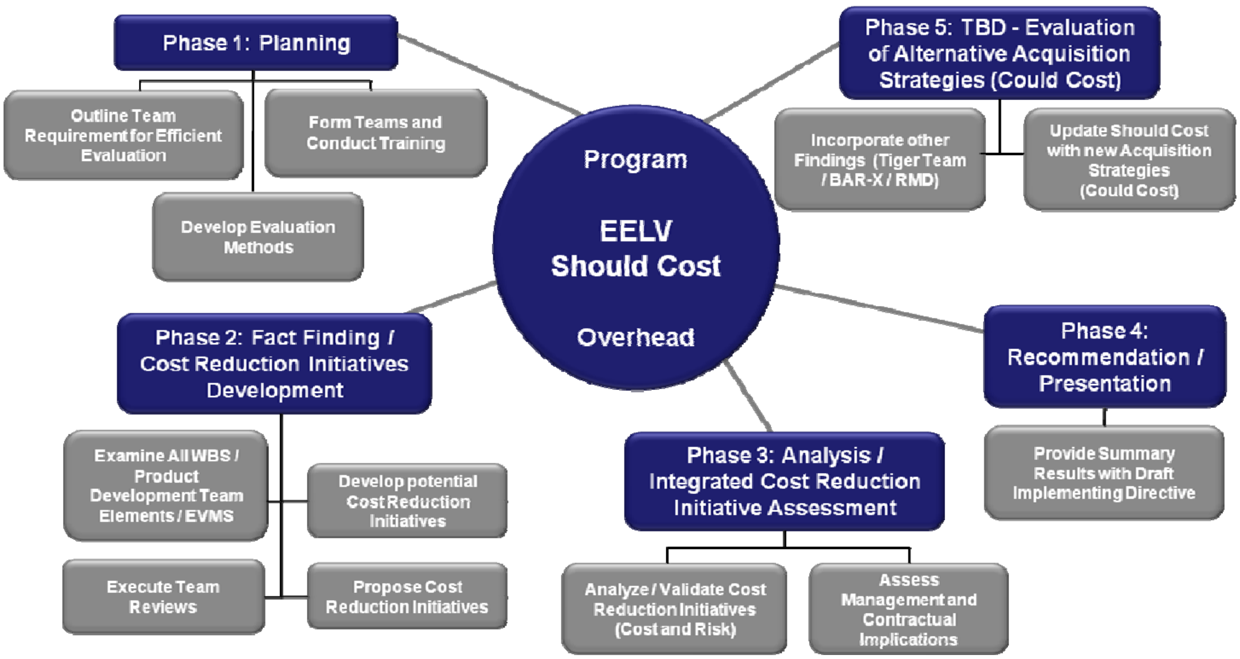

Figure 5

Phase 1 included orientation training and organizational set-up. Again, with little to no SCR experience readily available, the first few weeks were spent coming to terms with just how to proceed. Once the indoctrination training was complete, the team started about the business of developing and refining processes, while filling out the manning. There were several comments made in the EELV SCR Participant Survey indicating difficulties at the start, and most attributed that to a lack of established processes and prior knowledge. Representative of the comments is the following: “Problems with startup were due mainly to the fact that a process, along with supporting tools and procedures, was not already in place or well understood.” This phase was intended to prepare the teams to actually conduct the SCR, but in certain aspects it fell short. This will be discussed in greater detail in the Lessons Learned section.

Phase 2 was dedicated to data/information gathering and drafting Cost Reduction Initiatives (CRIs). Data was collected in a number of different ways: review of audits, proposals, and program office documentation; formal Requests for Information (RFIs); and interviews. During the data collection, several issues surfaced, some of which were foretold in the AMC Pamphlet: "All team members should be unemotionally critical of the contractor and his operation. If the team member is not, then the chances are he will accept superficial justifications and explanations when deeper analysis is warranted." Several team members noted in their survey responses that they observed this occurring. Another common issue noted in the surveys was that team members were not sure what the expectations were, relative to CRI content and subjects. The Phase 2 steps are shown in the top half of Figure 6.

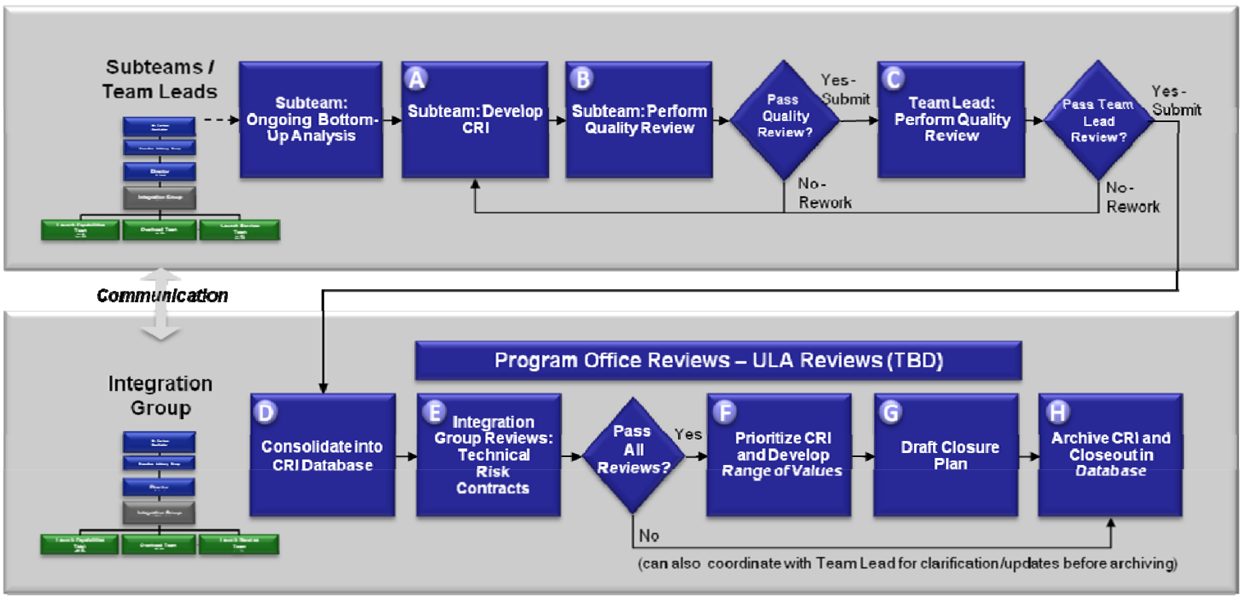

Figure 6

Phase 3 is where the Integration Group assessed risk for each CRI, identified cost savings and investment requirements estimates, and assessed contractual implications. The teams/sub-teams presented information on CRIs, BPIs, and Observations to the Integration group, who then made the final Recommendations regarding disposition of each CRI, BPI, and Observation across all teams and sub-teams. Risk was analyzed in three areas which were rolled up into a single weighted composite score. The three risks identified in the EELV SCR Final Report were the following:

- Technical Performance Risk: Risk of degradation to mission technical performance due to implementation of the CRI;
- Cost Risk: Risk that the net proposed cost savings/avoidance will not be realized; and
- Schedule Risk: Risk to baseline production schedule, launch manifest, or individual mission(s) schedule caused by the implementation of the CRI.

Each CRI, BPI, and Observation was also reviewed to determine any contractual implications. Finally, the Cost Team applied the investment and cost savings data to the cost baseline. Phase 3 activities are depicted in the bottom half of Figure 6.

Phase 4 is where the efforts came together in the form of a detailed report with drill-down data for each of the reviewed CRIs, BPIs, and Observations. The report was published in three volumes: Volume 1 is top-level SCR summary information and contains a list of CRIs and Observations. Volume 2 contains reports from each of the teams, detail data on the CRIs, as noted in Figure 7, and Lessons Learned/Best Practices. Volume 3 is a collection of all the material used to inform the SCR Teams'/Sub-Teams' efforts. As depicted in Figure 7, once each CRI was validated through a rigorous fact-based review and analysis, it was posted to the cost baseline application, and a standardized quad chart was developed. These two documents serve two purposes, an audit trail to document the outputs of the EELV SCR Team and the inputs for the SPO in developing their implementation plan, which is then a part of Phase 5.

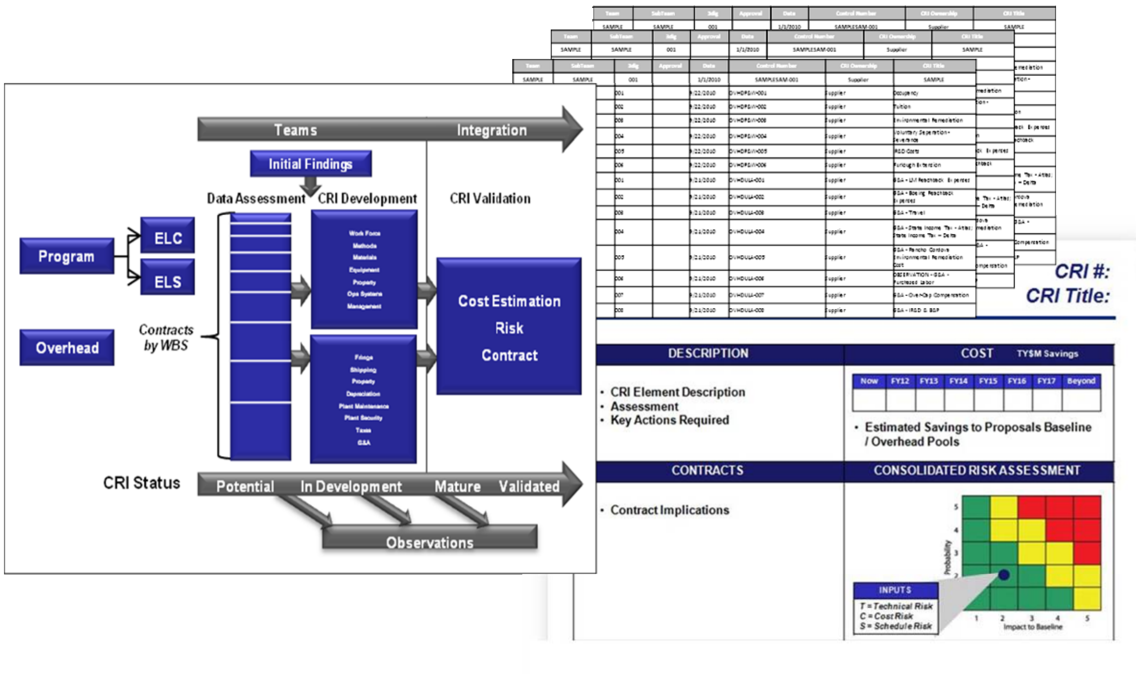

Figure 7

Cost Model

Integral to the success of the SCR was the establishment of a Cost/Pricing model. The model served two primary purposes, to establish the baseline as documented from proposals, and to serve as an easy-to-use application to evaluate the impact of CRIs. Built by the Cost/Price Team (heavily flavored with folks from the Navy Price Fighters), the cost application for the EELV SCR had models for both the ELC and ELS Teams. This allowed for insight into the major cost elements (labor, material, and overhead), such that the teams/sub-teams and Integration Group could investigate, analyze, and project CRI savings. Using the models, a Pareto Analysis was easy to conduct, and proved out, with 80% of the costs coming from about 20% of the cost drivers. This served as a starting point for investigation and analysis, but was not exclusionary, as any lower cost items with a potential for future significant impact to the program (i.e., some specific Avionics items) were also investigated. The added benefit of the models is their continued applicability after the SCR, by the EELV SPO. Robust and flexible, these models served the purpose of the SCR Team in establishing individual/overall impacts of the CRIs, but will also allow for the SPO to establish new baselines, as they can easily add/delete source data; and analysis of future cost savings initiatives and their impact can be determined, as applied to the new baseline. The top-level flow of cost data is shown in Figure 8.

As described in the EELV Final Report, Volume 2, the Cost Models had features that made them truly invaluable in estimating impacts of the CRIs to the baseline. As described in the report itself, these features include the following:

> *CRI On/Off*
>
> The model was designed to be able to turn each CRI on and off. This allows the user the capability to run any scenario of CRIs desirable. If all CRIs are off, the price is equal to the baseline. If all CRIs are on, the price is at the SCR value with all CRI reductions.
>
> *CRI Interaction*
>
> As multiple CRIs were entered into the model, it was imperative that the cost team was able to accurately portray the savings associated with each CRI without accounting for the same savings more than once. The detailed inputs into the model ensured that the SCR team did not double count any savings.
>
> *Escalation Adjustments*
>
> The model allows for escalation adjustments to each task within the ELC and ELS models. Each IDN (Identification Number that represents a specific Basis of Estimate [BOE] task from a proposal) can be assigned a separate index for material and labor. A composite rate is then developed and applied to the task. NRO CAIG Composite rates are used to escalate both the baseline and SCR values.
>
> *Instant Manifest Changes*
>
> The flexibility of the ELS model is unparalleled in its ability to show the prices across the many variants for the EELV program. The model allows for the capability to change configurations and mission unique aspects of launches. (USAF, 2010)

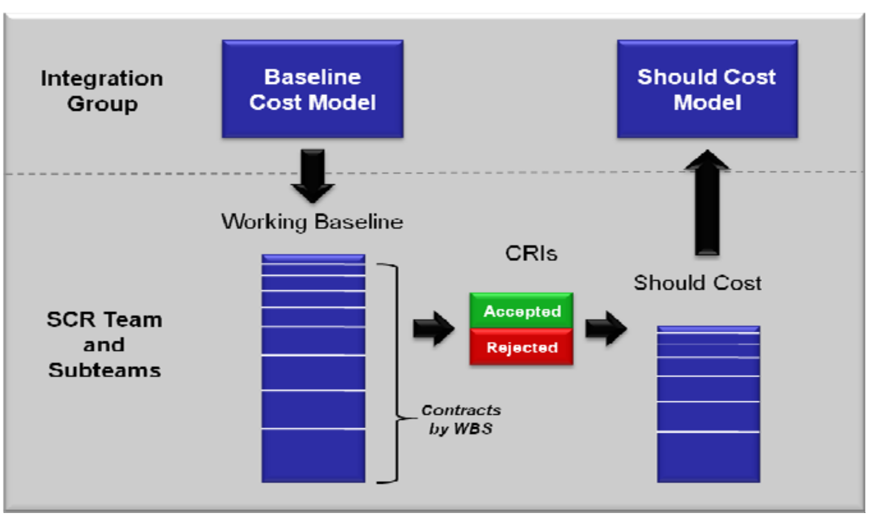

Figure 8

The CRIs were the focus of the effort. The teams did an outstanding job of identifying discrete initiatives, some of which fall into the "low hanging fruit" category. They also identified some broader ranging, more difficult to define initiatives, which bear further investigation and may yield tremendous efficiencies in management of the program and execution. The discrete initiatives have been well researched, and the SPO can make a determination as to whether they will implement or leverage as part of a better informed contract negotiation process. The initiatives that indicate systemic issues may be at the starting point for drill-down study and application of a continuous process improvement (CPI) methodology, such as Lean/Six Sigma or Air Force Smart Operations 21st Century (AFSO21).

Aligned With Continuous Process Improvement Efforts

As one continues to see more and more documentation surface on Should-Cost/Will-Cost management, the linkage to CPI becomes even more evident. As an observer/participant for much of the EELV SCR, it was obvious to me there was a natural connection between the SCR effort and Lean, along with the standard Six Sigma improvement model of Define, Measure, Analyze, Improve, and Control (DMAIC; see Figure 9). As Dr. Carter stated (2010), "The metric of success for Should Cost management leading to annual productivity increases is annual savings of a few percent from all our ongoing contracted activities as they execute to a lower figure than budgeted. Industry can succeed in this environment because we will tie better performance to higher profit, and because affordable programs will not face cancellation." This is in accord with what Harry Mikel (2000) wrote on Six Sigma: "In the past, quality programs adopted by corporations focused on meeting the customer's needs at virtually any cost; many companies, despite poor internal processes, manage to produce high-quality goods and services." He goes on to explain the cost of quality can be reduced by focusing on defect prevention, not just in the product line, but in the supporting processes, which is where many of the issues were discovered in the EELV program and may be indicated in other DoD acquisition programs.

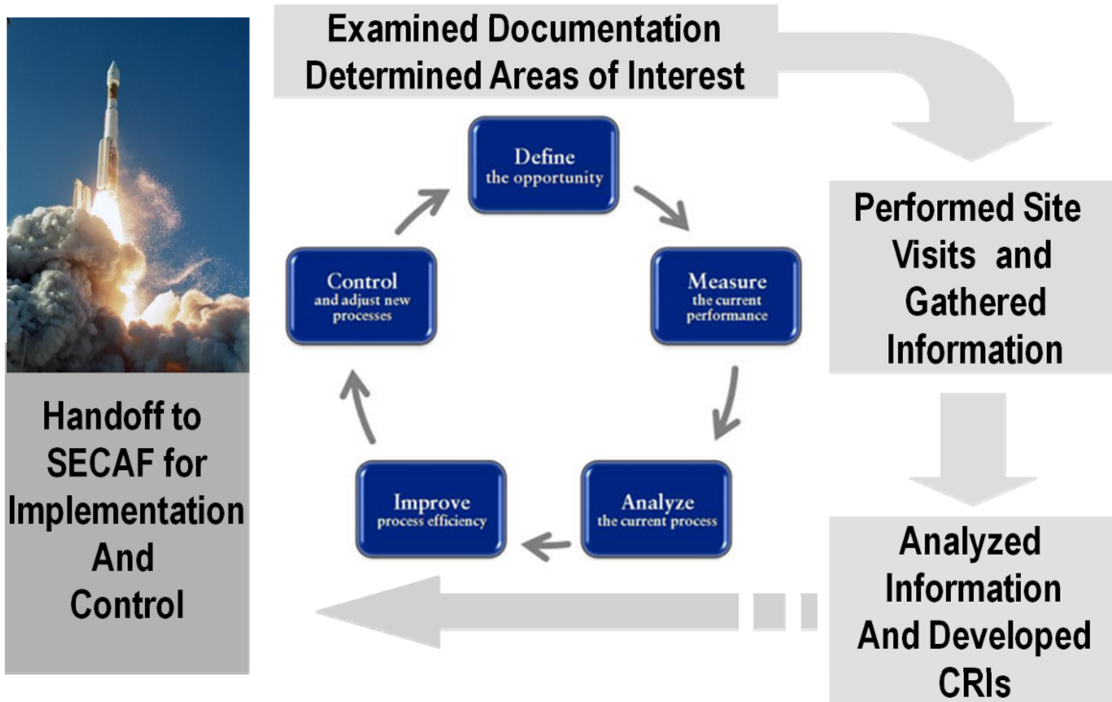

Figure 9

Ron Poussard (2010) further echoed similar words in the EELV SCR Final Report, as follows:

> Although ULA is motivated to successfully deliver satellites on orbit, the company is not motivated to do so in a cost efficient manner. Similarly, under the current acquisition strategy and contract structure, ULA is not motivated or incentivized to either reduce costs or increase the government's visibility into costs. ULA's inefficiencies combined with propulsion and other key subsystem cost increases will have a cumulative cost impact for the foreseeable future.

As SPOs move forward in Should-Cost/Will-Cost management, and if tasked with an actual SCR, they should consider ensuring they have persons trained and experienced in the application of CPI methodologies available to facilitate the efforts and provide counsel/guidance to the leadership responsible for the effort.

Best Practices and Lessons Learned

Recognizing this was the first major SCR since the C-17 in 1995, there was a dearth of available documentation and experience to draw on; understanding there would be at least a handful of SCRs to be conducted over the next couple of years, Ron Poussard chartered the Defense Acquisition University (DAU) to capture the processes and tools. As part of that effort, DAU team members identified and collected a significant number of best practices and lessons learned through three venues: sub-teams inputs, observations, and an SCR participant survey.

Best Practices

Team members were encouraged to identify which practices and procedures worked well during the SCR. It was often heard amongst the teams, “We are writing the book as we go,” giving them pride in ownership as they established a baseline of solid processes for future SCRs. The following are best practices based on the experience of the SCR Team members and the observations of DAU participants.

Team Charters

Team charters are essential to the decomposition of the Direction and Terms of Reference documents, to ensure key tenets are communicated and executed. They translate desired outcomes into specific objectives providing specifics relative to boundaries, schedule, resources, and goals. The charters also ensure the organizational structure, including the various teams and sub-teams, is clearly delineated, with identified roles and responsibilities.

Manning the Team(s)

The importance of selecting the right people to lead, participate in, and administer the effort cannot be understated. The AMC Should-Cost Analysis Pamphlet (AMC, 1972) supported this and added the following quote from a former team chief: “I sincerely believe that our team could have done a better job with only half the people we had, provided that we had known in advance which half to start with.”

The team must be multi-disciplinary and multi-functional, with representation from the requirements community, Service Headquarters and Acquisition Authority, and the Office of the Secretary of Defense (OSD) Agencies, to include Defense Contract Management Agency (DCMA) and Defense Contract Audit Agency (DCAA). One particular group that should be leveraged is the Navy Price Fighter$, who were invaluable in developing a working cost model to capture and analyze cost data and savings implications, as previously discussed.

The use of contractors and Federally Funded Research and Development Center (FFRDC) personnel can ensure expertise in specialized areas. At the other end of the spectrum, assigning interns to the various teams provides two big benefits: a fresh set of eyes to long-standing issues; and development of a larger pool of personnel with SCR experience. The interns also benefit with broadened professional development.

In addition to overhead and program based teams and sub-teams, establishing an Integration Group to cover cross-cutting functions (i.e., contracts and risk management) is critical to the success of the SCR as discussed previously.

Just-in-Time (JIT) Training

The use of initial training, to frame the effort and present it in the context of benefits, provides motivation and a common focus for the SCR membership. The teams were successful during site visits and Cost Reduction Initiative (CRI)/Observation generation meetings, using timely relevant training on data-gathering and analysis tools. JIT training on the use of the CRI form and database, and the cost model and baseline allowed for timely understanding of these tools and their uses. Facilitators/trainers knowledgeable on process improvement tools are ideally suited for this purpose.

Dedicated Central Operating Site

A dedicated central site to conduct team operations afforded numerous benefits, not the least of which was the development of esprit-de-corp. Team members were off-site from their regularly assigned work, allowing them to focus on the task at hand and be insulated from outside influences and distractions. This central location encouraged face-to-face discussions and interactions, while fostering synergism and collaboration across teams and sub-teams. The associated costs of a dedicated SCR work site is somewhat obviated if there is greater involvement by the SPO, and they have facilities that can be used for the SCR. Additionally, if it can be leveraged, the need for a dedicated central location can be mitigated.

Integration Group

The Integration Group was already discussed, but it merits further citation as a best practice. This group unifies the efforts of the other teams and is particularly essential for an SCR that includes both program and overhead elements.

Since the Contracts Sub-team was dedicated to identifying/reviewing contractual issues and concerns and business processes, all SCR members knew who to go to for expert advice on these matters. Contracts also had visibility across all other teams, and could identify and highlight trends and interrelated issues relative to contracts.

Having sub-teams for cost and pricing working hand-in-hand provided outstanding linkage and flexibility in the build of the cost database and pricing model. This model facilitated analysis to a greater depth than would have normally been available through source documentation, and provided the opportunity to conduct “what-if” scenarios.

Another key facet of the Integration Group was the Risk Management Sub-team review of all potential CRIs. The application of a disciplined process conducted by one team leveraged inputs from the sub-teams, and ensured consistent interpretation/application of the risk models/definitions for cost, schedule, and performance.

Operations and Technical Support

Often overlooked and forgotten, a cadre of persons vital to the SCR success was operations and technical support. First, the staff developed standard automated documents and detailed processes for all team members to use, thus reducing processing time and frustrations related to Requests for Information (RFIs), CRIs, and Business Process Initiatives (BPIs). Second, they standardized technical report writing, recorded team activities, captured minutes from meetings and site visits, and ensured near real-time availability of this information to the team members.

Finally, the staff and support personnel served as a one-stop-shop, accomplishing all logistics functions related to the travel, facility, and office supplies, thus, simplifying requests/services and easing the anxieties of team members.

Request for Information (RFI) Process

Recognizing the need to collect a vast amount of data from multiple sources, the Operations Team developed an automated form to draft and submit RFIs. Leveraging the experiences of earlier information requests, the form evolved to a user-friendly document for both the requestor and the information provider. Additionally, they developed and maintained a tracking system, so individuals could follow the status of RFIs on a near real-time basis and submit follow-ups as necessary. This process greatly reduced wait time and confusion.

Cost Reduction Initiative (CRI)/Business Process Initiative (BPI) Processes

The Integration Group went through iterative improvements to refine the CRI/BPI development and validation processes. The result was a well-defined process to review and analyze findings and categorize them as CRIs, BPIs, or Observations, as was discussed previously in this paper. This process provides a solid foundation for future SCR teams. The following key information should be considered when developing CRIs/BPIs:

- Basis of Analysis (e.g., interviews, proposal data, audits, briefings, survey, technical interchange, etc.)
- Need (or not) to pursue more detailed investigation to better substantiate
- Category (CRI, BPI, Observation)
- Proprietary nature of information used to develop the CRI/BPI
- Time Phasing of CRI / BPI (when and how it should be implemented)
- Team's confidence level that CRI / BPI has been fully vetted and understood
- Adoption of cross-cutting key words and terms
- SPO perspective
- Contract type impacted
- Basis of Estimate (BOE)
- Similar initiatives already in place by SPO, contractor, or other entity
- Risk of implementing/not implementing the recommendation

A mantra heard throughout the process was "nothing falls off the table." If a team proposed a potential CRI/BPI, it was never rejected out of hand. All findings had to be assessed and evaluated for consideration as a CRI/BPI or Observation. Those findings not accepted as CRIs/BPIs or Observations were documented with appropriate comments included. This ensured that the information would be available for future "deep dive" efforts. This process served the following two purposes: to identify fringe ideas that merit further investigation and analysis; and to encourage the team members to be innovative and have confidence that their efforts were recognized and valued.

Site Visits

The use of site visits to the SPO, prime contractor (ULA), and subcontractors was invaluable to the data-gathering process. These visits afforded opportunities to clarify information received in response to RFIs and to gather additional information in an interactive setting. As is espoused by all CPI methodologies, the ability to "walk the process" and observe the actual operations at the contractor and subcontractor facilities, in order to gain a sense of each facility's layout and capacities, is invaluable. As a side benefit, these site visits, if done properly, fostered cooperation between the teams/sub-teams and industry. The SCR teams conducted in-briefings to provide an overview of the SCR to the host companies, to outline the benefits, and to emphasize the SCR focus to collect information and to better understand their processes. It is important for all involved to understand the difference between the SCR and other site audits so information can flow freely, and cogent analysis can be conducted.

Knowledge Management

Use of a knowledge management system, such as My Mission Link (MML), is critical to attaining transparency in the SCR processes. The benefits of MML included near real-time sharing of data and information across multiple teams and access from any location at any time, which improved collaboration and opportunities for virtual teaming. The central repository must allow for the retention of all source data and documents, processing documents, and final reports/briefs. The key characteristics of the repository should include the following: easy access from any location "24/7," the ability to have secure areas, Really Simple Syndication (RSS) feeds for notifications, collaborative areas (discussion boards), and versioning. When coupled with other tools, such as Think Tank or Opinio, the power of virtual teaming is amplified.

All-Hands Meetings

Periodically, the entire EELV SCR team was brought together. These sessions went a long way towards infusing an inclusive and collaborative mentality through team building, training, and dissemination of critical information. The benefits included orienting everyone to a common baseline; sharing lessons learned and best practices; and identifying interdependent issues, duplicative efforts, and gaps.

Lessons Learned

Despite the best of intentions, even very talented teams will identify better processes through experience. All the SCR teams/sub-teams were as forthcoming in identifying lessons learned as they were in identifying best practices. If future SCR teams avail themselves of this information, they can benefit from our "learning moments."

System Program Office (SPO) Participation

It is critical for the SPO to be an active SCR participant. The benefits work in both directions. The relationship must be more than that of hosting site visits and responding to RFIs. The SPO can be a valuable source of information and insight to the rest of the SCR team. In a true teaming effort, the SPO would be able to assimilate information for strategic planning and development of implementation activities to smoothly integrate the CRIs and further investigate the BPIs. This, along with a knowledge management system, would be the biggest enabler for a successful Phase 5.

Early Start on Acquiring Operations/Staff Support

The sooner the administrative support for the various actions described previously in this report can be secured, the better. As soon as the need for an SCR is identified, these actions need to be started, in order to have resources and personnel in place with the stand-up of the SCR Team. There are two avenues to secure this support: organic or contractor. If available, dedicated organic support would work best and be the lower cost alternative.

Early Start on Enabling Activities

Activities that lay the groundwork for other activities must be completed as soon as possible. These include identifying work spaces/location, establishing IT services, and securing equipment such as computers, printers, copiers, and office supplies. These key efforts are the underpinnings of being able to take advantage of a dedicated location and web-based sharing system, as mentioned in the Best Practices.

Non-Disclosure Agreements (NDA)

Once the SCR Team and primary stakeholders have been identified, it is vital to finalize NDAs as soon as possible. In the course of requesting and obtaining needed data from the contractor and subcontractors, it became apparent that some companies identified a need to define access requirements for the data they shared with the SCR teams. Starting the NDA process early will eliminate delays in obtaining information and visiting contractor locations.

Site Visits

The site visits themselves were a best practice, but they could have been even more beneficial with a few improvements. First, it is important to allow sufficient time to properly prepare for each visit, conduct the site visit, and document/analyze data obtained in site visits. When possible, avoid scheduling back-to-back visits to contractor and subcontractor facilities, to avoid information overload, and to allow for preparation and analysis between visits. Allow time during each site visit to document observations and data obtained during interviews/site visits as quickly as possible, to prevent data loss and miscommunication. As such, teams should allow for an extra day or two at each site visit location to record findings while they are still fresh. This also provides an opportunity for immediate follow-up, when needed. Ensure teams are trained on various data collection tools, in interview techniques, on how to “walk a plant,” and in value stream mapping. When possible, use standard collection forms, and post reports as soon as possible.

Contracting Expertise

In any SCR, contracting expertise is essential. While availability of personnel may be constrained, efforts should be made to have contracting personnel dedicated to each team to allow for better understanding of contract impacts on the contractor processes and implications of CRIs/BPIs and Observations.

Dedicated Personnel Assignments

Core membership on the SCR Team must be a dedicated (full-time) assignment for the duration of the effort. Doing otherwise creates a “lose-lose” proposition. The individuals become frustrated, and both the SCR and the originating activities are saddled with false expectations as to what can reasonably be accomplished on a “part-time” basis. The use of specialized experts may be ad hoc, provided they are accessible, as needed, to provide clarification/further analysis.

Initial Training

In the first gathering of the SCR Team, time should be fenced to provide a quick orientation on standard process improvement tools (i.e., Pareto Analysis, Five Whys, PICK charts), and their application to the SCR processes. Recognizing time is limited, on-line resources can be used to supplement any initial and JIT training efforts, and to give team members access to information around-the-clock. If times permits, training on stakeholder relationships and team building can also contribute to a solid foundation.

Baseline Definition

Early identification of the baseline is essential. This baseline must be defined as explicitly as possible. It will prescribe what source documentation is needed (i.e., proposals, contracts, reports), and data requirements and their sources (i.e., program office and contractor databases). The baseline will also determine the foundation for the cost savings model and frame the nature of the savings. Similarly, it will also drive what the database looks like and how it is formatted, so it can easily feed the model with little manual manipulation intervention required. Once established, the baseline must be stabilized to reduce confusion and false starts. All team members then need to be trained on the structure and use of the model and database.

Survey

DAU developed and deployed a web-based survey to capture team composition data and team member inputs on improvement opportunities related to the following: SCR organization and structure, training, site visits, data collection techniques, and SCR process barriers and enablers.

Representative results are presented in Figure 10. Notable in these results is the majority of participants who believe the EELV SCR was well conducted in most every aspect. Two bottom-line figures that seem to encapsulate the prevailing sentiment of the team are the following:

- More than 85% believe other programs could benefit from this process.
- More than 82.5% believe this was a valuable expenditure of their time.

Representative Survey Questions	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree	N/A
The start-up of this SCR was well organized.	6%	15%	16%	35%	27%	1%
Expectations were sufficiently communicated.	3%	9%	13%	50%	25%	
The training I received in support of this SCR was sufficient and timely.	3%	9%	34%	45%	9%	
Important information affecting this SCR flowed freely.	4%	9%	18%	45%	24%	
My SCR team was correctly sized and staffed.	4%	20%	31%	32%	13%	
The SCR process was clear and straight-forward.	3%	9%	13%	45%	27%	3%
The site visits were useful.	0%	0%	3%	31%	53%	13%
My participation in the SCR had a positive impact during the overall process.	0%	0%	4%	59%	37%	
If given the opportunity, I would participate in another SCR.	0%	3%	19%	32%	46%	

Figure 10

Recommendations/Path Forward

Program offices have been charged with Should-Cost/Will-Cost Management. It is the intent of the USD(AT&L) that there will be a handful of programs which may be subject to the FAR-based SCR. There is little documentation and few experienced persons available, relative to the conduct of an SCR. To efficiently and effectively execute an SCR, future Directors/Teams should leverage the detailed reports and briefings generated during the EELV SCR. The detailed survey results with accompanying comments are also available. The keys to success will be upfront planning and training. Additionally, there should be a knowledge sharing site established and populated with information and tools relative to the SCR process itself (no data or information peculiar to the EELV Program need be posted) accessible to the DAW. Items resident on the site should include process maps, templates/forms, representative databases, models, and surveys.

Content of a similar nature should be provided to the DAU for development of learning assets to include the following: a continuous learning module, on-demand media assets, and infusion in appropriate current curriculums. All of these learning assets would then be made available to future SCR teams to facilitate their stand-up and execution efforts.

One alternative may be for the OSD to maintain a cadre of personnel with SCR experience to seed SCR teams as they are stood up, or at the very least to detail experienced CPI personnel (Master Black Belts and Black Belts) already assigned to the OSD staff.

Conclusions

The fact that this SCR team realized the successes it did, is a testament to the tenacious, adaptive senior leadership the SCR enjoyed. There was a premium placed on fact-based decision making and reporting and standardization in documentation and methodology, while allowing for continuous improvement and tailoring, as necessary, to meet the needs of specific sub-teams. If future SCR Teams take the time to understand the processes and tools the EELV SCR Team employed, and leverage the Best Practices and Lessons Learned, they will have a solid foundation on which to build, and will be able to avoid false starts and turbulence as they proceed.

One Final Note

The more things change, the more they stay the same. The following is excerpted from the May 1972 Army Materiel Command Pamphlet 715-7, titled "Procurement Should Cost Analysis Guide":

> The Need to Improve Defense Procurement
>
> 1. Large overruns and cost growth on many military programs in recent years have aroused severe criticism in the public press and have become topics of continued debate in the Congress. Meanwhile, the growing demand for public funds to support other Government needs is resulting in the availability of less money for Defense programs—while inflation and expanding technology are increasing the costs of Defense hardware.
>
> 2. Because of these factors, the procurement environment, the atmosphere in which we acquire our weapons and services, is significantly changed. There is

less money to spend and hence it must be spent more carefully and wisely. All agencies of the Government must react to this situation by improving their stewardship of public funds.

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Acknowledgements

The author is grateful to Mr. Ron Poussard for his outstanding leadership of the Should Cost Review (SCR) team, performing the first comprehensive SCR in over 15 years. The author also thanks the SCR team members who took the time to respond to the opinion survey—a vital source of information upon which the author based the findings of this research. The team members' perspectives proved invaluable. Finally, the author is appreciative of the leadership and empowerment the DAU West Region Dean, Andy Zaleski, demonstrates daily, and in particular, in the assignment of this author to the SCR team.

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Panel 19 – System-of-Systems Acquisition: Concepts and Tools

Thursday, May 12, 2011	
11:15 a.m. – 12:45 p.m.	**Chair: Rear Admiral David H. Lewis,** USN, Program Executive Officer, Ships ***Capability and Development Time Trade-off Analysis in Systems-of-Systems*** Muharrem Mane and Daniel DeLaurentis, Purdue University ***System-of-Systems Acquisition: Alignment and Collaboration*** Thomas Huynh, John Osmundson, and Rene Rendon, NPS ***Using Architecture Tools to Reduce the Risk in SoS Integration*** Chris Piaszczyk, Northrop Grumman

Rear Admiral David H. Lewis—Program Executive Officer Ships. Rear Admiral Lewis is responsible for Navy shipbuilding for surface combatants, amphibious ships, logistics support ships, support craft, and related foreign military sales.

Born at Misawa Air Force Base, Japan, Lewis was commissioned in 1979 through the Navy ROTC Program at the University of Nebraska–Lincoln with a Bachelor of Science degree in Computer Science.

At sea, Lewis served aboard USS *Spruance* (DD 963) as communications officer, where he earned his Surface Warfare qualification; USS *Biddle* (CG 34) as fire control officer and missile battery officer; and USS *Ticonderoga* (CG 47) as combat systems officer. His major command assignment was Aegis Shipbuilding program manager in the Program Executive Office Ships, where he helped deliver seven DDG 51 class ships and procured another 10 ships.

Lewis' shore assignments include executive assistant to the assistant secretary of the Navy (Research, Development and Acquisition), assistant chief of staff for Maintenance and Engineering, commander, Naval Surface Forces, where he also served as a charter member of the Surface Warfare Enterprise. Other ship maintenance and acquisition assignments ashore include the Navy Secretariat staff; commander, Naval Sea Systems Command staff; Aegis Shipbuilding Program Office; supervisor of Shipbuilding, Bath; and Readiness Support Group, San Diego. Upon selection to flag rank, Lewis served as vice commander, Naval Sea Systems Command. Lewis earned a Master of Science degree in Computer Science from the Naval Postgraduate School. He completed the Seminar Course at the Naval War College Command and Staff School, and received his Joint Professional Military Education certification. He is a member of the Acquisition Professional Community with Level III certifications in Program Management and Production Quality Management, and has completed his civilian Project Management Professional certification.

Lewis' personal awards include the Legion of Merit, Meritorious Service Medal, Navy and Marine Corps Commendation, Navy and Marine Corps Achievement Medal, and various service and unit awards.

Capability and Development Time Trade-off Analysis in Systems-of-Systems

Muharrem Mane—Associate Research Scientist, School of Aeronautics and Astronautics Engineering, Purdue University. Dr. Mane received his PhD from Purdue University in Aerospace Engineering in 2008. His current research interests are in risk analysis and propagation, resource allocation and design under uncertainty, and network modeling and analysis. He currently works in the System-of-Systems Laboratory led by Dr. DeLaurentis. [mane@purdue.edu]

Daniel DeLaurentis—Associate Professor, School of Aeronautics and Astronautics Engineering, Purdue University. Dr. DeLaurentis received his PhD from Georgia Institute of Technology in Aerospace Engineering in 1998. His current research interests are in mathematical modeling and object-oriented frameworks for the design of system-of-systems, especially those for which air vehicles are a main element; and approaches for robust design, including robust control analogies and uncertainty modeling/management in multidisciplinary design. [ddelaure@purdue.edu]

Abstract

Capability-based acquisition has led to the simultaneous development of systems that must eventually interact within a system-of-systems (or major sub-systems that must integrate on a single platform). The necessary interdependencies between systems also generate complexity and can increase development risk. Trades between capability and risk are essential during analysis of alternatives in pre-acquisition phases. For example, while legacy assets can potentially provide a certain level of capability with relatively low risk, their eventual capability may be restricted because of some specific characteristic or inherent rigidity. These features create a trade-off space between development risk and capability potential of a system. Existing tools for such trades can be cumbersome and non-intuitive when complexity is high. The authors' prior work has developed a Computational Exploratory Model to simulate the development process dynamics for these complex networks of systems intended for a system-of-systems capability. The progress documented in this paper couples the computational model with a capability module applied to the Airborne Laser (ABL) system and presents an exemplary analysis of alternatives by comparing expected development time and capability level under certain probabilities of disruption.

Introduction

The purpose of capabilities-based acquisition, as described by Charles and Turner (2004), is to acquire a set of capabilities instead of acquiring a family of threat-based, service-specific systems. The Missile Defense Agency (MDA), for example, uses capability-based acquisition to evaluate the success of a program based on its ability to provide a new capability for a given cost, and not on its ability to meet specific performance requirements (Spacy, 2004). The Joint Mission Capability Package (JMCP) concept is another example that aims to create a joint interdependency between systems to combine capabilities in order to maximize reinforcing effects and minimize vulnerabilities (Durkac, 2005). The goal is a more efficient utilization of both human and machine-based assets and, in turn, improved combat power. In these settings, systems are increasingly required to interoperate along several dimensions, which characterizes them as systems-of-systems (SoS; Maier, 1998). SoS most often consist of multiple, heterogeneous, distributed systems that can (and do) operate independently but can also assemble in networks and collaborate to achieve a goal.

The presence of interdependencies in layered networks spanning a hierarchy of levels is one of the sources of complexity in SoS development (DeLaurentis et al., 2008a, 2008b; Ayyalasomayajula et al., 2008; Kotegawa et al., 2008). The interdependencies between component systems often result in complex networks that exhibit vulnerabilities to disruptions in the development of even one system, especially if that one system places a central role in the network. Gell-Mann (2002) defines complexity as the amount of information necessary to describe regularities of a system effectively. Rouse (2001) summarizes the complexity of a system (or model of a system) as related to the intentions with which one addresses the system, the characteristics of the representation that appropriately accounts for the system's boundaries, architecture, interconnections, and information flows, and the multiple representations of a system. We can represent degrees of complexity by examining the graphs that result when we record the intentions, characteristics, interconnections, etc., in a given situation.

Acquisition programs have struggled with complexities in both program management and engineering design (e.g., NASA's Constellation Program [Committee on Systems Integration for Project Constellation, 2004] and FAA's NextGen [NextGen Integration and Implementation Office, 2009]). While first-order impacts of decisions are nearly always considered, the cascading effects that result from complex interdependencies obscure the quantification and visibility of the higher-order impacts of developmental decisions and disruptions. Furthermore, the network structure behind the collaboration can contribute both negatively and positively to the successful achievement of SoS capabilities and, even earlier, to the developmental success. Collaboration via interdependence may increase capability potentials, but it also contains concealed risk in the development and acquisition phases.

Our approach quantifies the impact of system interdependencies in the context of system development and capability. It provides a means to conduct analysis of alternatives while navigating the decision space that simultaneously considers the potential positive impacts of interdependencies (e.g., capability) as well as the negative impacts (e.g., development time). The work comprises new improvements to a Computational Exploratory Model (CEM)—a discrete event simulation model—previously introduced in prior Acquisition Symposia (Mane and DeLaurentis, 2009, 2010) that aims to provide decision-makers with insights into the development process by propagating development risk in the SoS network. The impact that system risk, system interdependencies, and system characteristics have on the estimated completion of a program are generated. We present a proof-of-concept application that analyzes the development time of the Airborne Laser (ABL) system and conduct a trade-off study between development time and capability while considering various alternatives for the constituent systems of the ABL.

Computational Exploratory Model (CEM) Overview

The CEM is based on the 16 basic technical management and technical system-engineering processes outlined in the Defense Acquisition Guidebook (DoD, 2008a), often referred to as the 5000-series guide. However, an SoS environment changes the way these processes are applied. The Systems Engineering Guide for System-of-Systems (SoS-SE; DoD, 2008b) addresses these considerations by modifying some of the 16 processes in accord with an SoS environment. The resulting processes and respective functions consist of translating inputs from relevant stakeholders into technical requirements, developing relationships between requirements, designing and building solutions to address requirements, integrating systems into a high-level system element, and performing various managing and control activities to ensure that requirements are effectively met, risks are mitigated, and capabilities achieved.

The CEM, centered on these revised processes, is a discrete event simulation of the development and acquisition process. This process creates a hierarchy of analysis levels: SoS Level (L1), Requirement Level (L2), and System Level (L3). Component elements at each level are a network representation of the level below. The SoS Level (L1) is comprised of the numerous, possibly interdependent requirements (L2) needed to achieve a desired capability. Similarly, satisfaction of each requirement in the Requirement Level (L2) requires a number of possibly interdependent systems (L3).

At the Requirement Level (L2), *Requirements Development* contains the technical requirements of the SoS (provided externally). The technical requirements are then examined in *Logical Analysis* to check for interdependencies among the requirements. A check for inconsistencies among requirements is also performed. *Design Solution* development and *Decision Analysis* are the next processes, which belong to the System Level (L3). They produce the optimal design solution from the set of feasible solutions to meet the given requirements. The optimal design solution not only is based on the current set of requirements and solution alternatives but also takes into account all previous information available through requirements, risk, configuration, interface, and data management processes. Because most acquisitions are multi-year projects involving many different parties, the overlap between the management processes, *Design Solution* and *Decision Analysis*, allows for greater tractability of decisions. It is at this stage that system interdependencies are identified. The optimal design solution obtained from this phase is then sent to the next stage: *Technology Planning* and *Technology Assessment*. In the event that an optimal or sub-optimal design solution to successfully implement the given requirements does not exist, the feedback loop to *Requirement Development* translates into a change in the technical requirements for the SoS. *Technology Planning* and *Technology Assessment* are System Level (L3) scheduling processes that oversee the implementation, integration, verification, and validation for all the component systems in the SoS.

The *Implementation and Integration* Phases of component systems constitute the lowest level of detail modeled in the CEM. The design decisions made at earlier stages must be implemented and integrated in these phases to generate the final product of a program. Figure 1 presents an abstraction of the layered networks that result from the modeling of the acquisition process: systems are grouped to satisfy a requirement, and requirements are grouped to generate a capability.

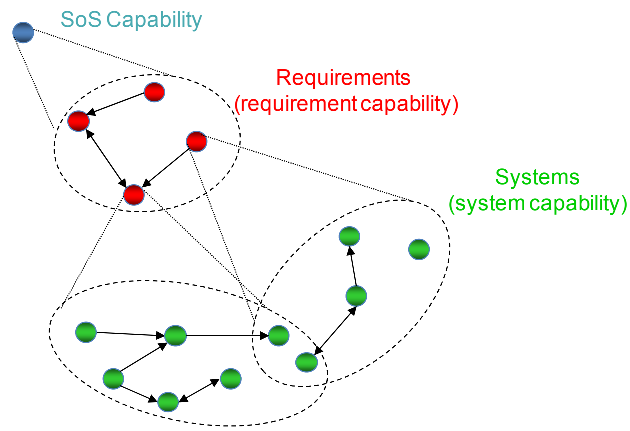

Figure 1. Layered Network Abstraction of Computational Exploratory Model

Systems can be independent, can satisfy several requirements, and can depend on other systems. The CEM simulates these layered relationships to capture the impacts that any changes—related to decision-making, policy, or development—in any of the component systems, requirements, and relationships between them have on the completion of a project. In our prior experiments, we studied the impact of different interdependency topologies. The exercise of the CEM described in this paper assumes a fixed topology and instead specifically targets variations in inherent system risk, the interdependency strength among systems, and the span-of-control of the SoS authority (if present). The next section presents the CEM model dynamics and input parameters.

Model Input Parameters

The CEM operates as a discrete event simulator of the development process. It models risk (probability of a disruption and associated consequence) present in the implementation and integration of each component system as well as the risk due to the system interdependencies. Furthermore, systems and SoS engineers are often faced with the decision of using legacy assets to satisfy a given requirement or opt for the development of brand new ones. The CEM includes parameters such as *readiness-level* to differentiate between legacy assets/platforms, new systems, and partially implemented/integrated systems (i.e., systems under development) and to investigate the impact that the inclusion of such systems in the development of an SoS has on the success of a project. Table 1 presents the input parameters, and the remainder of this section expands and explains their role in the CEM.

Table 1. Input Parameters of Computational Exploratory Model

Parameter	Notation	Description
Requirement Level (L2)		
Requirement dependencies	D_{req}	Adjacency matrix that indicates requirement interdependencies
Risk profile	R_{req}	Probability of disruptions in *Requirement Development Phase*
Impact of disruptions	I_{req}	Time penalty when disruptions hit *Requirement Development Phase*
System Level (L3)		
System dependencies	D_{sys}	Adjacency matrix that indicates system interdependencies
Development pace of design	t_{des}	Increase in completion of *Design Solutions Phase*
Design risk profile	R_{des}	Probability of disruptions in *Design Solutions Phase*
Impact of design disruptions	I_{des}	Time penalty when disruptions hit *Design Solutions Phase*
Span-of-control	*soc*	Indicator of how *Implementation* and *Integration* are performed (sequentially or simultaneously)
System initial readiness-level	$m^0(i,r)$	Initial readiness-level of system *i* to satisfy requirement *r* (for *Implementation Phase*)
System risk profile	$R_{sys}(i,r)$	Probability of disruptions (during implementation) of system *i* when satisfying requirement *r*
Impact of disruptions	$I_{sys}(i)$	Time penalty when disruptions hit system *i* during *Implementation*/*Integration*
Implementation pace	$p_{imp}(i)$	Increase in readiness-level at each time-step during implementation of system *i*
Integration pace	$p_{int}(i)$	Increase in completeness-level at each time-step during integration of system *i*
Implementation start	$l_{imp}(i,j)$	Readiness-level of system *j* when *Implementation Phase* of dependent system *i* begins
Strength of dependency	$S(i,j)$	Strength of dependency of system *i* on system *j*

The requirement dependency matrix (D_{req}) indicates how the development and satisfaction of requirements depend on each other, which impacts the sequence in which requirements are developed and satisfied. For example, if Requirement A depends on Requirement B, then development of Requirement A begins when Requirement B has been satisfied. As requirements are developed, the risk profile (R_{req}) of *Requirement Development* indicates the probability of disruptions at this stage in the development process. Disruptors signify a change in requirements or the addition of new requirements. When a requirement is changed after the acquisition process has begun, it affects all subsequent processes and causes a time delay (I_{req}) that is added to the project time. Every requirement that is implemented is fed into its own *Design Solution* and *Decision Analysis* process. The *Design Solution* and *Decision Analysis* processes feed into each other, and the risk profile (R_{des}) indicates the probability of disruptions at each time-step during the completion of the stage with a value between 0 and 1. Any disruptions at this stage indicate that the design solution provided is not feasible and a time penalty (I_{des}) that indicates a re-design of the solution is incurred. If the solution fails in multiple consecutive time-steps, then the requirement is sent back to the *Requirement Development* stage; otherwise, the set of component systems and their user-defined parameters are sent to the *Technical Planning* and *Technical Assessment* processes, based on the development-pace parameter of this stage.

The *Implementation Phase* simulates the development of each system. The nature of candidate systems may range from legacy systems to off-the-shelf, plug-and-play products to custom-built, new systems. Here, we define *legacy systems* as systems that have been developed in the past to achieve a particular requirement, and *new systems* as not-yet-developed systems envisioned to satisfy a new requirement. When considering the use of legacy systems to meet a new requirement, the capability of these systems to satisfy the new requirement is not necessarily the same as their capability to meet the original requirement for which they were designed. Additionally, the risk associated with the modification of a legacy system and the risk associated with the development of a brand new system can be quite different. Legacy systems may, however, provide cost and/or time benefits if modifications are less severe than a new development, as is the case with new systems. To delineate systems in a meaningful way, we describe the spectrum of a system's ability to satisfy a requirement in terms of its readiness-level.

System readiness-level, a concept proposed by Sauser et al. (2006), is a metric that incorporates the maturity levels of critical components and their readiness for integration (i.e., integration requirements of technologies). This is an extension of the widely used Technology Readiness-Level (TRL), a metric that assesses the maturity level of a program's technologies before system development begins (USD[AT&L], 2005). While similar in spirit to the SRL metric proposed by Sauser et al. (2006), readiness-level in the present work is defined in a different manner and with less detail. We define system readiness-level as the readiness-level of a system *i* to satisfy requirement *r*, $m(i,r)$, with a value between 0 and 1. A system with a readiness-level of 1 is a fully developed system that can provide a certain level of capability. The dynamic model starts the *Implementation Phase* of a system from its initial readiness-level and simulates its development/implementation until it reaches a readiness-level of 1. An initial readiness-level of 0 indicates a brand new system that must be developed from scratch, while a system with an initial readiness-level greater than 0 indicates a legacy system that is partially developed to satisfy a requirement *r* but needs further development to reach a readiness-level of 1. In general, careful research of a candidate system *i* will determine its initial readiness-level to satisfy a requirement *r*, and, therefore, the amount of development necessary to achieve a readiness-level of 1.0.

The CEM simulates the *Implementation Phase* as a series of time-steps in which a pre-determined increment of readiness ($p_{imp}(i)$) is gained at each time-step of each system *i* or lost if a disruption occurs (according to the system risk profile of system *i* in satisfying requirement *r*, $R_{sys}(i,r)$). This is clearly a gross simplification of the actual development process for a system; however, it adequately serves the purposes of the research, which is focused on the interdependencies between systems to develop a SoS capability and aims to capture the impact of disruptions on the development process. Accurate modeling of the *Implementation Phase* would increase the accuracy of the model for a particular application, but it would not change the nature of the observed results.

Representation of Disruptions

The risk associated with the development of a system is a function of its inherent characteristics (technology, funding, and complexity levels) and on risk levels of the systems on which it depends. The former may be estimated via a variety of analysis techniques that examine a system in detail, but the latter requires knowledge of system interdependencies that can be numerous, complicated, and often opaque. Developmental interdependencies of SoS create layered networks that often span among a hierarchy of levels (DeLaurentis et al., 2005; Butler et al., 2001; Ayyalasomayajula et al., 2008; Kotegawa et al., 2008). The complexity of these networks often hides many of the otherwise explicit consequences of risk. Depending on the network topology characteristics, disruptions to one of the critical nodes or links in the network can propagate through the network and result in degradation to seemingly distant nodes (Huang et al., 2008).

In this study, we express inherent risk as a density function that describes the probability of a disruption occurring at any time during the system development. We concentrate on the *Implementation* and *Integration Phase* as the development stage where disruptions occur. Here, inherent risk is the probability of disruptions due to the development characteristics of the subject system (e. g., technology readiness-level, funding, politics, etc.). Risk due to interdependencies, on the other hand, is the probability of disruptions during the *Implementation Phase* of a system due to disruption in the system on which the system of interest depends. This is essentially the conditional probability of a disruption, given that another system has a disruption.

This study assumes that the inherent risk of a system *i* in satisfying requirement *r*, $R_{sys}(i,r)$, is solely a function of its readiness-level, $m(i,r)$. While a somewhat simplified definition, expressing risk as a function of a system's readiness-level is logical since readiness describes the necessary development of a system to satisfy a given requirement. Therefore, risk changes as the readiness-level of a system increases. Equation 1 introduces a relationship between a system's readiness-level and inherent risk (probability of disruption).

$$R_{sys}(i,r) = \alpha_i \left(1 - m(i,r)^{\beta_i}\right) \tag{1}$$

In this relationship, α_i (with a value between 0 and 1) is a parameter that indicates the upper-bound value of risk for system *i* (i.e., producing maximum probability of disruption) while β_i is a shape parameter that indicates how quickly risk changes as a function of readiness-level. This formulation implies that risk is highest at the early stages of development (e.g., low readiness-levels) and it decreases (at different rates, depending on the value of the β_i parameter) as development progresses. For instance, when a system *i* has a readiness-level of 0.0—it is a brand new system—the probability of disruptions during development will be highest, and it will have a value α_i. However, when the system has a readiness-level of 1.0, the probability of disruptions will be 0. System inherent-risk is implemented in the CEM by using a uniform random distribution to select a value between 0 and 1 at each time-step of the *Implementation* or *Integration Phase* and passing it into a binary channel to see if the number is smaller or greater than the probability of disruption defined by $R_{sys}(i,j)$. This determines if a disruption occurs or not.

When all systems are independent, identification of the system with highest risk is trivial (e.g., the system that, on average, will contribute more to delays in completion time). However, when systems are interdependent, systems that otherwise have a low inherent risk can be greatly impacted by disturbances because of the transmission of risk from other systems. Systems are impacted by nearest neighbors (those systems on which they directly depend; first-order dependencies) and by systems that impact those nearest neighbors (higher-order dependencies).

The CEM models risk due to interdependencies in terms of the dependency strength between two given systems. Dependency strength, $S(i,j)$, is an input parameter that takes values between 0 and 1 and is defined as the conditional probability (uniform random probability) that system i has a disruption, given that system j (on which system i depends) has a disruption. Risk due to interdependencies is, therefore, a function of the readiness-level of the dependent-upon system as well as the strength of that dependency.

When considering the development of different system sets that can provide a desired SoS capability, the characteristics of interdependencies must be considered because they have a large influence on both capability and development time. Quantifying the impact that such characteristics have on the development process can aid decision-makers in selecting the most promising alternative. The next section of this paper presents a proof-of-concept application of the CEM to perform an analysis of alternatives study for different constituent systems of a development network while comparing capability and development time.

Proof-of-Concept Application

The ABL program serves as the proof-of-concept problem for demonstrating the Computational Exploratory Model (CEM), equipped with a capability estimate module, for performance of trade-off analyses between capability and development time. The CEM simulates the propagation of disruptions in the network of component system interdependencies and enables a trade-off study between the completion time of the ABL and its potential capabilities when different component system alternatives are considered.

The ABL is a theater defensive weapon concept that is designed to destroy ballistic missiles in their boost phase within the first two minutes of flight from hundreds of kilometers away (Davey, 2000). The current ABL, still under development, consists of an aerial platform (a modified Boeing 747-400), infrared sensors for detecting the missile, two solid state lasers for tracking the missile and measuring atmospheric disturbances, an Adaptive Optics System (AOS) for adjusting for atmospheric disturbances, and a Chemical Oxygen Iodine Laser (COIL beam) for destroying the missile. Figure 2 presents these component systems and their layout in the Boeing B747-400, as described in (Defense Industry Daily, 2009). Note that the ABL program may not be considered a system-of-systems operationally, but developmentally, it has all of the traits required of an SoS, as described by Maier (1998). In particular, the geographic distribution, along with managerial and operational independence, qualifies the development process of the ABL as a system of systems. Development of the ABL team is undertaken by three companies, who operate and manufacture their respective pieces of the ABL across the country. The Beam Control/Fire Control (BC/FC) system is designed by Lockheed Martin, the COIL beam is designed by Northrop Grumman, and the modifications to the aircraft and integration of systems are performed by Boeing. In addition, each company has been able to, at least partially, test their portions of the ABL separately (Davey, 2000), indicating some degree of operational independence.

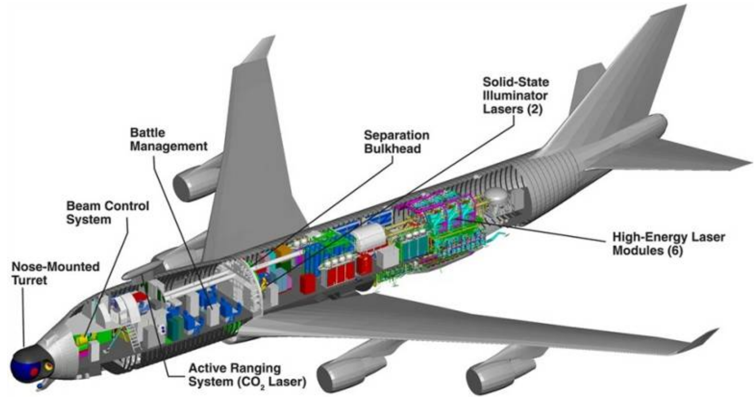

Figure 2. Airborne Laser Component Systems
(Defense Industry Daily, 2009)

The ABL operates as follows: first, several onboard Infrared Search and Track (IRST) sensors detect the heat radiated by the exhaust of the missile. Next, a solid state laser (the Track Illuminator) tracks one or more missiles, determines an aim point, and passes the information to the main ABL computers. The other solid state laser (the Beacon Illuminator) measures disturbances in the atmosphere so that they may be corrected by the AOS in order to accurately focus the main laser on the missile. This sequence adjusts the focus of the COIL beam and, together, is known as the Beam Control/Fire Control (BC/FC) system. Finally, the COIL beam—a dual line, multi-module laser—is focused onto the missile through a large turret on the nose of the vehicle until it compromises the structural integrity of the missile.

Several assumptions and simplifications are necessary to facilitate the proof-of-concept study. While the requirements of the ABL are comprised of several components/tasks—detect, track, aim and adjust laser beam, and destroy missile—here they are grouped into a single requirement. Additionally, the component systems of the ABL are grouped into four core systems: the aircraft system, the detection and tracking (D&T) system, the AOS, and the COIL beam system. Development of these four systems and their integration results in the ABL capability of detecting, tracking, and destroying theater ballistic missiles in their boost phase.

ABL Capability

The capability of a system is embodied by the quality with which it performs required functions. The required capability of the ABL, as described by Barton et al. (2004), is to disable ballistic missiles in their boost phase. Depending on the type of threat missiles, operating environment, and other operational variables, many metrics exist for describing the capability of the ABL system. In this work, we assume that the ABL capability of interest is its ability to disable threats from a range of 600 km. Tests and studies of the ABL have shown that 600 km is a reasonable performance goal (Barton et al., 2004). Hence, the achievable capability level of the ABL will be measured against this baseline value of engagement range.

Three functions are necessary on the ABL: detect and track the missile, engage the missile, and disable the missile. As previously mentioned, we assume that four constituent systems comprise the ABL system and perform the three functions. The contributions of each system to the execution of each function are presented in Figure 3.

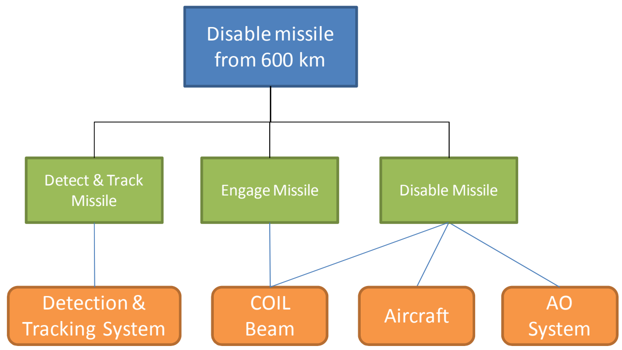

Figure 3. Assumed Capability Composition of ABL

The capability of the ABL is, therefore, a function of the performance levels of each of its constituent systems (Table 2).

Table 2. Performance Goals of ABL Systems

Constituent System	Performance Metric	Performance Level (units)
Detection & Tracking	Detection time, T_d	10 (sec)
Aircraft	Payload capacity	250,000 (lbs)
COIL beam	Beam power, P	5 (MW)
Adaptive Optics	Beam quality, b_q	1.2 (n/a)

The detection time, T_d, is the time that the D&T system requires to acquire a target and generate a track. This is an important performance parameter because it will dictate the time available to the laser to engage and disable the target during the boost phase. Based on the report by Barton et al. (2004), an acceptable dwell time (the amount of time that the laser must deliver its energy) for a liquid-propelled missile is on the order of 4 to 5 seconds. This means that for a given raid size, the D&T system has a limited time to acquire the target and generate tracks. We assume that in order for the ABL to disable up to 12 simultaneously launched liquid fuel missiles (with a boost phase of 170 seconds), the ideal detection time is 10 seconds (based on a dwell time, t_e, of 4.2 seconds; Equation 2).

$$T_d = \frac{boost\ time}{raid\ size} + t_e \quad (2)$$

The COIL beam is the centerpiece of the ABL system. The beam power, *P*, determines the amount of energy that will be delivered to the missile. Again, based on the extensive report by Barton et al. (2004), a reasonable power performance for the COIL beam is around 5 MW. The capability of the ABL will be a function of this performance parameter as well as the performance of the other constituent systems.

The aircraft hosts the other constituent systems of the ABL and provides the necessary mobility characteristics of this weapon. However, we assume that from a capability point of view (to disable a missile from 600 km), it can fulfill the necessary requirements to host the constituent systems of the ABL and is thus not a part of the capability trade space. Note that this is a simplifying assumption in this study but one that can be included in more detailed studies.

Finally, atmospheric disturbance must be accounted for, since it plays a significant role on the laser performance. Development of the ABL system includes the development of an advanced Adaptive Optics System that can account for the atmospheric disturbances and increase the energy delivered to the missile. The performance of these optics is typically described by the Strehl ratio. The Strehl ratio is a measure of the quality of optics that compares the peak intensity at the detection point with a theoretical maximum intensity. While various factors contributed to the quantification of the Strehl ratio, Barton et al. (2004) provide the simplified description:

$$S_R = \frac{1}{b_q^2} \quad (3)$$

where b_q is the beam quality diffraction limit and can be used as a performance benchmark for adaptive optics. Barton et al. (2004) state that a beam quality value of 1.2 represents a reasonable goal.

The amount of energy required to disable a missile varies according to the missile construction and the type of fuel it utilizes (fuel tanks are the most vulnerable part of the missile). Barton et al. (2004) offer a simplified relationship between the performance parameters of its constituent systems and the capability of the ABL to disable a missile from a distance *R*. In this relationship, the force required to disable a missile, F_c, is expressed as follows:

$$F_c = \frac{\pi}{4}\left(\frac{D}{\lambda}\right)^2 \frac{1}{R^2}(P \cdot t_e)S_R \quad (4)$$

where *D* and λ are the diameter and wavelength of the COIL beam, respectively; *R* is the slant range (e.g., the distance between the ABL and the target missile); *P* is the COIL beam power in Watts; t_e is the laser dwell time (e.g., the time that the laser delivers its energy to the target); and S_R is the Strehl ratio of the Adaptive Optics System. Solving this relationship for the slant range, *R*, describes the capability of the ABL as a function of the performance parameters of its constituent systems.

$$R = \sqrt{\frac{\pi}{4}\left(\frac{D}{\lambda}\right)^2 (P \cdot t_e)S_R \cdot F_c} \quad (5)$$

The capability contributed by the COIL beam is represented by the COIL beam power, *P*, (and fixed values of D = 1.5 m and λ = 1.315 μm); the capability contributed by the AOS is represented by the S_R value; and the capability contributed by the D&T system is represented by the available dwell time, t_e. We assume that the capability of the ABL will be measured in terms of its ability to disable a liquid-fueled ICBM, which requires a force of 32 MJ, F_c = 32 MJ/m^2 (Barton et al., 2004). The capability of the ABL will be computed by using this relationship for different combinations of constituent systems that can offer various levels of system-specific performance and will be compared to their estimated development.

ABL Development

The Air Force and the Missile Defense Agency (MDA) have been experimenting with the simultaneous development, testing, and integration of the component systems of the ABL. Because of this, development of these systems is interdependent. For instance, the aircraft developer needs the stability requirements and dimensional specifications of the Adaptive Optics System and the COIL beam system to determine the proper mountings and fuselage dimensions of the aircraft; or, development of the aircraft requires knowledge of the heat dissipated by the COIL beam to determine the amount of heat protection to include in the aircraft airframe and/or subsystems. Depending on the performance of the COIL beam—i.e., its maximum power output—the adaptive optics must provide a certain level of performance in order to deliver the required amount of energy to the target. Similarly, depending on the capability of the D&T system, the adaptive optics must be able to effectively compensate for the atmospheric disturbances of the detection range. Development of the AOS is, therefore, dependent on the development of the COIL beam and the D&T system. A representation of the interdependencies in this example problem and its layered network structure is presented by Figure 4.

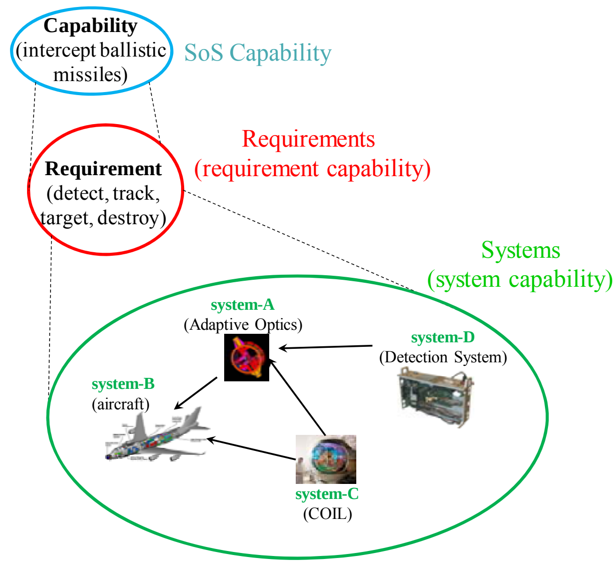

Figure 4. Assumed System Interdependencies in ABL Example

While more interdependencies may be present in the development of the ABL systems, for the purpose of this demonstration, we assume that the topology presented in Figure 4 represents the development interdependencies of the ABL system *and remains fixed during the analysis of alternatives*. The goal is to present a sample utilization of the CEM to perform analysis of alternatives and capability and development risk trade-off. The CEM will utilize these interdependency characteristics and other necessary parameters to estimate the development time of the ABL when alternative constituent systems (e.g., systems with varying levels of capability) are considered.

Results

For the proof of concept application presented here, the desired capability is the ability to engage and disable missiles from a range of 600 km. This capability is a function of the constituent, interdependent systems. Here, we assume that the designer has the option to select different constituent systems to satisfy this ABL requirement. The Boeing B747-400 is currently being used as the aerial platform that hosts the ABL system. The MDA stated in a 2007 report that an alternative to the current ABL platform is the utilization of Unmanned Aerial Vehicles (UAVs), which can offer longer endurance and eliminate the risk to crew members. Similarly, Davey (2000) reports that alternate systems to the currently used detection and tracking system could be considered to partially fulfill the ABL requirement (e.g., UAV or Space Tracking and Surveillance System [STSS]). Additionally, Barton et al. (2004) indicated that the ideal performance of the Adaptive Optics System and the COIL beam is still questionable, and sub-optimal “solutions” will be utilized following a spiral development strategy that will enable incremental improvement of these systems’ capabilities.

Three alternative aerial platforms and three detection and tracking systems are considered to fulfill the ABL requirement, while three levels of performance of the AOS and the COIL beam with different levels of initial readiness-level are considered. Table 3 presents these assumed values for alternatives for the aircraft system.

Table 3. Assumed Values for Alternative Systems for Aerial Platform

Aircraft Alternative	Max Payload [lbs]	TRL	Initial Readiness-Level [$m^o(i,r)$]	Implementation Pace [$p_{imp}(i)$]
new aircraft	TBD	5	0.56	0.04
KC-135A	105,821	6	0.67	0.04
B747-400	248,000	8	0.89	0.04

All alternatives are assumed to have an implementation pace of 0.04; this means that at every time-step during the CEM simulation, the completeness-level increases by an increment of 0.04, until a completeness-level of 1.0 is reached. The Boeing NKC-135A is included here as an alternate aerial host platform because it was the primary aircraft in the Airborne Laser Laboratory (ALL) —a precursor to today's Airborne Laser program—during the 1980s (Duffner, 1997). The purpose of this program was to perform tests and determine whether or not a laser mounted on an aircraft could actually shoot down an airborne target. The Boeing 747-400 is the aircraft that currently hosts the constituent systems of the ABL and has a payload capacity of 248,000 lbs (*Jane's All the World's Aircraft*, 2010). A GAO report (2002) stated that the present laser with six modules weighs 180,000 lbs and the laser design calls for a laser with 14 modules; while the actual power output of the laser is not known, we assume a linear relationship between the weight of the laser and its power output, and, therefore, a larger payload capacity is required for the aircraft to host the sub-systems of the COIL beam. The new aircraft alternative is assumed to provide this required payload capability.

Furthermore, because modifications are necessary to host the other component systems of the ABL, we assume that the KC-135A, the B747-400, and the new aircraft have a TRL of 6, 8, and 5, respectively. We utilize the TRL as an indicator of the risk associated with the development of a given system; the approach followed here normalizes the TRL value (by dividing by the maximum possible TRL, 9) and uses this value as the initial readiness-level of the system (m^0). The new aircraft alternative has the lowest TRL because it is a brand new system; however, it does not have a TRL of 0 because we assume that existing technologies can be utilized to meet its requirements.

The options to the designer for the detection and tracking system of the ABL are to design a brand new system or use legacy systems like the Space Tracking and Surveillance System (STSS) or UAVs. Table 4 presents the alternate systems and assumed capabilities along with their initial readiness-levels.

Table 4. Assumed Values for Alternative Systems for Detection System

Detection Alternative	Detection Time [sec]	TRL Level	Initial Readiness-Level [$m^o(i,r)$]	Implementation Pace [$p_{imp}(i)$]
New System	10	6	0.67	0.04
UAV	11	8	0.89	0.04
STSS	12	9	1.00	0.04

One option that the MDA has considered for the early detection and targeting of missiles is the utilization of UAVs (Buttler, 2009). However, because current concepts of operations involve the UAV accepting a cue from satellites about the threat missile, we assume that the detection time for such a system is of 11 seconds. Recall that detection time impacts the available laser dwell time (e.g., longer detection time reduces the available time to disable the missile during the boost phase). Furthermore, because UAVs are currently used to perform reconnaissance missions, we assume that utilizing UAVs for detection and tracking has a TRL level of 8. Another option for detecting and tracking the missile is the use of the Space Tracking and Surveillance System (STSS). As of 2003, the MDA has decided to fund the design but not the production of a competitive sensor for use aboard the satellites (Smith, 2003). We assume that the STSS has a TRL level of 9 and can achieve a detection time of 12 seconds if it is used as the detection and tracking system of the ABL. Finally, we consider the development of a new system to provide the D&T capability for the ABL system. Based on the GAO report (2002), the D&T system under development has a TRL level of 6. Because this is a custom system designed specifically for use in the ABL system, we assume that it can achieve a detection time of 10 seconds, which would enable the detection of up to 12 simultaneously launched missiles before the end of the boost phase, assuming a 170-second boost phase and a dwell time of 4.2 seconds.

While alternative systems for the aerial platform and the D&T system exist, the COIL beam and the Adaptive Optics System are new technologies for which alternatives do not exist. Because the level of performance of these systems is still uncertain, we assume that different levels of beam quality and power output for the AOS and COIL beam, respectively, can be achieved given the different TRL levels. Table 5 and Table 6 present these assumed values.

Table 5. Assumed Values for Alternative Systems for Adaptive Optics System

Detection Alternative	Beam Quality Diffraction Limited	TRL Level	Initial Readiness-Level [$m^o(i,r)$]	Implementation Pace [$p_{imp}(i)$]
Alternative 1	1.2	2	0.22	0.02
Alternative 2	1.3	3	0.33	0.02
Alternative 3	1.4	5	0.56	0.02

Table 6. Assumed Values for Alternative Systems for COIL beam System

COIL Beam Alternative	Power [MW]	TRL Level	Initial Readiness-Level [$m^o(i,r)$]	Implementation Pace [$p_{imp}(i)$]
Alternative 1	3	4	0.44	0.03
Alternative 2	4	3	0.33	0.03
Alternative 3	5	1	0.11	0.03

The GAO-02-631 report (2002) provides the TRLs for Alternative 1 for both the AO and the COIL beam systems, and assumed TRL and capability values are used for the other alternatives, as well as implementation paces. The systems engineer would like to know which combination of constituent systems results in a (ABL) system with lowest estimated completion time and provides the largest capability potential. We assume that all alternatives have a maximum probability of disruption of 0.2 (α_i = 0.2), which decreases as the completeness-level of a system increases. This implies that alternatives with a larger initial readiness-level will have a smaller probability of disruption than systems with a smaller initial readiness-level.

In the present study, the interdependency strengths between systems are varied for each potential ABL architecture, based on the initial readiness-level of the candidate constituent system. We assume that the initial readiness-level of a given system indicates the interdependency strength between that system and all the systems that depend on it and that the interdependency strength is the complement of the initial readiness-level. For instance, if one of the alternatives for the COIL beam has an initial readiness-level of 0.33, then the strength of the dependency of the aircraft system on the COIL beam system is 0.77 (1-0.33).

Based on the alternative systems in Table 3, Table 4, Table 5, and Table 6, there are 81 possible combinations of D&T, aircraft, COIL beam, and Adaptive Optics Systems that could satisfy the requirement of the ABL, albeit at a different capability level. For the purpose of this study, these describe the design space for the analysis of alternatives. The goal is to quantify the trade-off between the ABL capability (in terms of the engagement range) and the estimated development time. To simplify, we assume that the interdependencies between the systems will not change in the scenarios where the alternative systems are utilized (i.e., the system interdependencies presented in Figure 4 will be invariant).

CEM simulates the development process and estimates the completion time of the entire program and uses system-specific capabilities to compute the ABL capability. Recall that the initial readiness level determines the maximum risk of the initial stages of the development process. The estimated completion time, therefore, reflects the impact that risk (both inherent and due to interdependencies) has on the completion time of the ABL program for the different alternative systems, their combinations, and implementation strategies. Figure 5 presents the expected completion time of the ABL project, as estimated by the computational model and the potential capability for the 81 combinations of alternative systems.

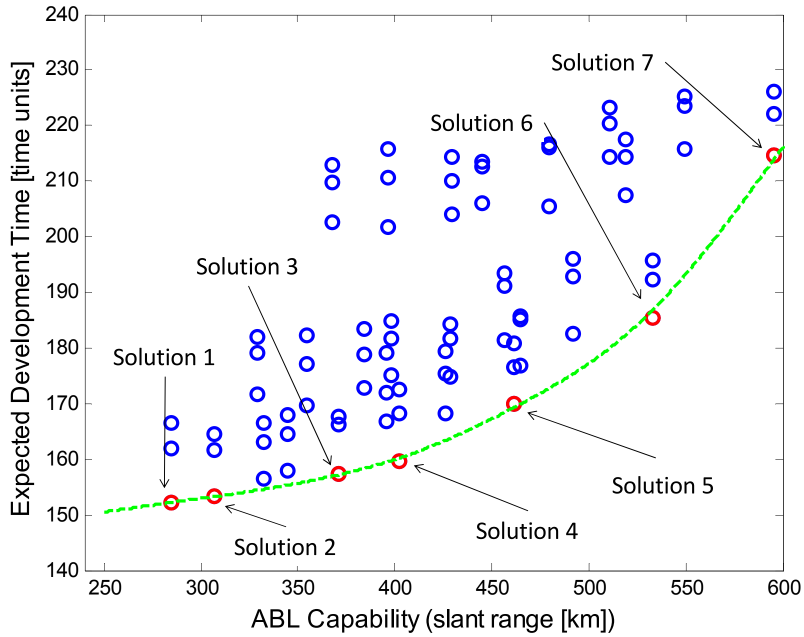

Figure 5. Tradeoff Between Expected Completion Time and Potential Capability of ABL

The seven solutions called out in Figure 5 represent the seven combinations of these alternative systems that yield promising combinations of capability and expected completion time. They are the non-dominated solutions of this trade-off study and, as such, define a Pareto Frontier. Essentially, by choosing any of these seven solutions, it is impossible to improve the expected completion time without giving up capability. Table 7 lists the systems that comprise each of these seven solutions, the resulting potential capability, and expected completion time.

Table 7. Description of Non-Dominated Solutions

Solution	D&T System	Aircraft System	COIL Beam System	AO System	ABL Capability [slant range, km]	Expected Completion Time [time units]
1	STSS	new system	Alternative-1	Alternative-3	285	152
2	STSS	new system	Alternative-1	Alternative-2	307	153
3	UAV	new system	Alternative-1	Alternative-2	371	157
4	UAV	new system	Alternative-1	Alternative-1	402	160
5	new system	new system	Alternative-1	Alternative-1	461	170
6	new system	new system	Alternative-2	Alternative-1	533	185
7	new system	new system	Alternative-3	Alternative-1	596	215

As expected, developing brand new systems for the D&T and aircraft system, combined with high capability COIL beam and AO system alternatives, produces the maximum possible capability (assuming that requirements will not change) but also the highest development time. Systems that provide the highest level of performance also have the lowest initial readiness-levels, which, in turn, means high development risk. Conversely, utilizing legacy systems with a relatively high readiness-level (e.g., STSS, alternative-1 for the COIL beam system, and alternative-3 for the AOS) results in the shortest development time but also the lowest capability-level. The model results, at these extremes, are verified with our intuition.

A new aircraft system is always preferred. Recall that the aircraft does not impact the ABL capability here but contributes to the development time. Furthermore, for the first five non-dominated solutions, the COIL beam system that has the lowest capability (e.g., 3 MW of power output) is selected. This means that the expected development time to be incurred to achieve higher power output is not worth the increase in the ABL capability (for the assumed risk values used here). Conversely, the Adaptive Optics System selected for the last four solutions (4–7) is the alternative that provides the highest capability. This means that the expected higher development time of this system justifies the potential capability that it can provide to the ABL. These results align with the observations of Barton et al. (2004), who showed in their sensitivity studies of the ABL capabilities that improvements in the COIL beam power output are not as critical as the ability of the Adaptive Optics System to correct for the atmospheric disruptions and deliver the required energy to the target.

Although the capability and initial readiness-level values of the candidate systems in this study were assumed, the trade-off study represents a very real decision-making situation for system engineers doing AOA in pre-milestone B portions of the acquisition process. The approach could be improved by using physics-based modeling tools for technical capacity and initial readiness-level estimation, as well as process modeling for the impact of disruptions under different system implementation strategies. The CEM enables this type of investigation by considering the relatively explicit inherent development risk of component systems as well as the implicit risk due to system interdependencies.

Conclusions

The development of complex systems (and SoS) is beset by risk. Risk analyses of individual systems can explain the threats and opportunities of systems but do not capture the impact that disruptions to individual systems have at the enterprise level, where multiple systems—explicitly or implicitly interdependent—collaborate to achieve various capabilities. The presence of interdependencies in layered networks of development systems often result in increased risk and higher order disruptions that are not always visible or predictable. The network structure behind the collaboration can contribute both negatively and positively to the successful achievement of SoS capabilities and, even earlier, to the developmental success. Collaboration via interdependence may increase capability potentials, but it also contains concealed risk in the development and acquisition phases.

This paper considered the Airborne Laser system under development by the Missile Defense Agency to present the CEM, its parameters, and example trade-off studies between estimated completion time of the program and its potential capability. Results of the analysis of this simplified system revealed that a Pareto Frontier exists when the completion time of a project is compared to the potential capability that it can provide. In this example, only seven of the 81 combinations of alternative systems for the aircraft and detection and tracking systems were non-dominated solutions. The highest capability (and highest completion time) was achieved when all component systems were developed from scratch and, conversely, the lowest capability (and lowest completion time) was a result of utilizing mature legacy systems that require minimal modifications.

The Computational Exploratory Model presented here is an ongoing research effort that aims to provide a framework for the aggregation of the system-specific risk to the enterprise level. The extensions to the model presented here via a proof-of-concept application point to the ability of such a framework to quantitatively perform analysis of alternatives and enable knowledge-based acquisition. It is our goal to improve/facilitate the decision-making process of systems engineers and system integration by providing the means to model risk in the system development process and quantify the cascading effect of risk for families of systems, or SoS, as well as enable quantitative analysis of alternatives. Analytical models in pursuit of the same goals are also under development; one version of an analytical approach was presented at the 2010 Annual Symposium.

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Acknowledgments

The authors acknowledge the support for this work from a grant from the Naval Postgraduate School's Acquisition Research Program (N00244-10-1-0021).

System-of-Systems Acquisition: Alignment and Collaboration

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Abstract

System-of-systems (SoS) acquisition research has identified lack of alignment and lack of collaboration as two important issues leading to problems in SoS acquisition. This paper captures the exploratory work toward improving alignment between and collaboration among the individual system programs in the development of a SoS. A collaborative web-based system is proposed, on which personnel of all programs associated with a SoS can input and retrieve information required to align the individual programs. The overall development of the SoS and component systems is treated as a critical-path network and the need points for component system inputs are identified as intermediate milestones requiring SoS-component system collaboration. An attraction mechanism to effect SoS inter-program collaboration is incorporated in a model capturing this web-based SoS collaborative system. Simulation using this model then provides results to establish the feasibility of such a SoS collaborative system. This work forms a basis for building a web-based SoS collaborative system to support Department of Defense SoS acquisition programs.

Introduction

The most common type Department of Defense (DoD) systems of systems (SoS) development is one in which a SoS is to be created by integrating separately developed systems—legacy systems, developmental systems, or some combination of both. Research in SoS acquisition has identified lack of alignment and lack of collaboration as two important issues leading to problems in SoS acquisition. By lack of alignment it is meant a system is not ready for its integration into a SoS, or, because of the lack of the front-end SoS systems engineering (SE), the SoS integration discovers that the system does not meet the performance requirements or the interface requirements. By lack of collaboration it is meant the individual system programs fail to work with each other to achieve the goals of the SoS program.

SoS acquisition requires the availability of surrogates of component systems and later the "as built" component systems in a timely manner in order to support SoS integration testing. However, the acquisition schedules for the component systems are typically developed independently of the SoS development schedule. There is thus no assurance that the SoS integration testing can be completed as planned, resulting in the SoS schedule slip and associated cost overrun. Even when the schedules are aligned, but because of the lack of the front-end SoS SE, a system, during the SoS integration, may not meet the performance requirements or the interface requirements or there may be misalignment of resources to support SoS integration testing, such as, for example, the absence of component system experts to support SoS integration testing.

The lack of alignment is related not only to the front-end SoS SE in the SoS acquisition, but also to the lack of collaboration. Collaboration in the development of a SoS is multi-dimensional—between DoD system program offices, between contractors, and between DoD program offices and contractors. "Inter-organizational collaboration has been cited as a critical requirement for successful outcomes; and for those agencies struggling to achieve their goals, lack of inter-organizational collaboration has been cited as a factor accounting for failure (Kirschman & LaPorte, 2008). Inter-organizational collaboration requires collaborative capacity. Mirroring the definition of collaborative capacity by Hocevar et al. (2007), collaborative capacity in SoS acquisition is defined as the ability of individual system programs to enter into, develop, and sustain inter-system programs in the pursuit of SoS collective outcomes. Such collaborative capacity is needed, in addition to contracting structure and organizational structures (Rendon, Huynh, & Osmundson., 2010; Huynh, Rendon, & Osmundson, 2010), to effect resolution of the SoS acquisition issues raised in (Osmundson et al., 2007). These issues are initial agreement, SoS control, organizing, staffing, team building, and training data requirements, interfaces, risk management at the SoS level, SoS testing, measures of effectiveness, emergent behavior.

The issues addressed in this research are not just the ability of individual system programs to "enter into, develop, and sustain inter-systems programs," but also the approach to and mechanism of inducing or motivating the individual system programs to develop and maintain such an ability. The mechanism is intended to remove barriers against and implement factors favorable to the realization of collaborations among the individual system programs. The approach proposed in this work to bring about collaboration among the individual system programs is to combine this mechanism and the implementation of a front-end SoS SE in the SoS acquisition. As the lack of alignment is tied to both the lack of the front-end SoS SE in the SoS acquisition and the lack of collaboration, the collaboration brought about by this approach in turn aids in improving the alignment of the individual system programs.

As constrained by the scope of this paper, the front-end SoS SE in the SoS acquisition is not discussed here. Its discussion can be found in Huynh et al. (2010). A quantitative analysis of the benefits of having the front-end SoS SE in the SoS acquisition in SoS acquisition is currently conducted as part of a master's thesis (Heng, 2011). This paper is focused only on collaboration among the individual system programs as it is related to the misalignment issue.

Enhancement of program collaborations might include re-organization of program structures, creating new program structures, and use of incentives. These techniques, however, are not necessarily the only means to effect enhancement of program collaborations. In this work, the key idea underlying the approach proposed here is the collaborative behavior observed on some existing web-based systems. That is, we extend what has been done with web-based collaborative systems to a system to facilitate the development of a SoS through collaborative behavior from the individual system programs. The web-based system concept inspires the mechanism proposed in this research for inter-program collaboration. To quantify the performance of the inter-program collaboration, modeling and simulation (M&S) is employed, incorporating factors that directly contribute to and barriers that prevent the enhancement and sustainment of collaboration among inter-system programs.

System-of-systems (SoS) modeling and simulation has recently been applied to the problem of engineering SoSs in order to prevent undesired emergent behavior (Osmundson, 2009a). Example SoSs that have been studied are the collateralized debt obligation market (Osmundson et al., 2009b) and the North American electric power grid (Osmundson et al., 2008). Theoretical studies of these SoSs have also been carried out to validate the results from the modeling and simulation work (Huynh & Osmundson, 2008; Huynh & Osmundson, 2009). The results of these studies indicate that SoS modeling and simulation can be used, at least in some cases, to predict undesired emergent behavior in SoSs that consist of engineered systems and non-engineered systems, including people, and to identify ways to prevent or mitigate undesired behavior.

Essentially, to deal with the lack of alignment and collaboration in SoS acquisition, we recommend that a SoS acquisition program institute an overarching front-end SoS SE in the SoS acquisition program and to implement an approach to achieving collaboration among the individual system programs.

In this paper, a collaborative web-based system is proposed, on which personnel of all programs associated with a SoS can input and retrieve information required to align the individual programs. The overall development of the SoS and component systems is treated as a critical-path network and the need points for component system inputs are identified as intermediate milestones requiring SoS-component system collaboration. An attraction mechanism to effect SoS inter-program collaboration is incorporated in a model capturing this web-based SoS collaborative system. Simulation using this model then provides results to establish the feasibility of such a SoS collaborative system.

Our goals in this paper are as follows:

- Discuss in some detail some existing web-based collaborative systems;

- Explain our exploratory work toward improving alignment between and collaboration among the individual system programs in the development of a system of systems; and
- Elucidate the approach proposed in this research for achieving collaboration among the individual system programs.

The rest of the paper is organized as follows: We first describe and explain the web-based collaborative systems; then we discuss modeling and simulation of the web-based collaborative systems; next we continue with a discussion of the SoS inter-program collaboration approach; and finally we end with some remarks.

Web-Based Collaborative Systems

The Underlying Idea of Web-Based Collaborative Systems

Many web-based systems are based on what is known as network effect:

> [A] network effect (also called network externality or demand-side economies of scale) is the effect that one user of a good or service has on the value of that product to other people. When network effect is present, the value of a product or service increases as more people use it. ("Welcome to Wikipedia," n.d.)

When the network effect is present, the value of the system to customers or collaborators is thus dependent on the number of customers or collaborators already using the system.

Network effects become significant after a certain number of people have subscribed to the system, called the critical mass. At the critical mass point, the value obtained from the good or service is greater than or equal to the price paid for the good or service. Cost also incurs in using a web-based. Cost could be payment of money for a service or product, time to prepare inputs for the system, time spent using the system before a match is found, or a loss associated with the risk of using the system such as not receiving goods paid for, receiving incorrect goods, or some other loss. There may also be some cost associated with attracting the participants. At the critical mass point, the value obtained from the system is greater than or equal to the cost encountered when obtaining the good or service provided by the system. As the value of the good is determined by the user base, this implies that after a certain number of people have subscribed to the service or purchased the good, additional people, because of the positive value/cost ratio, will subscribe to the service or purchase the good.

Prior to reaching the critical mass, and depending on the system type, the system must attract early adopters by investment capital, incentives, or other means. In the interim, before the critical mass is achieved, some early adopters may drop out of the system because of lack of perceived value, while others join the system. Thus, the success of a web-based system depends on achieving a critical mass of subscribers before the effectiveness of attracting additional subscribers to the system is exhausted.

The system factors that determine the success or failure of a web-based system include the number of subscribers or participants as a function of time; the factors that attract a subscriber; the factors that cause a subscriber to leave the system; the value of the system's services or to the subscriber/participant; and the cost of the system's services or products to the subscriber/participant. The term 'participant' will be used exclusively hereafter, as the individual system programs are 'participants', although in a strict sense the term 'subscriber' more properly refers to someone who pays for a service while a participant refers to a person who invests time and effort to obtain a product or service, but does not pay money for it. It is assumed that a participant wants to find a match in the system—the match may be with another participant, or with a product or service provided by the system that meets the participant's search criteria. Value to the participant is associated with finding a match.

Examples of Collaborative Systems

The type of web-based system of most interest is a collaborative enterprise whose success depends on the number and quality of the participants, but not on how much revenue the system attracts. Examples of this type of system are those that are established to facilitate a process through collaborative behavior such as eBay, Facebook, and the Zerox Eureka system.

eBay is an online auction and shopping website in which individuals and businesses buy and sell a wide variety of products and services. eBay was founded in 1995 and experienced very rapid growth. By the second year of operations eBay hosted 250,000 on-line auctions, and 2 million on-line auctions the following year ("eBay," n.d.). Facebook is a social networking website that began in February 2004 and had more than 500 million participants by July, 2010 ("Statistics," n.d.). Participants maintain personal profiles, can add people as friends, send messages to friends, notify friends about updates to their profile, and access friends' profiles. The Eureka system, developed by Xerox ("The Eureka Project," 2010), allows customer service engineers to share validated tips on problems encountered and solutions on Xerox's family of copier machines. The system is an example of a net-based community of practice within an organization. Customer service engineers browse the Eureka system to see if there is a known solution to a problem that they are encountering. Five years after its introduction, the Eureka system had been widely adopted by Xerox technicians and has resulted in significant savings in time and parts cost (Bobrow & Whalen, 2002).

Modeling and Simulation of Collaborative Systems

The SoS modeling and simulation approach discussed in the Introduction section is used in this research to model a system of individual system programs collaborating to form a SoS. This M&S approach has been illustrated with eBay, Facebook, and Eureka (Osmundson & Olgerson, 2011). To be self-contained, this paper briefly discusses the M&S approach and results of these collaborative systems.

This M&S approach considers a collaborative system to consist of people, databases and other elements. People interact with one another directly, through databases and/or other elements to achieve outcomes. The collaborative system models are populated with an initial population of users, database items, and other necessary elements. Users are assumed to want to match with other users or database items, and individual user's desire to join the system and remain a part of the system is assumed to depend on their success in finding matches. Further, the probability of finding a match is assumed to depend on user and database item populations, the type of collaborative system, and the number and standard deviations of the parameters that are required to determine a match. People's choices are heavily influenced by other people's choices. Thus, if a SoS reaches some critical threshold in terms of number of users and/or number of successful interactions—hits—one would expect the SoS to be successful. On the other hand, if users are unsuccessful in obtaining useful matches with the system, the assumption is that they will withdraw from the system, thereby reducing the user population and the number of hits. At some point in time the population should keep growing, reach a stable, useful level, or decline to a point where the system is no longer viable.

The probability of matches may depend not only on match parameters but also on the manner in which the parameters are retrievable by the users. Each model of a specific type of system has one or more probability models appropriate to the type of system. There can also be competitive behavior. For example, users may want recognition for having the most hits on their blog and therefore may compete with other users in creating content.

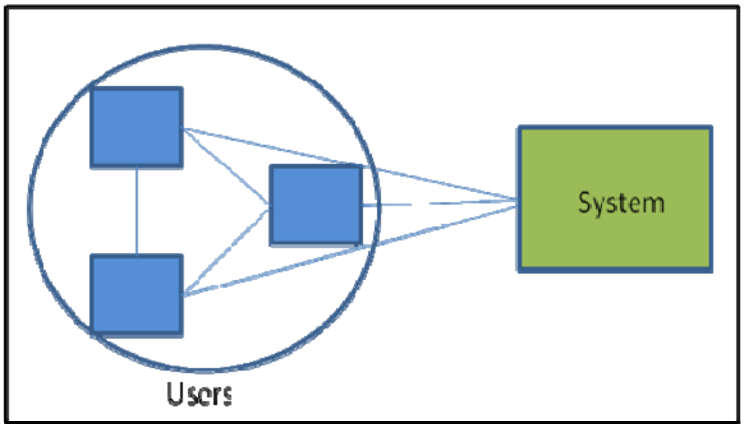

Figure 1. Abstract Form of Web-Based Systems Model

Three types of discrete-event models represent eBay, Facebook, and the Xerox Eureka system. Each model assumes a specific type of attraction mechanism, unique to each system, which attracts sufficient users over time, resulting in a successful system whose value exceeds its costs. In Figure 1, the users interact with other users and/or the web-based system. In each case there is a small initial seed population of users. If the users are attracted to one another and/or to the system in sufficient numbers, over time a successful net presence ensues. The key to this type of system is the attractor mechanism, which is the mechanism that provides value to the users while at the same time a cost is imposed on the users. The cost could be a monetary fee and/or—more likely in many cases—the time and effort required to participate in the system and the potential risk in participating in the system. Each of the models of the three types of systems are implemented in Extend,©[1] a discrete-event modeling and simulation tool, and results of each of the three types of models agree closely with real world data.

Cost and value are specific to each example system. As the eBay model represents on-line sellers and buyers of a variety of goods, the value to the seller is low cost of sales and potentially a large number of buyers and the value to the buyer is a wide selection of goods at low prices. These values are functions of the number of users over time; as the number of sellers and buyers increases the value to both parties increases. There are also costs to the seller and buyer. The seller is at risk of not being paid and the buyer is at risk of not getting the goods at all or getting miss-represented goods and/or suffering identify theft. Initially these risks were relatively high, but as improvements to eBay over time, such as introduction of seller ratings and use of Pay Pal, these risks declined. Thus the value-to-

[1] Extend is a product of Imagine That Inc., 6830 Via Del Oro, Suite 230, San Jose, CA, 95119 USA.

cost ratio can be represented by the time-dependent number of eBay users and an S-curve function representing declining risk over time. The rate at which sellers enter the system is dependent on the number of buyers in the system. The buyers' risk factor is given by an S-curve function. A detailed discussion of the simulation results of the Extend eBay model, as well as the Extend Facebook model and the Extend Eureka model, is in Osmundson and Holgerson (2011). In this paper, it suffices to point out the agreement, as shown in Figure 2, between the simulation results and the eBay user growth data.

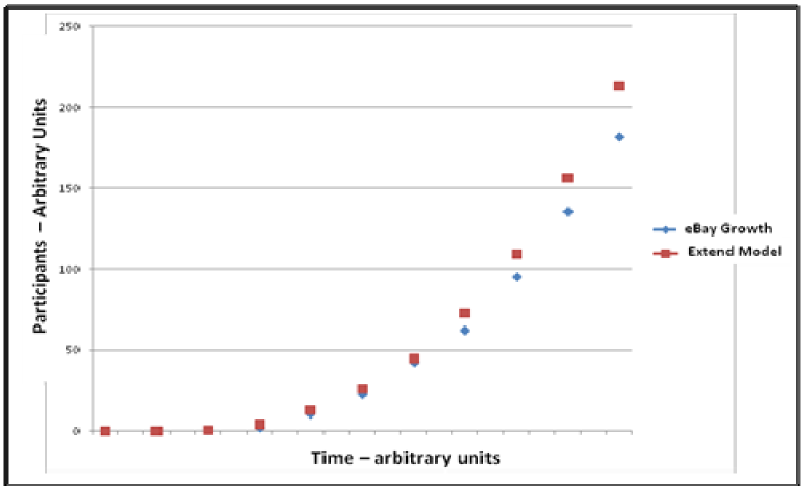

Figure 2. Results of the Extend eBay Model
("eBay.com's Site Profile," n.d.)

Note. Red markers are model results, and blue markers are eBay actual growth numbers ("eBay.com's Site Profile," n.d.).

The Facebook model represents people who want to form social networks with their friends. The value to each individual is the ability to communicate on a regular basis with a large number of friends by posting text and pictures to their Facebook homepage, which can be viewed by their friends. Value increases with the number of friends added up to a point where the cost of maintaining meaningful connections is outweighed by the incremental value of adding additional friends or becoming a friend on another person's site. There is an initial population of participants and new participants arrive at a rate proportional to the total population. Participants look for a match—that is, a friend, and the probability of finding a friend is proportional to the total population. As shown in Figure 3, the Extend model results fit the actual Facebook population data fairly well through the first 41 months, but beyond that point the model population grows at a rate faster than the actual population. The Extend model is a very simple model and does not include any saturation effects such as might occur if the early adopters of Facebook are more likely to find friends among a given population than are late arrivals, or if the Facebook population begins to approach a limit of all possible networked users.

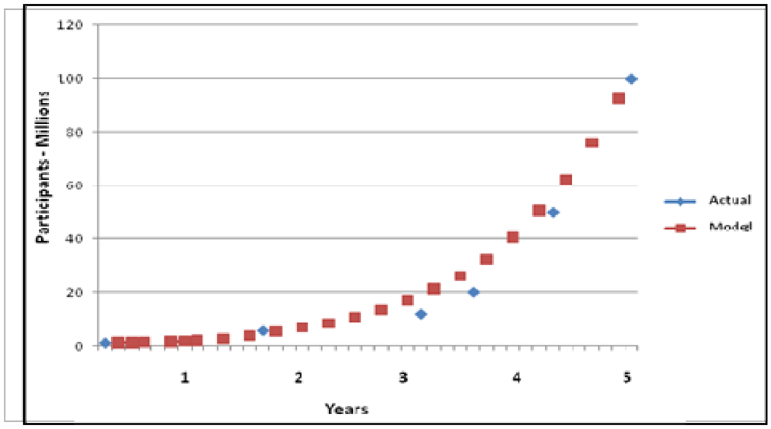

Figure 3. Results of the Extend Facebook Model

Note. Red markers are model results and blue markers are Facebook actual growth numbers (Statistics, n.d.).

The Eureka model begins with generation of experts who initially are assigned problems randomly; the experts then enter tips for solving each of the problems. This generates an initial set of validated tips. Other technicians are generated next. The experts are randomly assigned new problems, they check the data base for tips and if a tip exists they utilize it and solve the problem quickly. If no tip exists they take a long time to solve the problem and, with some probability, enter either a new tip or not. The probability of entering a new tip is given by an S-curve function that is dependent on the number of times a given person's tips have been utilized. This reflects the fact that technical workers are highly motivated by peer recognition and is consistent with Xerox's experience.

The Eureka model was initially run and the probability with which technicians checked the database was adjusted until a best fit was obtained with real world data. The best fit occurred when the probability of checking the database at a given time was set to 0.4T/P, where T is the number of tips generated up to a given time and P is the total number of problems that are expected to be encountered. Based on available data on Xerox's Eureka system, the initial number of tips was 100–200 ("The Eureka Project," 2010), the total number of technicians during the first 5 years of use was 19,000, the number of technicians participating in the Eureka system after 5 years was 15,000 and the total number of unique vetted tips after 5 years was 36,000. The total number of problems to be solved was not available; for purposes of calibrating the model the total number of problems was assumed to be 50,000. It was also assumed that it took an average of 1 hour to solve a problem with a tip and an average of 8 hours without a tip and that technicians completed approximately one trouble call per day. Jack Whalen (personal communication, October 14, 2010) estimated that non-routine problems occurred more frequently than once per week, but less frequently than once per day.

The most important measure of effectiveness of this type of system is the participation rate. The participation rate drives the number of new tips generated over time and is the main factor in determining the reduction in time to solve problems. Participation rates at the end of one year and at the end of five years, as a function of initial tips and total expected problems, are shown in Figures 4 and 5, respectively. The results clearly show that the ratio of initial tips to number of expected problems to be encountered is critical to success, particularly in achieving a reasonably high rate of technician participation.

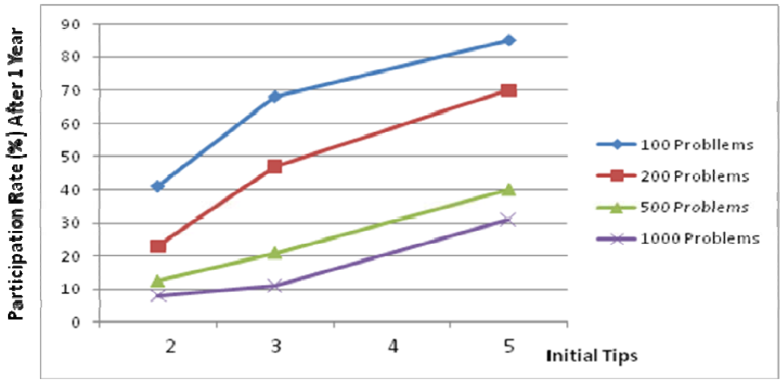

Figure 4. Participation Rate After One Year as a Function of Initial Tips and Number of Problems to be Encountered

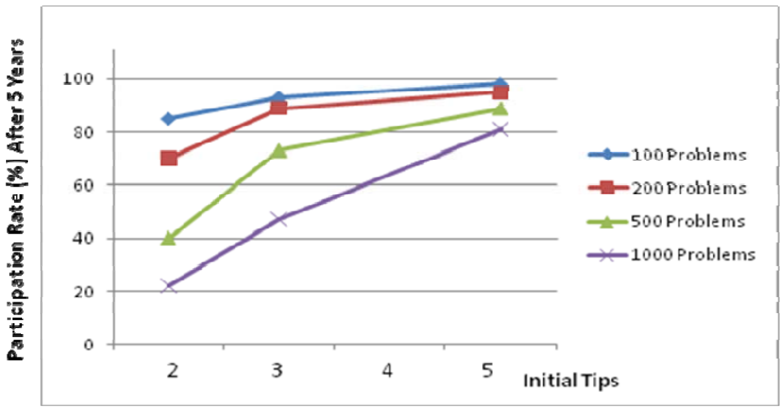

Figure 5. Participation Rate After Five Years as a Function of Initial Tips and Number of Problems to be Encountered

SoS Inter-Program Collaboration Approach

As discussed in the Introduction section, collaboration among the individual system programs participating in a SoS acquisition depends on the presence of mechanisms to induce the willingness on the part of the individual programs to collaborate and to enable their collaboration. Mechanisms can include formalized structures for coordination; formalized processes including meetings, deadlines, etc.; sufficient authority of participants; clarity of roles; and assets such as personnel that are dedicated for collaboration. Lateral mechanisms can include interpersonal networks, effective communication and information exchange, technical interoperability, and training (Hocevar et al., 2006). As discussed in the section on Modeling and Simulation of Collaborative Systems, a web-based service-oriented architecture is an efficient means of providing a mechanism that provides many of the mechanistic requirements for collaboration. However, successful web-based collaboration is highly dependent on the value/cost ratio that applies to a given system.

Like eBay, Facebook, and Eureka, the collaborative system envisioned for SoS acquisition needs to have an attraction mechanism—to attract the individual programs to collaborating with the other programs to achieve the objectives of the SoS acquisition program. Such a mechanism, just like those implemented with eBay, Facebook, and

Eureka, should be highly related cost and value of collaboration, as it provides value to the participating programs while at the same time a cost is imposed on them.

Each individual program invariably is burdened with the production of a system with required performance on schedule and within budget. Consequently, the value and cost derived from collaborating with the other programs are related to these parameters—performance, schedule, and budget. There is also, however, another element that can highly motivate participation in a collaborative system—recognition. Value is in terms of recognition. In the Eureka system, if technicians see that another worker has been recognized for providing a tip for solving repair problems, they too will want similar recognition and will be motivated to enter a new tip. If a technician sees that his own tip has been useful to others, he will be motivated to provide additional tips in order to achieve further peer recognition. Thus, in addition to promoting value and compensating for cost, recognition should be instituted for contributing to the development of the SoS acquisition. But, in what form should recognition be realized—money, promotion, reputation, rewards beyond a program manager's tour on the program? And to whom should recognition be attributed—just to the program managers, or to the entire team?

Some contributors to the cost of collaboration, hence the barriers to collaboration, are observed. The cost of dedicating their resources to developing the parts that are required to satisfy the SoS requirements. The cost to program personnel collaborating in this effort is the additional time spent on executing the SoS part of the system. The cost associated with a potential delay in the development of their own systems, caused by their participation in the SoS development. The individual programs that are not compensated for these costs will more than likely decline to participate or pay lip service to collaborating in the SoS acquisition.

Assessing value for collaborating is more problematic. There is high value to the overall SoS through keeping the individual system programs aligned in order to support SoS testing, but there is not necessarily much value to each individual component program. Program managers are typically rewarded for producing the desired system, on time and within budget, but they are not presently rewarded for aligning their programs with other programs. Value to individual program managers and program offices must be provided in order to achieve effective collaboration.

The system factors that determine the success or failure of this collaborative SoS acquisition system include the number of participating programs which depend on the aforementioned incentives, the factors that attract a collaborator, the factors that cause an individual program to continue to buy in collaboration, the values of the SoS to the participating programs, and the cost or risks to their programs. As in the web-based collaborative systems discussed above, it is assumed that a participant wants to find a "match" in the collaborative system. That match need be understood for the collaborative SoS acquisition system. Value to the participant is associated with finding a match.

One mechanism that holds promise for meeting many of the requirements for inter-program collaboration is a web-based service-oriented architecture system on which personnel of all programs associated with a SoS can input and retrieve information required to align the individual programs:

> Service Oriented Architecture (SOA) is an architectural paradigm and discipline that may be used to build infrastructures enabling those with needs (consumers) and those with capabilities (providers) to interact via services across disparate

> domains of technology and ownership. Services act as the core facilitator of electronic data interchanges yet require additional mechanisms in order to function. Several new trends in the computer industry rely upon SOA as the enabling foundation. (www.adobe.com)

As discussed in the Introduction section, to achieve a successful SoS acquisition, we propose a web-based service-oriented architecture on which personnel of all programs associated with a SoS can input and retrieve information required to align the individual programs.

The overall development of the SoS and component systems is treated as a critical-path network and the need points for component system inputs are identified as intermediate milestones requiring SoS-component system collaboration, typically a joint review. This approach is consistent with knowledge-based acquisition, since the SoS development proceeds only as the required component information is available. In this work we analyze the development of a SoS from a systems engineering perspective, identifying the points in the SoS development where information, surrogates, software and hardware are needed from the component systems. The web-based SoS acquisition system is envisioned to incorporate the knowledge-based acquisition approach.

An Extend model is built to capture this web-based service-oriented architecture. An attraction mechanism is incorporated in the model. Simulation of this model then provides results to establish the feasibility of such a SoS collaborative system.

Conclusion

System-of-systems (SoS) acquisition research has identified lack of alignment and lack of collaboration as two important issues leading to problems in SoS acquisition. This paper captures the exploratory work toward improving alignment between and collaboration among the individual system programs in the development of a SoS. Inspired by some existing web-based collaborative systems, such as eBay, Facebook, and Eureka, a collaborative web-based system is proposed, on which personnel of all programs associated with a SoS can input and retrieve information required to align the individual programs.

The overall development of the SoS and component systems is treated as a critical-path network and the need points for component system inputs are identified as intermediate milestones requiring SoS-component system collaboration. An attraction mechanism to effect SoS inter-program collaboration is incorporated in a model capturing this web-based SoS collaborative system. Simulation using this model then provides results to establish the feasibility of such a SoS collaborative system.

This work forms a basis for building a web-based SoS collaborative system to support DoD SoS acquisition programs.

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Using Architecture Tools to Reduce the Risk in SoS Integration

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Abstract

DoD acquisition is evolving from the traditional approach focused on individual systems to system-of-systems (SoS) integration. In DoD terminology, SoS is a collection of systems integrated together to obtain a higher level system that offers more than the sum of its parts, though the individual systems are acquired independently. System interactions within the SoS typically produce emergent capabilities that may or may not be desired. Any undesired behavior represents an integration risk and must be recognized, analyzed, and understood. Architectural tools are evolving to provide this understanding. These tools can be used for analyses of SoS designs to predict unexpected couplings and to avoid the potential for missed, underutilized or duplicated functionalities. Architectural artifacts developed with these tools expose potential issues to the design community. In addition, these artifacts provide a foundation for integration test planning by identifying and documenting the interfaces between hardware, software and humans that constitute the SoS. This presentation describes the related concepts and processes.

Systems-of-Systems and Systems

The term "system-of-systems" needs some discussion. A number of interpretations are in use by the systems engineering community. In a certain sense, "every system is a system-of-systems." Since every system-of-systems is, by definition, also a system, this way of thinking leads to a tautology that is not very useful.

One of the possible SoS definitions has been proposed by Mark Maier (famous Eberhardt Rechtin's collaborator on *The Art of Systems Architecting*) in his 1998 paper "Architecting Principles for Systems-of-Systems." To summarize Maier's definition of SoS,

1. SoS components must be able to usefully operate independently.
2. SoS components are independently acquired and maintain independent management existence.
3. SoS continues to evolve.
4. SoS exhibits emergent properties.
5. SoS components interact only by information exchanges (are geographically distributed).

This definition defines a subclass of the more general concept of a system. Hence, according to this definition, every system-of-systems is a system but not every system is a system-of-systems. As discussed in the following, the ideas contained here can be explored with useful outcomes.

Since Maier's definition consists of multiple parts, it leads to several weaker forms, each defining a subset of the set of systems with the class of system-of-systems defined according to Maier being as their set theoretical intersection. Below, this definition is examined more closely, with the conclusion that the most important characteristic of the SoS defined with it is the first part stating that SoS components must be able to "usefully operate independently." Thus, for example, a bicycle is a system but not a system-of-systems. There are parts of the bicycle, such as the frame, that cannot "usefully operate independently," except perhaps with some very creative ideas.

Interestingly, the criterion of operational independence immediately brings to mind the concept of a system consisting of loosely coupled objects known from discussions of open architectures. However, for these objects to form a system-of-systems, they also have to be able to completely decouple and act independently, in addition to being loosely coupled. Thus, there may be open architecture systems that are not systems-of-systems, and systems-of-systems that are not open architecture. Since it is possible to find examples of systems-of-systems with open architectures, such as for instance the Internet, the most one can say is that the intersection of the two sets is not empty.

The second part of Maier's definition, the criterion of managerial independence, requiring components of the SoS to be independently acquired and maintaining independent existence is a qualifying attribute that is perhaps not as important for the formal definition of system-of-systems in general settings. In his paper, Maier further distinguishes between "directed," "collaborative," and "virtual" systems-of-systems that represent variations on the degree to which the SoS satisfies this condition. A "virtual" SoS satisfies this condition completely, a "directed" SoS satisfies it to the least extent and a "collaborative" one falls somewhere in between. Maier's examples of virtual systems-of-systems include the World Wide Web and national (and even more so) international economies. The Internet, on the other hand, is presented as an example of a collaborative system-of-systems, governed by the Internet Engineering Task Force by means of standards published in the form of Requests For Comments (RFC). An integrated air defense network, such as NORAD, centrally managed to defend the US, is an example of the directed kind of SoS. One could say the need for including this criterion in the definition of a system-of-systems is somewhat questionable even for DoD acquisitions, because many DoD system-of-systems are acquired and managed by one and the same organization, the DoD, although its many branches do operate independently, to a degree.

As for the third part of Meier's definition, it can probably be safely stated that the evolution of a system-of-systems could already be a natural consequence of the fact that its components are independently acquired and maintain independent existence, including independent evolution. On the other hand, any system of sufficiently large size evolves out of necessity to keep operating. This may be forced by high cost of its replacement. Loose coupling of components in an open architecture system is a characteristic designed for facilitating this evolution.

It is also debatable if "emergent properties" are truly a characteristic limited to systems-of-systems. First of all, there is a problem with the word "emergent." This word carries an aura of mystery. It has given rise to its own school of philosophical thought going back to the post-Darwinian England. "Emergentists" included such luminaries as J. S. Mill. In his 1843 opus, *A System of Logic, Book III*, he expressed the idea that "to whatever degree we might imagine our knowledge of the properties of the several ingredients of a living body to be extended and perfected, it is certain that no mere summing up of the separate actions of those elements will ever amount to the action of the living body itself" (Ch. 6, § 1). The term continues to be used in biology literature to this day.

Although it must be conceded that some systems and their properties are so complex that they cannot be computed even today, the properties of every system can be unexpected or expected depending on the level of understanding of the system behavior characterized as "emergent." To quote Arthur Clarke (1961), "Any sufficiently advanced technology is indistinguishable from magic." However, such esoteric situations are outside the scope of this paper.

The point being made is that the properties of any system are always more than the "sum of its parts." Thus, "emergence" is not a qualifying attribute that distinguishes systems-of-systems from systems in general. The emphasis of this paper is on finding ways to prevent potential undesirable "emergent" effects. All passengers of commercial air transport feel much more comfortable thinking of an airplane as a system rather than a "collection of parts flying together in close proximity." However, it is very desirable to know and understand all possible "emergent" properties of this system.

The fifth of the Maier's criteria is very applicable to computer networks, which must have been the focus of the systems-of-systems engineering in 1998. However, a common example of a system-of-systems satisfying this criterion is provided by any group of human beings, and these go back much further in time. Human beings exchanged information by voice, paper and other methods long before computers were even conceived of. Perhaps methods developed by the systems-of-systems engineering can find fruitful application in the field of sociology. On the other hand, restricting the entire systems-of-systems discipline to those that are geographically distributed and interact only by information exchanges may be overly limiting. It may be more productive not to impose it.

In the following, consideration is given to systems-of-systems defined either in the strict sense by the full set of the five criteria in Meier's definition or a wider class defined by its weaker form consisting of just a subset of these satisfying at least the first one of them.

Elements of Risk (and Opportunity) in Systems-of-Systems Integration

There are many forms of risk associated with the development and integration of any system. Some risks are technical and some programmatic. A full investigation of all systems-of-systems integration risks was outside the scope of this effort. A more complete discussion may be presented in the future. The intent of this paper is only to highlight the usefulness of the architectural products in mitigating these risks in general. The discussion is limited to selected types of risk that appear to be mostly associated with systems-of-systems, as a set of examples as follows:

1. Missed/underutilized functionalities and/or interfaces of the component systems.
2. Undesirable emergent behavior, sneak interactions and unintended consequences.
3. Independent components evolution drifting to non-compliance with original standards.
4. Evolving SoS not following stakeholder needs.

A very significant form of risk associated with integration of systems consisting of independent systems is that of potentially missed or unidentified functionalities and/or interfaces of the components systems. These would then remain untested while the system is being integrated and could “show up” suddenly when the system is deployed and in use. This can happen because the components systems of the system-of-systems are not being designed to specifications flowing down from the requirements set of the system-of-systems but are used “as they are.” Being independent, the component systems are not modified for integration into a system-of-systems by their original developers but are only “stitched together” to provide a new desired functionality at a higher level.

Of course, if a particular functionality of a component system is not initially recognized and is discovered, this could also represent an opportunity for making the system-of-systems more efficient and less costly. Otherwise, undiscovered functions represent a very real risk of failure when the system is put in operation and two formerly unidentified functionalities of the components systems interfere with one another. Similarly, an unidentified interface could represent a risk of the system simply not functioning as necessary or interfering with the desired operation. Undesirable emergent behavior, sneak interactions and unintended consequences are all potential manifestations of the risks of missed functionalities or unidentified interfaces having been realized.

Since the components systems of the system-of-systems are independent and therefore independently evolving, they could evolve away from the original standards they complied with when they were initially selected by the system-of-systems architects to the point where they will no longer fit with the rest of the system-of-systems. In the integration construct represented by a system-of-systems, especially one of the “virtual” category, the original interfaces and functionalities of the system-of-systems component systems can be defined solely by means of voluntarily followed standards. If these are the only means of “control” over the evolving components, nothing prevents the developers and manufacturers of these component to switch to a different standard or discontinue their products altogether. When the original product was not widely available from many sources, it may no longer be available at some point in time. Such possibility represents a kind of risk that at the parts level that the logistics discipline treats as Diminishing Manufacturing Sources and Material Shortages.

Uncontrolled evolution of a system-of-systems can lead to a paradoxical situation where it no longer satisfies the evolving needs of its stakeholders. This situation may continue for some time in some cases, but eventually, the funding stop may be brought about for various reasons depending on the SoS under consideration.

Mitigation of Risk (and Extraction of Opportunities) in Systems-of-Systems Integration

This paper postulates that the systems-of-systems integration risks identified in the previous section can be mitigated with the help of architectural tools. The context for this use of architectures is the developing new Model Based Systems Engineering paradigm that focuses the three core systems engineering processes consisting of requirements analysis, system design and requirements verification and validation around a model of the system. Since systems-of-systems are systems, methods developed for reducing the risks associated with development of systems are applicable to the systems-of-systems.

The following discussion shows how the architectural tools can be used for mitigation of systems-of-systems integration risk examples identified in the previous section:

1. Use of architectural tools to identify component functionalities and interfaces
2. Use of modeling and simulations to predict undesirable emergent behavior, sneak interactions and unintended consequences
3. Use of open standards to permit use of suitable replacements for components that will not be available as time progresses (avoid proprietary interfaces)
4. Management of evolving SoS requirements

Architectural tools are highly relevant to the task of identifying component functionalities and interfaces. Primarily, these tools provide the means to generate a graphical form of documentation but also, at least with some of the tools available at this time, to verify consistency of the architectural information entered into the tool database.

Modeling and simulations come at many levels, from the highest system level to the details of physics and chemistry of the tiniest component. A great variety of modeling and simulations tools are being used throughout science and engineering as suitable and necessary. Architectural tools provide capabilities to model the system as it is defined by "business" rules, states and modes, and swim lanes. These are in the category of PETRI nets, executable UML/SysML, etc., that will be briefly discussed in the following section. The usefulness of this level of modeling and simulation consists of gaining insights into system level behavior and discovery of potential undesirable effects of integration of the formerly independent component systems into the system-of-systems in question. Analysis of these models can potentially uncover the so-called "sneak interactions" that weren't apparent at first sight and after integration could produce "unintended consequences." There are no guarantees that all such bad side effects of system-of-system design decisions can indeed be discovered as a lot depends on the skills of the modelers, however, without this effort even the simplest behaviors can remain hidden until disaster strikes.

Development of open architectures, open standards and open business models is a major DoD thrust expected to yield significant cost savings in all acquisition programs. The desired benefits can only be achieved if the program follows the open systems guiding principles from the start. Open system architecture requires an investment in infrastructure. Patching up an existing design at a system-of-systems level usually requires a major architecture redesign that may be a difficult cost-to-benefit ratio to justify.

The 2004 DoD Joint Task Force *Modular Open Systems Architecture (MOSA) Program Manager's Guide* lists five "principles" (that look rather like steps of a management process) necessary to achieve an open architecture system design. These principles are as follows:

1. Establish an enabling environment.
2. Employ modular design.
3. Designate key interfaces.
4. Use open standards.
5. Certify conformance.

Most of the contents of the MOSA guide could be categorized as programmatic (or SOW-type) requirements. It is, after all, a "program manager's" guide. Clearly, Principles 1 and 5 are program management responsibilities. Principle 2 is calling for a modular design, which in MOSA's terms means the following:

- The system is functionally partitioned into discrete scalable, reusable modules consisting of isolated, self-contained functional elements.
- System design makes rigorous use of disciplined definition of modular interfaces, to include object-oriented descriptions of module functionality.
- Components are designed for ease of change to achieve technology transparency and, to the largest extent possible, make use of commonly used industry standards for key interfaces.

Programmatically, modularity is a requirement to produce a set of architectural artifacts that show the modules with identified functions and interfaces. In technical terms, a list of required system functions needs to be identified and then allocated to a set of components in such a way that closely interacting functions are lumped together in one module while less closely interacting functions are split across different modules. This approach simply minimizes the interactions between separate modules, reducing the necessary number of interfaces between them. The resulting minimal set of interfaces is then carefully characterized and published, creating the openness of the architecture. This facilitates the design or acquisition of a replacement in case the original component system is no longer available on the market or better performance can be obtained with a software update.

MOSA's Principle 3 is calling for identification of the Key Interfaces. Again, according to the *MOSA Program Manager's Guide*,

> the focus of MOSA is not on control and management of all the interfaces within and between systems. It would be very costly and perhaps impractical to manage hundreds and in some cases thousands of interfaces used within and among systems. …A key interface is an interface for which the preferred implementation uses an open standard to design the system for affordable change, ease of integration, interoperability, commonality, reuse or other essential considerations such as criticality of function.

The MOSA guide tells the Program Manager (PM) that "Programs must determine the level of implementation (e.g., subsystem, system, system-of-systems) at and above which they aspire to maintain control over the key interfaces and would like these interfaces to be defined by widely supported and consensus based standards." Thus, the PM decides at what level the Open Architecture (OA) requirements flow down should stop. This requires careful considerations with architectural artifacts being a key ingredient.

The last but certainly not least risk example identified for the system-of-systems acquisition in the previous section was the risk that the system will simply evolve away from the stakeholders' requirements. Well, the most important step in mitigating this risk is to identify those stakeholders' requirements in the first place. One cannot see that the evolution of the system is drifting away from the target unless one has a clear picture of what this target is. Here again, the architectural tools come to the rescue.

Architecting is an integral part of the systems engineering iterations consisting of requirements analysis, system design and requirements verification and validation. Requirements are used to manage the entire process by clearly identifying the objectives of the system development. Systems engineering, as a discipline, evolved in the post World War II era to reduce the risk associated with acquisition of increasingly complex defense systems, beginning with the Inter-Continental Ballistic Missile (ICBM), through Ballistic Missile Defense (BMD), and so on all the way to today's software-intensive multilayer products consisting of thousands of humans and computers organized into networks distributed across several continents, air, sea and space. Identification of separate, individually defined requirements reduces this risk by reducing complexity. It is much easier to manage the development and evolution of a complex system if it can be broken up into smaller, more easily digestible pieces.

This contribution of architectural tools can be illustrated with the following figure that shows the standard process beginning from the elicitation of stakeholder requirements followed by development of system specs, followed in turn by system design and ending with system implementation. Obviously, this is a very simplified view of this process. In reality this process is highly iterative and ebbs and flows back and forth, challenging program management as iterations can accumulate program costs not originally budgeted for.

The risk of the system evolving away from the stakeholder needs consists of three sub-risks: risk of requirements gaps, risk of design gaps and risk of implementation gaps. Mitigating these three risks requires attention to the derivation of technical requirements from the stakeholder needs, conversion of the technical requirements to system design and the implementation of the design into a physical system. Gaps can appear in any part of this process. Each gap has its own mitigation method. For example, gaps that can occur in the requirements derivation step, from stakeholder requirements to system specs, are addressed with tools specialized for maintaining requirements traceability, such as the Dynamic Object Oriented Requirements System (DOORS). In the MBSE paradigm, the requirements derivation step is strongly supported by the architectural products.

The risk of design gaps potentially appearing in the transition from specs to design is addressed with a process architecture allocation in which requirements are allocated to specific parts of the system architectures (functional, system and physical). Clearly, architectural tools must be employed to produce the architectures required in this step.

Finally, potential gaps in implementation of the design into physical form are prevented with the Requirements Verification Matrix (RVM), which is used for managing the test program. Requirements verification is also supported with architectural artifacts in the form of graphical representations of systems connections into a system-of-systems.

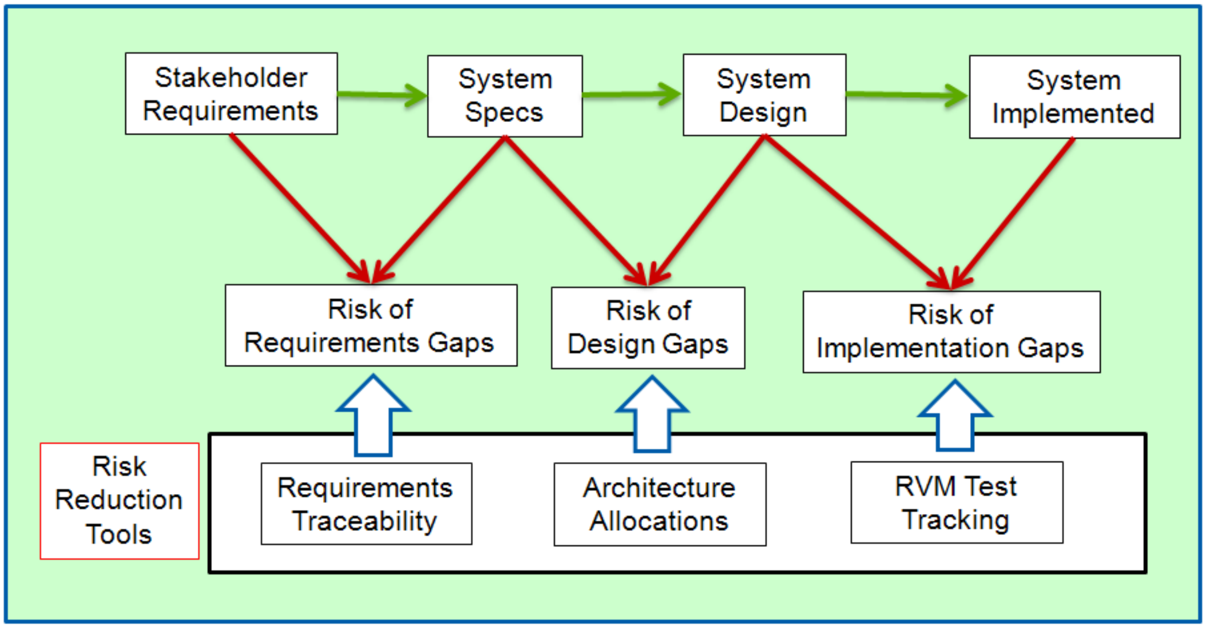

Figure 1. Architectural Tools Contribution to Risk Reduction in the General System Context

Architectural Tools and Products

Since the early 70s, an intensive effort has been underway to implement computer technologies in business environment. This effort has transformed the way we all work and live. The original leading agent of this change was IBM. Out of this organization came forth ideas that today are known under the name of Enterprise Architecture (EA). In his 1987 paper, "A Framework for Systems Architecture," John Zachman proposed a method for organizing the architectural artifacts into a matrix with six rows, corresponding to different levels of detail, and six columns, addressing the questions: what, how, where, who, when, and why. This construct became known as the Zachman Architectural Framework (ZAF). This brilliant idea was quickly adopted across a wide area of applications.

The DoD published its own C4ISR Architectural Framework in 1997, followed in 2003 by the DoD Architectural Framework (DoDAF), that by now is in revision 2.0, published in 2009. Other military organizations followed suite with the MoD Architectural Framework (MoDAF), NATO Architectural Framework (NAF), and so on. Civilian organizations were not far behind with The Open Group Architectural Framework (TOGAF), etc. Basically, the architectural frameworks define how to organize and structure the views associated with an architecture.

Computer science, another fast-developing field, brought us several generations of computer languages and programming approaches with the latest being the Object Oriented methodology incorporated into software development tools such as, for example, the Unified Modeling Language (UML). In 2006, the systems engineering community developed an extension of UML called the System Modeling Language (SysML) that can be used for modeling general systems.

Basically, SysML is a diagrammatic notation designed specifically to describe and understand general systems. Another category of graphical tools that can be used for the same purpose is the Integration Definition (IDEF) derived from the Structured Analysis Design Technique (SADT). DoDAF can be implemented with either the Object Oriented SysML or the Structured Analysis IDEF. DoDAF is another big subject, so the following is limited to the fundamentals.

DoDAF Operational Views

As mentioned previously, the Zachman framework defined six levels or viewpoints. The original, first version of DoDAF, used four: All-Views, Operational Views, System Views and Technical Views. The latest version of DoDAF, 2.0, defines eight viewpoints. Like in the Zachman's framework, each viewpoint in the DoDAF includes multiple types of views. This paper focuses on the most important operational view for this discussion, the OV-5, Operational Activity Model, and the two most relevant system views, the SV-1, System Interface Description and the SV-4, System Functionality Description. A more complete discussion of DoDAF products (views) recommended for SoS architecting can be found, for example, in the *Naval SoS SE Guidebook* (2006). Additional details can be also found in the original DoDAF documentation.

The Operational Views (OVs) are focused on the activities that are performed by the operators. They are normally developed as the first part of the analysis and assume that a system is a "black box," the details of which are as yet undefined. One starts with a very high-level overview, called OV-1, which is just a cartoon version of the proposed system in operation. Then, gradually, all operators, their activities and the information exchanges taking place are identified and documented with the OVs. In fact, the OV-5, Operational Activity Model, consist of boxes representing activities and arrows representing the information exchanges.

An OV-2, Operational Node Connectivity Description, presents a complementary picture where the boxes represent operational nodes containing aggregations of activities and lines represent bundles of information exchanges between activities allocated to each node. Each operational node is a collection of activities, an abstraction that can be used to represent geographic separation or some other form of organization. In DoDAF 2.0, the OV-2 was renamed Operational Resource Flow Description, to extend the application of this view beyond information exchanges to more general resource flows. As a consequence, the operational views in DoDAF 2.0 can now formally be used to represent systems that are more general than information systems.

Generally speaking, the OVs are very useful for analyses of the human side of the system-of-systems design, roughly corresponding to an expanded concept of Use Cases known to software systems engineers using UML. While the OVs view the SoS as a black box, the System Views (SVs) define its internal workings.

DoDAF System Views

The SV-1, System Interface Description, uses boxes to represent the component systems of the system-of-systems and arrows to represent the interfaces between the systems. Thus, the SV-1 is essentially a block diagram which shows how the system-of-systems is integrated from its components. As such, it is an essential tool for managing any integration process, including integration test planning. One cannot envision integrating any system without some kind of graphical representation telling the integrators how the components connect together.

What's needed to complete this picture is a view that describes the functions performed by every one of the components and various layers of the system-of-systems assembly. One can begin by marking up the functions performed by the system components within each box that represents them. When integrating a system-of-systems consisting of existing or otherwise known components, this part is relatively simple to accomplish.

One needs to remember, however, as stated in the beginning, that a system is more than a simple sum of its parts. Hence, multiple layers of system-of-systems integration need to be documented with multiple SV-1s to show the functions emergent for every assembly of component systems, assembly of assemblies, and so on, to the final layer representing the complete system-of-systems as a single box with inscribed system-of-systems level functions. This leads to a multitude of SV-1s that may be difficult to digest. A hierarchical structure of functions at the various levels of system-of-systems assemblies can be summarized with one view called, SV-4, System Functionality Description. This view is also commonly known as a functional architecture of the system-of-systems.

The functional architecture essentially represents functional requirements in a graphical form. Functional requirements are basically a translation of the stakeholders' needs into technical terms. They need to match the activities previously identified in the OVs. While the system was represented by a "black box" in the OVs, here one takes a peek inside. All the details of the internal machinery of the system are not yet visible, only a set of smaller "black boxes" labeled with individual functions.

Functional architecture identifies required system-of-systems functionalities in a manner independent of specific choices made in selecting the component systems. This knowledge can now be used to accommodate changes in specific technological implementation of one of the component system changes, by simply replacing it with another implementation that provides the same functionality. This reflects the principle of "separation of concerns" proposed by E. W. Dijkstra in *Selected Writings on Computing: A Personal Perspective* (1982, pp. 60–66).

A familiar example of this principle in action is the layered Open Systems Interconnection (OSI) stack used in computer networking. The stack allows a complex design problem to be split into less complex smaller problems with changes constrained to one layer at a time. Ultimately, such layered schema also leads to an open business model. Provided the vendors supply the desired functionality and comply with the interface standards governing the interactions with other layers, no one needs to see the inner workings of their systems. Accordingly, the system-of-systems (such as a computer network in this case) creates a market with many suppliers who are able to protect the intellectual property of their specific implementations.

Additional views are needed to provide a more complete picture of the system-of-systems for inputs to the modeling and simulation. These include the SV-10c, System Event Trace Matrix, that model the dynamics of events that occur when the system-of-systems is operating. This view corresponds to an OV-6c, Operational Event Trace Description on the operator side. For completeness, one should also include the SV-10a, Systems Rules Model that defines the conditions determining when specific system events are allowed to follow others and SV-10b, Systems State Transition Description that presents the states the system may find itself in and how it transitions from one state to another.

Using Architectural Tools and Products to Reduce the Risk in Systems-of-Systems Integration

As mentioned before, one of the risks encountered in integrating a system-of-systems is in missed or unidentified functionalities and/or interfaces of the components systems. The claim being made here is that using architectural tools that provide graphic representations of the component functions and interfaces that can be inspected by the SoS design team will contribute to the reduction of this risk in a significant manner. First of all, just adding a task that consists of creating such architectural artifacts forces the team to examine the component systems and document the results of this examination. Furthermore, functions and interfaces identified in such a task will provide inputs to the analysis of derived requirements that are part of the overall SoS requirements set. Finally, these requirements are the foundation for preparing the integration and test plans and procedures that will be used to manage the integration and test programs for the system-of-systems in question.

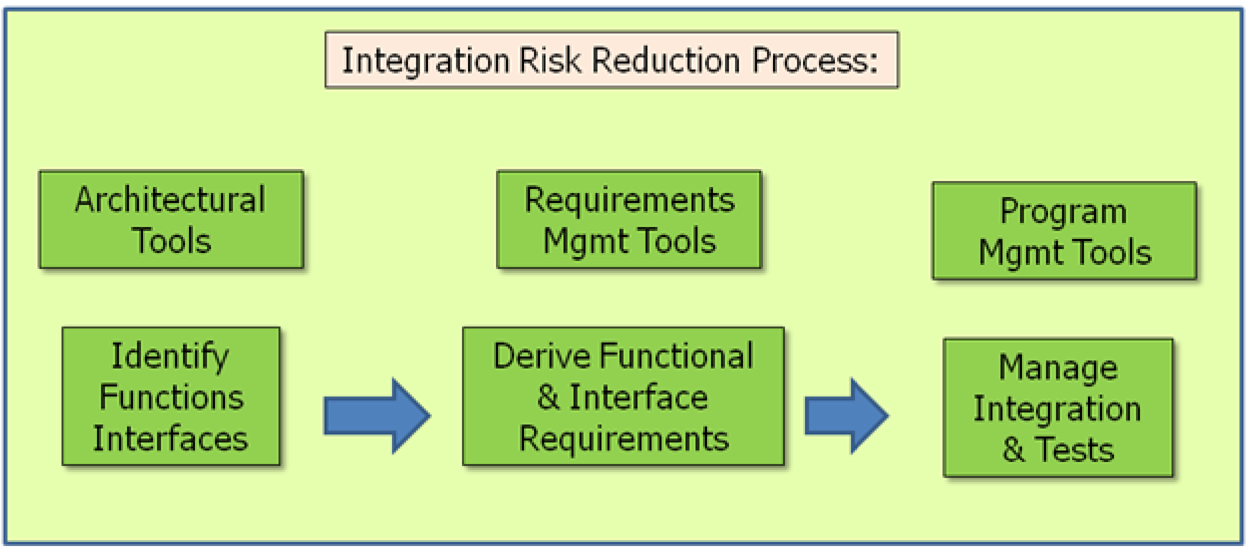

Figure 2. Functions & Interfaces Identified with Architectural Tools are Used to Derive Requirements and Manage Integration & Tests

The process is that of reverse engineering applied to each component system that will be integrated with the planned system-of-systems. The DoDAF SV-4 is used to document the provided functionalities and the DoDAF SV-1 is used to document the interfaces. Depending on the complexity of the component system under consideration, this analysis may be limited to the top-most layer or may delve into some internal details. Typically though, the top-most layer will suffice. The component system SV-1s and SV-4s are then used like LEGO blocks to construct the SV-1s and SV-4s for the entire system-of-systems.

Using Architectural Tools and Products to Reduce the Risk of Undesired Behavior

Another type of risk that exists in system-of-systems integration is the risk of undesired behavior that suddenly appears when component systems that have been developed for other uses get connected together. As discussed above, this undesired behavior can fall into many categories such as the so-called emergent behavior, sneak circuits or other unintended consequences. Although emergent properties have been associated with certain "esoteric" ideas, especially when the particular system-of-systems under consideration is at the edge of the current extent of accumulated human knowledge, many such effects can be uncovered through sufficiently detailed modeling and simulation. The architectural tools can be used to reduce the risk of unexpected behaviors of the system-of-system hiding behind an insufficient understanding of the functionalities and interfaces of the component systems. These functionalities and interfaces are an indispensable input to the modeling and simulation tools that can be used to analyze "sunny day" and "rainy day" scenarios where undesired SoS behaviors can be identified. Once identified, these behaviors can usually be mitigated.

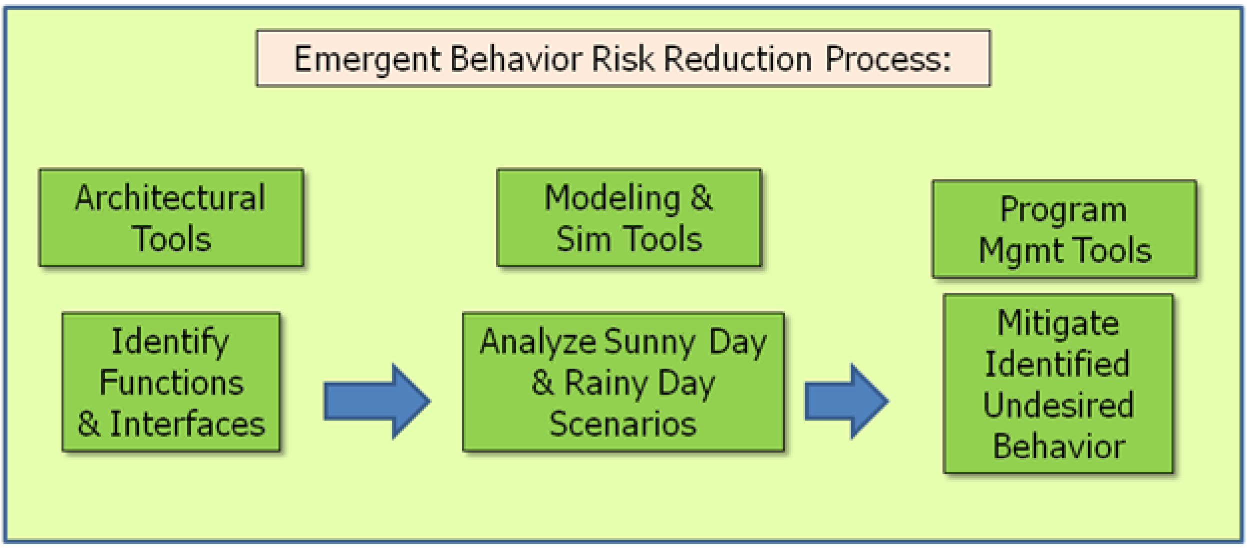

Figure 3. Architectural Products Help Mitigate Undesired Behavior

At the system-of-systems level, one can now use the information previously identified in the SV-1 and SV-4 to build DoDAF System Event Trace Matrix diagram, SV-10s. The system-of-systems architect will also develop an SV-10a, the Systems Rule Model that defines the conditional behavior of the SoS. System State Transition Description, SV-10b will help examine the system-of-systems states and modes. This diagram describes what response is to be expected for a given stimulus. System-of-systems response may vary depending on the current state, the type of stimulus, and the trigger guard conditions. Explicit responses to stimuli are not found in a functional architecture. Missing states, responses and conditions are equivalent to missing requirements.

Using Architectural Tools and Products to Reduce the Risk of Components Obsolescence

The risk of components obsolescence and the more general risk of the system evolving away from its original intent are two types of risk that are definitely more prevalent for system-of-systems that are integrated from independent component systems capable of evolving on their own than for systems developed as one entity. Principles of modularity and openness of architecture have been specifically developed to promote reuse and reduce obsolescence. These principles were defined and discussed in detail earlier in this paper.

As discussed, the architectural tools are key to identifying the functions and interfaces of the component systems. Carrying it one step further, the same tools can be used to identify functions and interfaces of assemblies of the component systems within the system-of-systems all the way up to the highest level. Implementation of modularity and open architecture in the design is basically the task of partitioning the design to isolate certain groups of functions to specific assemblies or modules and selection of open standards for key interfaces between these modules. An assembly here can consist of a single system. Once the design has been modularized in this fashion, multiple vendors can compete in the open market for each module and reduce if not eliminate the obsolescence risk, an effect experienced daily with computer technologies.

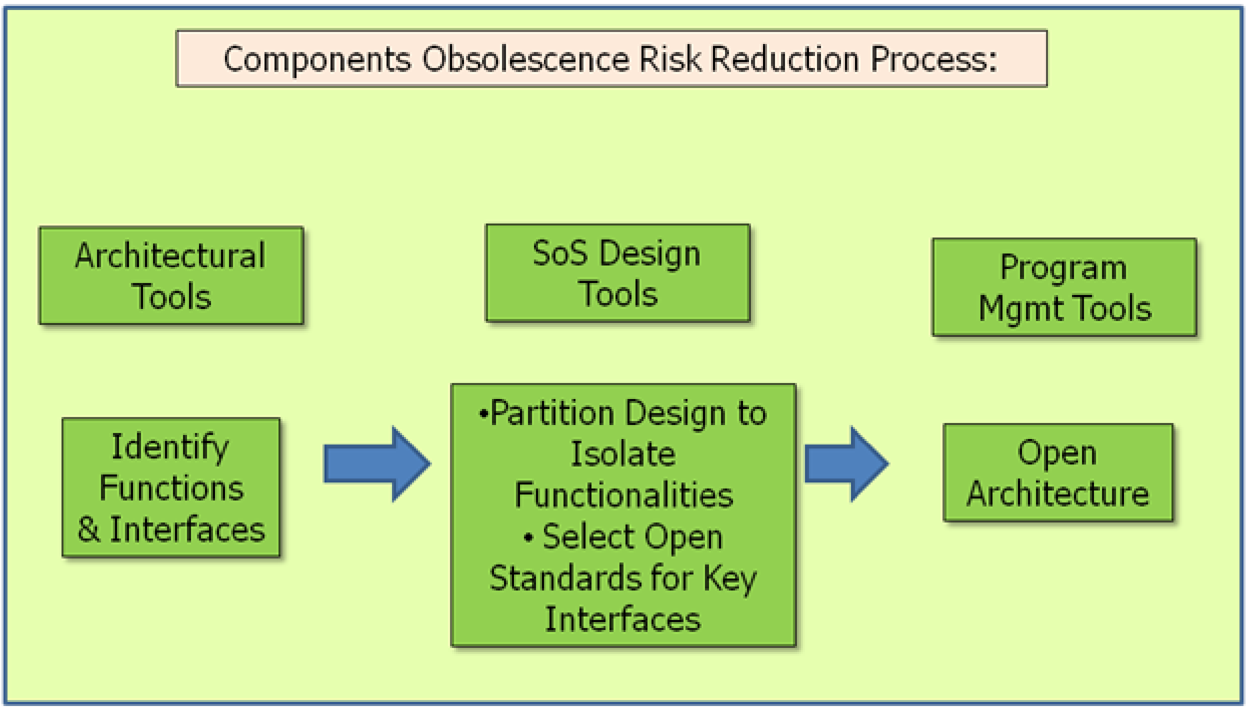

Figure 4. Architectural Products Help to Build an Open Architecture

Control of the evolution of the entire system-of-systems is part of its configuration management process. Architectural tools provide the necessary documentation. The system-of-systems SV-1 documents its overall configuration, identifying the component systems and their interfaces with other component systems. Their associated functionalities are documented with the corresponding SV-4 diagrams. Operational Activity views, OV-5, related to the system views via the SV-5a, Operational Activity to Systems Function Traceability Matrix, and SV-5b, Operational Activity to Systems Traceability Matrix, document the ways the operators use the system-of-systems. Through allocations, derived requirements are associated with each element of the system-of-systems architecture. Traceability binds the derived requirements to the top level originating stakeholders' requirements. Having the system-of-systems configuration documented in the form of architectures tightly bound with the top level and derived requirements allocated to the architectural elements is a great step towards reducing the risk of a system evolving in such a way that it would no longer serve its stakeholders.

Summary and Conclusions

In summary, several significant types of risk that appear in system-of-systems integration were analyzed and appropriate mitigation methods based on application of architectural tools were presented. Discussion of several available architectural frameworks and tools for developing architectural artifacts introduced the reader to these concepts and recommendations for further reading were provided. Specific ideas for application of these architectural artifacts bring us to the conclusion that use of architectural tools and products does reduce the risks in systems-of-systems integration as follows:

- Documented functionalities and interfaces for SoS components enable generation of requirements for better planning of system integration and test (and these reduce the risk of program failure).
- Documented functionalities and interfaces for SoS components enable higher fidelity modeling and simulation providing more insight into emergent behavior (and this reduces the risk of possible surprises).
- Documented functionalities and interfaces for SoS components facilitate creation of open architectures with layers of abstractions that will enable future integration of component replacements (and this reduces the risk of component obsolescence).

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Panel 20 – Investing in People: Research in Workforce Professionalization

Thursday, May 12, 2011	
1:45 p.m. – 3:15 p.m.	**Chair: Dr. James McMichael,** Vice President, DAU ***Developing Program Management Leadership for Acquisition Reform*** Neil McCown, USN ***Experience Catalysts: Understanding How They Can Help Fill the Acquisition Experience Gap for the Department of Defense?*** Robert Tremaine, DAU ***Program Manager Professionalization: The "Return on Investment" Question*** Keith Snider, NPS

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Prior to assuming his current position, Dr. McMichael served 14 years as the director of acquisition education, training, and career development in the Office of the Under Secretary of Defense for Acquisition, Technology, and Logistics. In that position, Dr. McMichael was the principal proponent for workforce management, and he formulated policies and programs to ensure the quality and professionalism of the workforce. Throughout his career, Dr. McMichael has also served as the technical director for the Navy Personnel Research and Development Center in San Diego, CA; the special advisor for manpower, personnel, and training with the Office of the Chief of Naval Operations; and the chairman of the Psychology Department at Long Island University, NY, where he taught for eight years.

Dr. McMichael is a graduate of Princeton University, and he received his advanced degrees at the University of Delaware. He was a fellow in the Woodrow Wilson School of Public and International Affairs at Princeton University from 1982 to 1983.

Developing Program Management Leadership for Acquisition Reform

Neil McCown—CDR Neil McCown has served in the U.S. Navy for 18 years, including three deployments to the Persian Gulf and operational tours flying tactical, training, and transport aircraft. He recently completed in-resident study at the Naval War College and is currently assigned to OPNAV N09X, Enterprise Integration and Analysis. [neilmccown@hotmail.com]

Abstract

Recent reform measures in acquisition processes support the acquisition community's long-established goal of providing warfighters with the highest quality and most cost-effective weapons systems. Since the role of the Program Manager remains pivotal to overall program success or failure, efforts to reform the acquisition community must supplement and expand traditional expectations of PMs, focusing on four key concepts: ensuring leadership continuity, providing systems engineering training, requiring increased hands-on training, and employing trust-building tools. The turnaround of the USAF C-17 program illustrates the successful effects of building trust among program stakeholders. With these qualities, PMs leading the development of future weapons systems will unquestionably contribute to the U.S. military's sustained role as the most capable, powerful, and respected military in the world.

Introduction

Relative to its closest competitors, the United States military stands alone as the most capable, powerful, and respected military in the world. The Department of Defense (DoD) acquisition community, charged with providing the U.S. warfighter with the highest quality and most cost-effective weapons systems, is arguably as important to maintaining that superiority as the Army, Navy, Marine Corps, Air Force, or Coast Guard. Yet despite little acknowledgement or recognition, the health of that community is rarely addressed. Although characteristics of the acquisition workforce and the defense acquisition system itself may contribute to recent program cost and schedule overruns, the role of the Program Manager (PM) remains pivotal to the program's overall success or failure. As a result, efforts to reform the acquisition community must supplement and expand traditional expectations of PMs, focusing on four key concepts: ensuring leadership continuity, providing systems engineering training, requiring a minimum level of hands-on training, and employing trust-building tools.

Acquisition Reform and the Program Manager

The acquisition community has seen an unfortunate rise in the number of reasons for reform. Shifting system requirements, poor cost estimating, or errant program oversight have plagued numerous recent programs. In some cases, one or more of those factors have completely stalled defense programs, some of which include the Armed Reconnaissance Helicopter, Combat Search and Rescue replacement (CSAR-X), VH-71 Marine One replacement, and Armed Common Sensor. In fact, the total budget excess of the DoD's largest 95 acquisition programs has been $295 billion, and those programs' schedules have slipped an average of two years. Current trends indicate that, without significant change, cost overruns will continue in an unsustainable manner.

Several characteristics of today's acquisition workforce complicate efforts to reverse these trends. First, compared to its workload, it is grossly understaffed. Over the previous 20 years, the DoD eliminated a large number of its acquisition positions in an effort to correct historic problems and cut costs. In doing so, it lost many of the positions responsible for building a solid foundation during the early stages of a program; applying that expertise during that time period is arguably the most critical factor for ensuring a program remains on track throughout its life cycle. Next, organizational issues limit the acquisition workforce from being fully recognized as a professional component. Dominant among those issues is the notion that the acquisition community operates with insufficient regard for combatant commander's needs, resulting in weapons systems that fail to adequately address the most pressing threats facing warfighters. Third, a significant portion of the workforce is nearing retirement age. Finally, more lucrative opportunities in the private sector are an irresistible pull for many in the workforce.

Fundamental qualities of the defense acquisition system further hamper efforts at change. At its core, it has more in common with a business enterprise than other functions within government. This remains true even though the defense acquisition system represents the world's most powerful customer, who sets and enforces procurement rules. Furthermore, the government continues to promote cumbersome, bureaucratic processes, which emphasize the pursuit of "exquisite" weapons systems and are reluctant to pursue "good enough" —though possibly somewhat imperfect— systems. The outcome is an acquisition system which is unable to produce desirable results in an efficient manner.

Characterized by a pervasive lack of trust, the relationship between the DoD, Congress, and the Defense Industry (known as the "Iron Triangle") remains an additional challenge to defense acquisition. The varying perspectives and motivations of each member of the Iron Triangle test the ethical foundation of the entire enterprise. Striving to achieve profits and shareholder value, the Defense Industry is strongly tempted to overpromise on capabilities. At the same time, the executive branch and the DoD display a frequent tendency to modify requirements and specifications during the course of a weapon system's development as threat conditions evolve and leadership changes. These alterations consequently increase cost and create schedule delays. The interests of the constituents in their districts and a desire to retain control of programs through selective spending, meanwhile, drive the actions of Congress. Throughout the Iron Triangle, self-interested members of each corner resist changing the acquisition system due to the financial and career incentives it offers.

Non-military issues draw congressional attention and funds away from acquisition programs, and without funds necessary to sustain the existing bureaucracy, pressure builds to fix the inefficient defense acquisition processes that saddle U.S. national security. Fiscal pressures are numerous: coping with the health care crisis, ensuring a stable supply of energy, preserving the natural environment, restoring the world economy, rebuilding the U.S. physical infrastructure, and others.

While numerous factors contribute to a need for defense acquisition reform, particularly from a leadership perspective, the PM is at the heart of the process. Charged with operating within cost, schedule, and performance limits, a PM is assigned to each acquisition program. DoD Directive 5000.01 (USD[AT&L], 2007) provides the overarching policies governing the defense acquisition system, as well as a definition of the PM:

> The designated individual with responsibility for and authority to accomplish program objectives for development, production, and sustainment to meet the user's operational needs. The Program Manager shall be accountable for

credible cost, schedule, and performance reporting to the Milestone Decision Authority.

Although this definition accurately encapsulates the responsibilities of the PM, additional elements of the position may illuminate some root causes of problems the defense acquisition community faces.

Continuity of Leadership

The fact that military officers are assigned to relatively short PM tours is one potential source of trouble. While a typical tour for an officer rarely exceeds three years, most weapons systems spend far more time than that in development. As a result, it is very unlikely that a single PM will remain assigned to a weapons program long enough to guide it from its early developmental stages through fleet introduction. Indeed, due to the length of time required for a large program to move from one major milestone to the next, most military PMs are only involved with a program long enough to guide it through (at most) one milestone before they rotate out of the job. A military officer admittedly has the added career goal of gaining a broad exposure to a variety of programs, a necessary prerequisite for higher levels of leadership. The relative importance of this goal, however, should be carefully weighed in relation to its impact on the long-term success of weapon system programs.

An alternative approach to ensuring continuity in program leadership is to shorten the duration of the program itself, which requires an examination of the underlying requirements process. In a broader sense, the problems facing this process can be viewed as a misalignment of ends and means. Military operators, representing the weapon system customer, understandably seek an optimum material solution to a threat scenario. Current trends indicate operators desire the threat be overwhelmed with an “exquisite” application of technology. Unfortunately, this often translates into a proposed weapon system that is beyond current technical capabilities. Neither the Joint Capabilities Integration and Development System (JCIDS) process nor the Planning, Programming, Budget, and Execution System (PPBES) community fully address the technological uncertainty, which results in programmatic delays and cost escalation.

Systems Engineering

Although a PM may have limited ability to prevent military operators from seeking an unachievable capability, or to change JCIDS or PPBES, an increased emphasis on systems engineering skill sets may assist in identifying unrealistic requirements and managing technical risk early. As applied to defense acquisition, system engineering refers to the process of preliminary developmental planning, and importantly, it occurs prior to the formulation of formal requirements. In addition to considering all-new weapons systems, it stresses alternative solutions to perceived needs, such as commercial or foreign-made products, or modifications to existing systems. With the best solution identified, system engineering also focuses on the development of core technologies for future weapons systems. Not surprisingly, congressional critics have identified a lack of these skills as a significant source of the defense acquisition’s difficulties.

Unfortunately, as a cost-saving measure in the 1990s, programs providing system engineering skills were abandoned. This, in turn, resulted in a significant degradation in the services’ ability to perform critical systems analysis. A renewed effort to incorporate systems engineering training and experience requirements for PMs, however, would provide them with an effective means to identify and manage technical risk. That capability may or may not shorten program development cycles, but it would better prevent unforeseen cost and schedule overruns due to an overreliance on immature technologies.

Training and Experience

Although not specifically in systems engineering, some encouraging signs are beginning to appear that indicate improvement in training and experience requirements. The Defense Acquisition University, charged with educating the acquisition professionals, is currently engaged in active programs to ensure that the workforce has the needed skills. Specific measures include growing and improving training courses, increasing experience requirements, and enhancing workforce planning. These efforts combine with the military services' leadership training, particularly professional military education programs. Mid- and senior-grade officials in military and civilian organizations can now take advantage of a considerably expanded selection of executive and leadership courses offered through the DAU.

Experience remains an essential element of effective program management. The "management" aspect can be taught, and PMs can gain knowledge of how to apply a variety of processes and tools, but "leadership" ability remains distinctly different. As it relates to the PM role in defense acquisition, the ability to apply and gain acquisition experience is the leadership quality essential for effective program performance. Since the acquisition system and the business world have much in common, it is significant that business places a premium on experience. In particular, it views hands-on experience as directly related to the ability to make sound decisions.

The military officer corps serve as a valuable source of acquisition professionals, yet operational commitments often prevent those officers from gaining the hands-on acquisition experience needed. One method to overcome this challenge is to create opportunities for officers to gain PM experience early in their careers.

Building Trust

Even PMs armed with high-quality experience, however, are impacted by the distrustful environment of the Iron Triangle. Fluctuating streams of funding from Congress, creeping requirements from military operators, and unrealistic performance capabilities promised from suppliers are common obstacles to effective cost and schedule management that the PM faces. Each of these results from the tendency to misrepresent actual conditions due to underlying motivations: pleasing constituents, exerting control, and increasing profit and value.

This dishonesty—real or perceived—forms the beginning of a vicious cycle of mistrust. A human tendency to exaggerate perceptions of negative behavior (in this case, dishonesty) transforms minor actions (or misperceptions) into significant ones. A further tendency, referred to as the "norm of reciprocity," leads each side of the "Triangle" to reciprocate with negative behavior. That (actual) negative behavior likewise creates a genuinely negative response, and the result is a downward spiral of dishonesty and erosion of trust.

To break the vicious cycle of mistrust, the PM can focus on making a distinction between misperceptions and actual dishonest behavior. One method to accomplish this is to seek the opinion of an outside party, one who does not have a stake in any corner of the Iron Triangle. Another method is to seek extenuating circumstances that may not be obvious, and may influence the other side's decision-making in a way that creates the appearance of ill intent. Finally, the PM could simply ask the other side to explain their behavior. If any of these methods does provide a better understanding, it may become apparent that there is a reasonable difference of opinion.

With the cycle of mistrust broken, an important follow-on step is to trigger a virtuous cycle that builds trust. An effective tool to accomplish this is to create the perception of fairness, not only in the outcome of a specific interaction, but also in the interaction itself. On average, whether or not one side considers an interaction fair depends upon whether that side had sufficient opportunity to voice their opinion. Just as important, that side must believe that the other side has listened to and seriously considered it.

Carefully listening to the other side's perspective gives that side the impression that they were treated fairly, and accomplishes three things toward building trust. First, even if the outcome of the interaction was undesirable, the other side will have a greater sense of satisfaction with the results. Next, the other side will be more likely to follow through on agreements that they believed were fair. Finally, and perhaps most significantly, the chances of successful cooperation with the other side in the future increases. The turnaround of the USAF C-17 program illustrates the beneficial effects PMs can achieve through this trust-building tool.

The USAF C-17 Program and the Effects of Building Trust

In May 1993, the USAF C-17 program was in a state of crisis, and in danger of being terminated. The first flight was delayed nearly two years, and the estimated unit cost grew from $178.4 million in 1988 to over $500 million by 1993. The sources of these schedule and cost overruns could be traced to each corner of the Iron Triangle. First, system requirements from the DoD shifted constantly, partially due to new personnel continuously being added to the program and the disappearance of the Soviet threat. Next, McDonnell Douglas (the prime contractor) repeatedly encountered technical and personnel challenges. Finally, shifting priorities in Congress caused funding streams to continually fluctuate or stop altogether, keeping the C-17 development and production in a tumultuous and unpredictable state. In his testimony before the House and Senate, Undersecretary of Defense John Deutch identified a lack of trust as a principal reason for the program's problems. The gridlock stemming from the negative relationship between the U.S. Government and McDonnell Douglas prevented the program from successfully moving forward.

A critical initiative resulting from those observations, which helped transform the C-17 program from a state of crisis to a path toward success, was to create an open path of communication between top-level USAF and McDonnell Douglas leadership. Called "CEO" meetings, they had the effect of providing the other side with an opportunity to explain their behavior and reach an understanding. With the cycle of mistrust finally beginning to break, both sides could create perceptions of fairness by agreeing to substantive concessions. Among other things, McDonnell Douglas dropped over $1B in legal claims, and the Air Force relaxed numerous specification requirements. The settlement achieved a significant change in the management environment of the program. People on both sides stopped working as adversaries and, instead, moved forward with a sense of cooperation, partnership, and optimism.

Conclusions

As the C-17 program demonstrates, the appropriate application of trust-building tools can result in a far-reaching program turnaround. Likewise, weapons systems programs directly benefit from efforts to ensure leadership continuity, to provide systems engineering training, and to require a minimum level of hands-on training. Despite previous initiatives intended to make improvements in these areas, increasing demands for reform in the defense acquisition community raises expectations that they be implemented effectively. Focusing those efforts on the PM remains critical, since the PM leadership is essential to ensuring that warfighters in the Army, Navy, Marine Corps, Air Force, and Coast Guard receive high-quality weapons systems on time and within budget. Going forward, weapons systems consistently developed in this manner will unquestionably contribute to the U.S. military's sustained role as the most capable, powerful, and respected military in the world.

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Experience Catalysts: Understanding How They Can Help Fill the Acquisition Experience Gap for the Department of Defense?

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Abstract

This paper addresses the issues of experience and professional certification, and explores the following questions: Can experience be accelerated to bolster certification effects across the range of professions? Are there any innovative methodologies that can appreciably accelerate experience and shrink the time it takes to achieve it? If so, many professionals, including Defense Acquisition Workforce personnel, could be the beneficiaries since their certification levels rely heavily on experience (in addition to education and training). The Defense Acquisition Workforce Improvement Act of 1990 became law 21 years ago, but experience shortfalls are still surfacing. If left alone, these experience shortcomings could result in acquisition limitations and delay the fielding of essential systems that warfighters need. It is time to take another look at the experience variables that are extremely important in the acquisition workplace performance equation. What matters and what doesn't?

Introduction

In any business, trade, or profession, experience matters, especially when our lives depend on it. Not surprisingly, the public tends to look at experience as an absolute necessity when personal safety is paramount. Professions like the medical, transportation, and construction industries rely heavily on experience. They take considerable time to qualify their respective corps through various experience incubators like internships, fellowships, apprentices, etc.—all on-the-job means, and for obvious reasons. They learn by "doing." Without doing, these personnel may face challenges later that they cannot easily overcome when "know-how" matters the most. As a result, and for practical reasons, many of these professions use quantitative measures such as "hours" or "years." They serve as experience markers. It not only gives these trades more confidence—it also gives the public more confidence. After all, assured and demonstrated competencies are a vital necessity since an experience failing could lead to life-threatening consequences. No one wants to rely solely on fatal experiences to avoid future catastrophes.

Many of these same professions are also backed up by licensing boards focused on maintaining minimum standards. For example, burgeoning surgeons spend many years practicing their craft under the watchful eye of experienced surgeons before they ever get sanctioned as qualified surgeons. Entry-level military and commercial airline pilots must earn a minimum number of successful flight hours under a wide range of operating conditions before they are allowed to climb into the left seat (from the right seat) as qualified pilots-in-command. To make sure they do not become an electrical danger to themselves or anyone else, apprentice electricians require a minimum number of years as apprentices under the close supervision of a senior lineman before they go solo installing or repairing electrical lines. In all these cases, fundamentals like educational achievement, aptitude, previous job performance, and so forth serve as initial career screening mechanisms. However, the existence of a certification or qualification component tightly connected to experience levels seems to be a distinguishing characteristic that makes these particular professions different enough from those without one. Certification also serves as the basis for expected outcomes. But, can experience be accelerated to bolster certification effects across the range of professions? Are there any innovative methodologies that can appreciably accelerate experience and shrink the time it takes to achieve it? If so, many professionals, including Defense Acquisition Workforce (DAW) personnel, could be the beneficiaries since their certification levels rely heavily on experience (in addition to education and training). Twenty-one years after the Defense Acquisition Workforce Improvement Act (DAWIA) of 1990 became law, experience shortfalls are still surfacing. If left alone, these experience shortcomings could result in acquisition limitations and delay the fielding of essential systems that warfighters need. It is time to take another look at the experience variables that are extremely important in the acquisition workplace performance equation. What matters and what doesn't?

Methodology

This investigative effort used a phenomenographical methodology (i.e., aggregate views drawn from personnel experiences) by surveying a wide range of acquisition professionals (e.g., program managers, systems engineers, logisticians, contract specialists, and budget, cost estimators, and financial managers) in various product lines (e.g., ships, tanks, aircraft, satellites, munitions, information, warfare, etc.) and services (e.g., IT, research, security, etc.). This investigation sought their views on experience catalysts. More specifically, what mattered more to them than others, what didn't matter, and why? The answers to these key questions would confirm key experience solutions that could help fortify the capabilities of the professional acquisition corps and combat the uncertain and sometimes turbulent programmatic challenges that lay ahead.

The survey separated experience catalysts (EC) into three tiers: foundational (Tier 1 [T1]), enhancers (Tier 2 [T2]), and accelerators (Tier 3 [T3]). Decomposing them into these tiers would afford a more definitive analysis later. This partitioning might also lend itself to a greater understanding of experience gateways as well as the prevailing obstacles (real or artificial) that could be interfering (in the form of barriers) with experience gains along the acquisition "experience building" pathway. Mathematically, the total sum of these factors would look something like the following:

$$EC = \sum_{i=1}^{n} (\text{Tier } 1_i + \text{Tier } 2_i + \text{Tier } 3_i) - \text{Barriers}_i \qquad (1)$$

Findings

1,414 defense acquisition personnel (1,236 government, 152 military, and 26 support contractors) responded to this survey. The results reinforced both the importance and influence of a wide range of experience catalysts operating inside and outside of the workplace. The data exposed a few that were not operating at expected levels. The results also generated several "ahas."

1st Tier: Experience Foundations

Many professions rely on sturdy and enduring academic *foundations*. The acquisition profession is no different. Depending on the specific functional area(s) a member of the DAW pursues, these academic foundations tend to serve as *formal* learning tollgates before personnel arrive *on the job*. Of course, well-described job competencies reinforced by definitive performance expectations ensure that personnel are properly placed and appropriately guided. Nonetheless, systems engineers should be ready to apply engineering basics; contract specialists should be ready to carefully evaluate written agreements; and cost estimators should be steeped enough in math to comfortably work with budget and cost estimate equations. Despite the profession, these *formal* foundational learning gates are less than half of the total learning equation in the workplace. The remainder occurs at the workplace. In fact, more than 70% of most new knowledge and skills actually take place at work through a combination of *informal* and *incidental learning* (Good & Brophy, 1990). This is where the workforce tests their inherent capabilities every day. Where do experience catalysts play into all of this? They appear to take root more in the context of these informal and incidental learning methods (i.e., "learning by doing"). If that is the case, what did the DoD acquisition workforce actually say about the effectiveness and value of these experience catalysts early on 'in" the job? What mattered most?

The survey respondents were asked to rate the importance of a broad range of experience factors. The majority have been well-documented by research. Others, like *off-sites* and *immersion days*, have not been well documented, but for purposes of this investigation, they have been sub-categorized as *knowledge-sharing* components.

As Figure 1 indicates, the results were consistent with previous research. *On-the-job training* mattered the most. Active involvement in the experience strengthened their experience foundations according to many respondents in this study. *Knowledge sharing* with colleagues and *challenging work* trailed very closely behind. Several respondents felt "learning from others' experiences reinforced their own." *Knowledge sharing* can have far-reaching considerations since knowledge is generally seen as "the most strategically-important resource which organizations possess and a principal source of value creation" (Cummings, 2003). *Supervisory guidance* represented the next data point. One of the respondents echoed the views of others. She claimed that "having a well trained supervisor who is a great teacher, allowing me to fly semi-alone…built [my] confidence, knowledge and courage to complete more challenging tasks." The next lower grouping included *DAWIA classroom training*, *formal mentorship, professional development, well-defined organization processes, on-line training,* and *certification standards*. Unexpectedly, three of these seven (*DAWIA training*, *well-defined organizational processes*, and *certification standards*) all scored noticeably low and could be explained for several reasons.

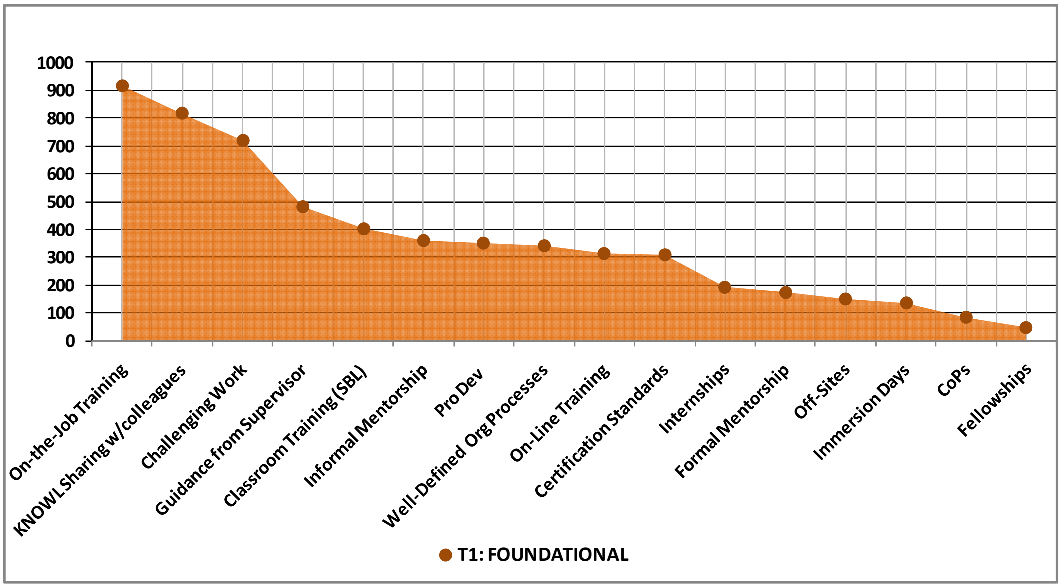

Figure 1. T1 Experience Catalysts

Why the low score for DAWIA c*lassroom training*?

- Its value could be muted compared to other more dominant experience catalysts. Some respondents felt classroom experience will "never be able to replace of OJT, mentoring or knowledge sharing at work." Others emphasized that DAWIA training is "rather generic and doesn't actually teach enough of the job specifics." In other words, the training could be too general in nature.
- Students might be showing up too early for training in their career and may not be quite ready.
- Students might be showing up too late for training. Several respondents noted that it's difficult to keep up with additional training demands.
- Students forgot what they learned before they could apply it.
- It could have a looser connection to experience in its current form.
- Its benefits might not be well understood, especially the connection to performance outcomes—something the General Accountability Office (GAO) recently questioned.

In a recent report, the GAO declared that without appropriate outcome metrics, acquisition Technology & Logistics programs will be "unable to demonstrate how certification training actually contributes to organizational performance results" (GAO, 2010). Inarguably, what the GAO underscored is tough to demonstrate without a comprehensive program that tracks behavioral changes at work. The discovery that as much as 90% of training resources are spent on the design, development, and delivery of training events only yield 15% on-the-job application (Brinkerhoff, 2006) makes training an easy target for additional examination. In the context of Donald Kirkpatrick's well- known Four Levels of Learning Evaluation, the first two learning levels (Reaction [I] and Learning [II]) have been relatively easy to demonstrate during the classroom delivery timeframe. Level III (Behavior) and Level IV (Results) have been a lot tougher to validate. Some researchers assert that if Level 3 evaluations were conducted as part of existing career development and performance reviews, then it might "improve, explain, control, and predict performance although managers must be willing to observe, document, and evaluate the desired behaviors" (Mayberry, 2005). Brinkerhoff and Montesino (1995) found even modest supervisor involvement before and after the training can have a significant impact on whether trainees use their newly developed skills" (Bassi & Russ-Eft, 1997). Other studies have shown that "the more managers are trained in how to support and coach the skills their employees learn, the more those skills will be used and sustained in the workplace" (Leimbach & Maringka, 2009).

Decades ago, the DoD instituted a formal performance evaluation program for all its employees to signal the importance of training. In 1958, the Government Employees' Training Act expected training would improve performance and prepare personnel for future advancement. In 1962, the Salary Reform Act required an "acceptable level of competence" determination for granting General Schedule within-grade increases; provided for the denial of the within-grade increase when performance is below the acceptable level; and authorized an additional step increase for "high quality performance." While these formal evaluation measures have continued to evolve, they have not specifically traced personnel performance to training activities. It has been generally assumed that training focuses on the required knowledge, skills, and abilities necessary to perform and improve assigned duties within the workplace. In fact, there is plenty of literature that substantiates this probabilistic connection, but there are so many other intervening factors that complicate the relationship, including individual attitude, motivation, cultural realities, learning self-efficacy, age, etc., that make a deterministic forecast more difficult (Bassi & Russ-Eft, 1997). Other factors ebb and flow, such as team structures, incentives, use of analytic tools for capturing and analyzing information, and psychological safety, and tend to moderate the influence between experience and performance improvement (Edmondson, 1999). In the private business sector, training has been found to have a positive impact on profitability (Cosh & Hughes, 2003). Many years ago, the DoD made a similar association for its acquisition workforce and invested heavily in training. It still takes training very seriously.

As far as other experience foundation catalysts go, there are several others that require further introspection.

Why the low score for well-defined organizational processes?

- Personnel might believe these processes are already embedded in the direction they received and might not necessarily see them as a distinctive element.
- Personnel might be more sharply focused on their day-to-day tasks at hand and not find them a necessity (yet).
- Personnel haven't found the ones in place to represent much value.

Why the low score for certification standards?

- They could be generally misconstrued.
- They don't go far enough and/or are too watered down to be significant.
- The connection to accountability might not be readily apparent.

Why the low score for *communities of practice,* another form of knowledge sharing?

- Personnel may not find it a rich source of useful knowledge.
- Personnel may not find the information current enough.
- Personnel may not be aware of its existence.

- Information may not be appropriately curated (e.g., information has not been properly maintained or trusted for use).
- It's missing the social interaction that generally creates more value.

2nd Tier: Experience Enhancers

The impact of experience catalysts expressed as experience *enhancers* seemed relatively consistent to those described as foundational (Figure 2) and were very closely correlated. *On-the-job* training didn't diminish in importance; neither did *knowledge sharing*, *challenging work*, nor *supervisory guidance*. In relative terms, they all rose slightly. While still having noticeably fewer experience catalysts than the big three, both *classroom training* and *on-line training* rose much more noticeably in relative terms.

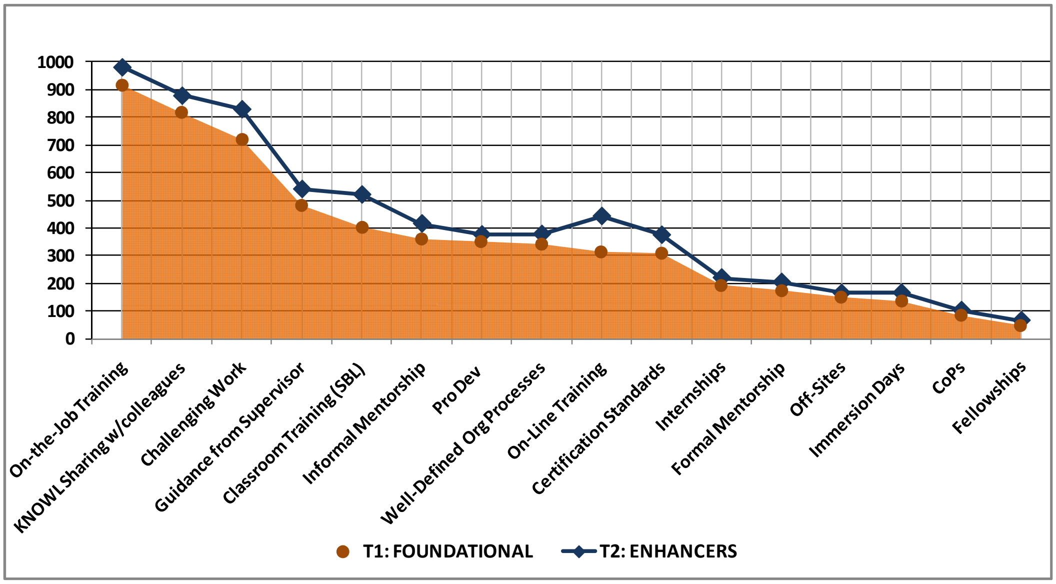

Figure 2. T1 and T2 Experience Catalysts

The uncharacteristic rise in *on-line training* could be attributed to (a) how *on-line training* complements certain experience foundations previously forged or (b) the presence of more effective delivery methods (e.g., greater interactive features and less of a "page turner," perhaps). Traditionally, DAWIA *classroom training* that uses scenario-based learning (SBL) methods enjoys more of an advantage than other classroom methodologies. It gives students a chance to practice representative training scenarios alongside their peers and to reflect *about* their jobs while they are *away* from their jobs. Reflection and practice have been found to have a significant impact on experiential learning of this kind. Long ago, David Kolb, an American educational theorist, reported that in order to gain genuine knowledge from an experience, the learner "must be able to reflect on the experience as well as be willing to get actively involved in the experience; possess and use analytical skills to conceptualize the experience; and possess decision making and problem solving skills in order to use the new ideas gained from the experience" (Kolb, 1983). Classroom training that employs SBL does just that and is used extensively these days since it adheres to a performance improvement imperative rather than the acquisition of just knowledge and skills (Schulz, 2001). SBL also promotes defining moments by exposing an individual's strengths and weaknesses. By imitating something real, SBL has shown to pay huge experience dividends by igniting the senses. Many have already found their way into organizations that vitally depend on training. Soaked with real-world conditions, they test an individual's ability to demonstrate how certain critical competencies prevail (or not). Captain Chesley "Sully" Sullenberger III, a former U.S. Airways seasoned pilot, experienced the benefits first-hand. He spent the better part of two full days every six months at the controls of an Airbus 319 flight SBL simulator while several lifetimes' worth of disasters broke loose around him (Budiansky, 2009**)**. At what point was he prepared for a water landing on the Hudson River when he piloted Flight Number 1549 on January 15, 2009? How many years did it take for him to turn a potential disaster into a miracle? He met his flying experience markers (in years), but up to the moment before he set his aircraft on the Hudson, a SBL simulator allowed him to fly at the edge of the flight envelope and test him for just about any contingency—except a water landing. The Airbus 319 isn't a watercraft, but Captain Sully knew he had to treat it like one, given the threatening outcome of two failed engines. His many years as an experienced line pilot, combined with recurring scenario-based simulator training and with the ability to handle "the unexpected," helped him save 155 lives that day. Aside from their long-standing presence in the flying community, as long as the experience is seen as realistic and valid, simulators also show promise for many other professions that require continuous practice and steady reinforcement.

Virtual simulators were previously an expensive proposition. Not anymore. Now, high-fidelity virtual simulations and the introduction of gaming that even uses 3-D capability are relatively inexpensive and widespread. They could eventually become commonplace in many workplace settings. When that occurs, they might have a noticeable impact on experience gains for many professions by letting workers safely practice a wide range of challenges unique to their own areas of expertise *on the job.*

3rd Tier: Experience Accelerators

The data associated with this last tier resulted in several interesting surprises. First, there were fewer correlations with 1st and 2nd Tier factors. Second, *professional development, well-defined organizational processes,* and *formal mentorship* took a marked leap in importance as accelerators (Figure 3). Third, *challenging work* and *certification standards* took visible dips. What caused certain experience catalysts to rise in importance and others to fall?

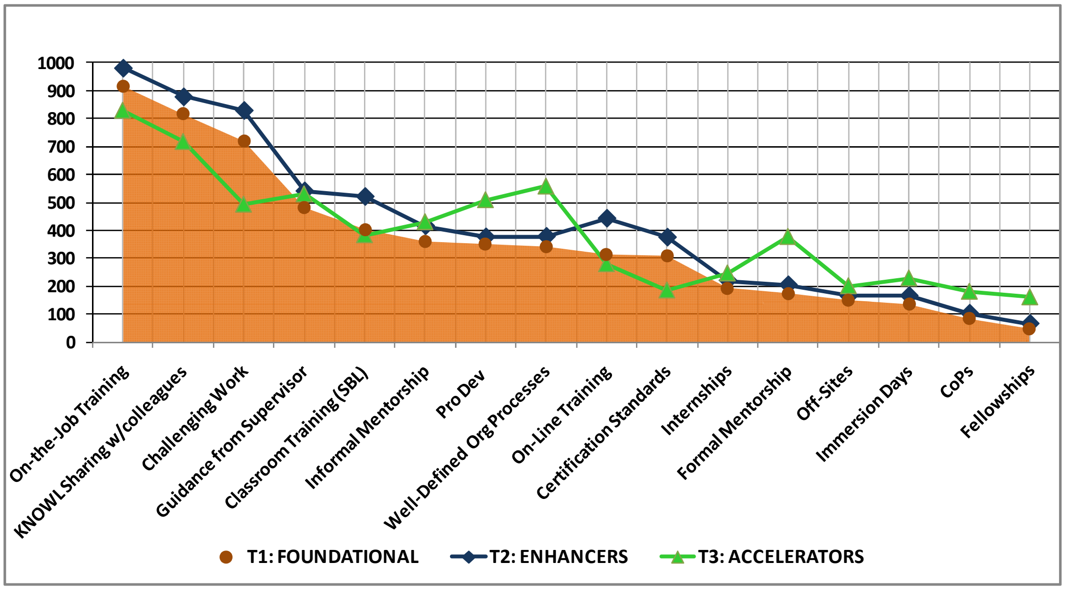

Figure 3. T1, T2, and T3 Experience Catalysts

The following could help explain the T3 experience factors that rose in importance:

- The rise in professional development (i.e., off-the-job training) could be attributed to the potential knowledge gains found outside the workplace on supplementary/complementary subjects and/or interactive knowledge-sharing venues with leaders in their same fields. Some respondents emphasized the importance of training with industry and other professional development opportunities.
- The rise in well-defined organizational processes could be attributed to the tangible benefits of more definitive, written organizational guidance that might have been less obvious before. Research has shown that learning from direct experiences depends critically on organizational processes that generate experiences. (Schultz, 2001)
- The rise in formal mentorship could be attributed to personnel seeking advice and counsel from more seasoned professionals in their same career fields in their own work environment. One respondent commented that "having a hands-on mentor made a world of difference." Another stated that "having a hands-on mentor at the start of their career would have made a world of difference."

A few possibilities could help explain the T3 experience factors that dropped in importance.

- The dip in challenging work could be attributed to the following:
  - The work at hand may no longer be challenging enough and could be holding people back.
  - Good work is rewarded with more work and eventually could feel more like work overload without the time to adequately learn it.
  - The complicating effects of increased administrative burden (seen by some as more work) is too much sidebar work to promote any real experience gains.

- The dip in certification standards (and the lowest of all experience accelerators) could be attributed to the following:
    - Poorly described benefits—some personnel may not easily see the future professional and personal payback.
    - Personnel may also find the achievement thresholds too low or less relevant to their current jobs, as many of the respondents stated.
    - The time they were awarded their certification level was long ago.

Barriers

Over time, experience undeniably prepares the workforce for the challenges ahead. However, past experience can also artificially interfere with the need for innovation and modernization, something the DAW or any other profession can least afford. Epistemologists (who study the *theory of knowledge*) might argue that knowledge, skills, and attitudes (KSAs) are so tightly connected to experience that they could become a little too grounded in yesterday's beliefs and dismiss the truths that might no longer apply. In other words, the same attributes that yield conventional wisdom could sometimes produce fixed mindsets, superstitious learning (e.g., single perspectives, learning the wrong things), competency traps, and erroneous inferences (Levitt & March, 1988). Before 1947, engineers believed the speed of sound represented a physical barrier for aircraft (and pilots) because of the formation of a violent shock wave that would dramatically increase drag, induce uncontrollable shaking, lose airlift, and eventually cause complete flight control failure. Placing a man on the Moon then must have been an absolutely wild idea. That all changed when Chuck Yeager broke the sound barrier in the Bell X-1 "Glamorous Glennis" on October 14, 1947; and when Neil Armstrong walked on the Moon on July 20, 1969.

As previously indicated, this research study also looked at the presence of barriers that could be interfering with experience gains. The respondents were asked if the lack of or reduction in these experience catalysts served as barriers. As Figure 4 shows, the barriers followed a close inverse correlation to experience accelerators. These barriers did not necessarily predominate, but they did highlight a couple of areas worth further examination.

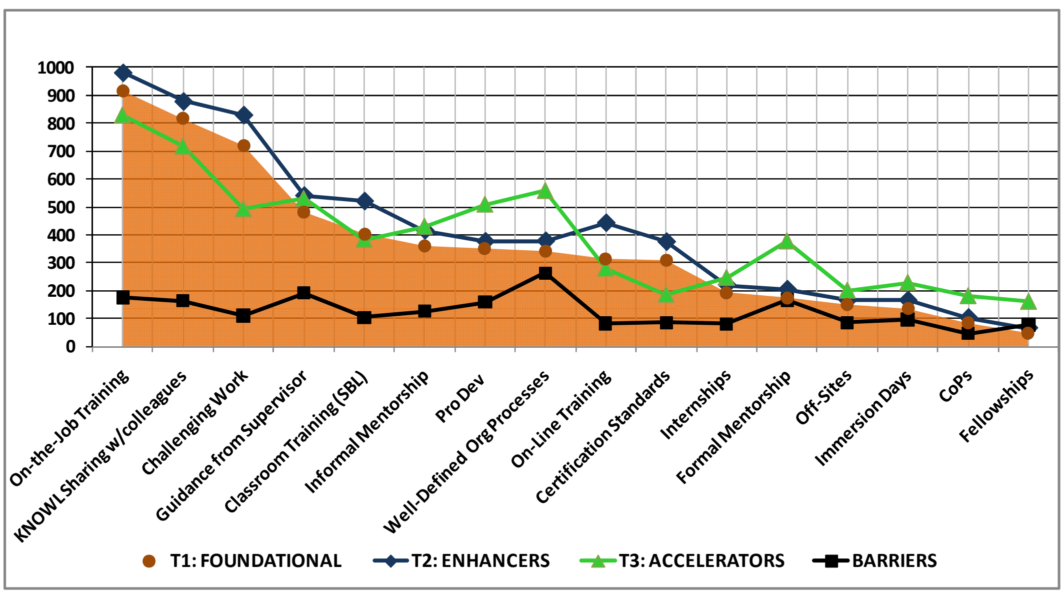

Figure 4. T1, T2, and T3 Experience Catalysts & Barriers

The lack of *well-defined organization* processes (also seen as an experience accelerator when visibly present) were the most prominent and could be attributed to

- outdated processes that no longer apply;
- reduced support for existing organizational processes;
- ambiguity that certain key organizational processes even exist; and
- poorly conveyed guidance without adequate explanation or appropriate justification (One respondent stated that the lack of published work processes curbed his experience gains).

While less of a barrier, although still noticeable, the lack of *formal mentorship* (and also seen as an experience accelerator when visibly present) emerged as a barrier, suggesting that some personnel might need more coaching from more senior personnel whom they trust and respect.

The lack of participation in *communities of practices* (CoPs) was considered neither a barrier nor a substantial experience factor in any one of the three tiers. While CoPs can give access to a tremendous set of colleagues steeped in relevant knowledge and experience, they appear to have less of an impact on experience growth than expected.

Certification standards were not seen as a barrier, suggesting that the workforce did not necessarily see them as either inhibiting experience gains or helping to achieve them.

Recommendations

The data in this study confirmed the substantial influence of certain experience catalysts where they tend to predominate—in the workplace. Understanding the correlation and value of these high flyers can have a marked impact on individual performance and acquisition outcomes if fully exploited. The experience catalysts operating in a less influential state could perhaps have a noticeable impact as well. If appropriately recognized (and in some cases, either clarified or [re]energized), they could also represent a powerful force multiplier for even more experience gains.

The acquisition workforce who participated in this study re-validated the major experience gains achieved by work-related experience catalysts. Accordingly, the sooner that formal training and informal training converge, the greater the impact off-the-job training will have. More importantly, however, is the convergence between *on-the-job* and *off-the-job* experience catalysts. When these two converge, they will better prepare the workforce for many more *on-the-job* eventualities (Figure 5).

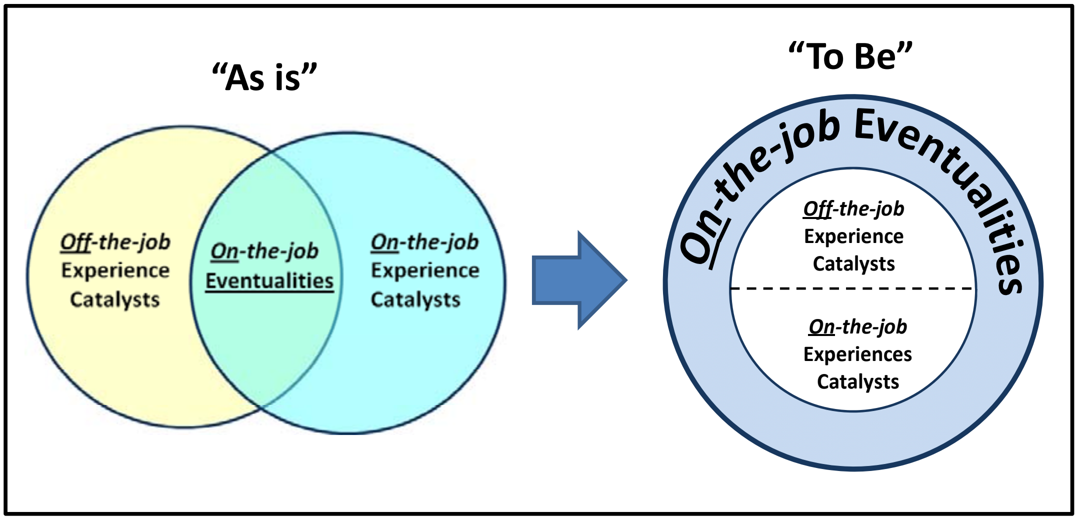

Figure 5. Convergence of Off-the-Job and On-the-Job Experiences

Convincing organizations to fully grasp the actuality that they also serve as informal *learning organizations* where experience really takes root (i.e., *on the job)* could serve as a crucible for many experience catalysts. To meet that end, the following recommendations are warranted for defense acquisition operating units:

1. Codify acquisition operating units as *learning organizations*. Recognize the wide range of experience catalysts in use daily in the workplace and how they can favorably impact organizational outcomes. Institute and monitor with regular frequency the effect of these experience catalysts inside the organization, and adjust as required. Reduce the barriers that might be limiting certain experience gains. More specifically,

    a. *Keep the work challenging and in perspective.* The acquisition workforce expects to be challenged—a key part to their professional growth. Workers tend to stay at the job and keep focused when the work is challenging and relevant. They leave when the work is not. Even when the tasks are sometimes repetitious, one respondent commented that they were different enough to strongly influence his motivation to stay since he also saw the impact he was having.

    b. *Capitalize and promote knowledge sharing opportunities.* Build an organic, flexible, logical, current, and enduring information architecture warehouse that contains actionable information that personnel can tap into freely. Give personnel easy access to key information sources of expertise. It deepens the workforce's knowledge base, expands perspectives, and fuels their experience engine. Without the open and continuous dialogue with peers, colleagues, and experts, competency gaps are more likely to occur and experience growth might plateau. Give project teams enough time to process new information. Personnel need slack time, organizational experience, and decision-making autonomy to fully benefit from access to new knowledge (Haas, 2006). Reward personnel for integrating and applying new knowledge when it creates organizational performance gains.

c. *Get supervisors involved in the training process before and after the event*. With greater involvement by the supervisor, the training can have more relevance and create more favorable impacts back on the job. The most important work environment factors affecting training transfer include "discussions with the supervisor on the use of new learning, the supervisor's involvement or familiarity with the training and positive feedback from the supervisor" (Nijman, 2011). Just as importantly, supervisors need to measure the performance outcomes of their personnel back on the job and show the dividends that training has produced. If the training is not hitting the mark, the first line supervisors would be the first to know and should clarify what needs to change through the appropriate channels. Supervisor commitment is crucial in validating the usefulness of training.

d. *Clearly articulate and punctuate the effectiveness of organizational processes*. Keep processes current, effective, and relevant. Communicate their usefulness with regular frequency. Show the benefits. Consider revising or terminating the ones that have outlived their usefulness. Ask the workforce what needs to change (or not). They are just as much the owners of the process as anyone else.

e. *Promote and support professional development opportunities*. It broadens the workforce's knowledge base by giving them an opportunity to further develop themselves by reaping the experiences and effective practices of others. It creates new professional relationships and future experience networks that the workforce can leverage for years to come. It makes an organization stronger. It combats competency gaps and helps break down obsolete mental mindsets.

f. *Promote mentorship*. Recipients can draw from the rich experiences from seasoned and respected leaders who possess a wealth of experience. Mentors encourage introspection. They motivate and inspire. They can help build a sustainable career pathway for personnel who are looking to widen their experience gains in both depth and breadth as they pursue their professional careers.

g. *Recognize the efficacy of DAWIA training*. Ensure that workforce members are ready for the training and the training is meeting the needs of the workforce. Provide useful and timely feedback to the training communities.

h. *Explore how immersion days and off-sites could promote and result in experience gains for personnel back on the job*. These very focused events cover a lot of ground, but the agenda should also include a component that targets individual and organizational performance. If they don't, then their connection to experience catalysts will remain nominal.

The following recommendations are warranted for defense acquisition training organizations:

2. Tighten the connection between *off-the job training* and *on-the-job training*. Learners need to understand the connection by witnessing the connection. The clearer the link between the skills taught and the skills required at work, the more required and newly acquired skills will stick. Make it truly experiential. Validate the learning objectives taught in class with outcomes in the field through a pain-free measurable follow-up initiative later in the field. Specialize and personalize the training whenever possible. Mimic their work environments as much as possible through methods that truly ignite their senses. In his book, *Talent is Overrated*, Geoff Colvin argues that "the road to exceptional performance is the result of deliberate practice" (Colvin, 2010) at what they need to know how to do.

    a. *Maximize SBL*. Few training techniques mimic the actual work environment better. They test the workforce under realistic conditions and give the workforce a chance to show their grit without the threat of dangerous consequences. It also brings together both cognitive (e.g., mental processes, knowledge application) and affective (e.g., feelings, attitude) behaviors, thereby increasing the quality of the experience. "Everything depends on the quality of the training experience" (Dewey, 1998).

    b. *Reinforce the benefits of certification standards*. Show the workforce the proof. While it should have bearing on upward mobility, it should not be the principal motivator. Too many acquisition professionals still do not see the returns. Many respondents saw getting their certifications as a way to get promoted and represented some of their motivation to take the course in the first place.

    c. *Monitor the usefulness of communities of practices (CoPs) closely*. Either reinvigorate certain CoPs that have dropped sharply in popularity or replace them with other knowledge-sharing methods that show more promise. If seen as invaluable, personnel will frequent. CoPs can provide the workforce with tremendous access to a wider experience network, but it has to go beyond simple data transmission. Research evidence shows that knowledge-sharing methodologies involving people interactions are superior to those involving only document exchanges since knowledge often needs to be carefully adapted to a new context in order for it to be effectively utilized (Cummings, 2003).

Conclusion

Today, in the face of declining budgets and increased public scrutiny of every dollar the DoD spends, the defense acquisition workforce is facing growing pressure to make every dollar for its goods and services count. While experience has and will continue to be a fundamental component of the human capital development equation, it is vitally important that the DoD recognizes what experience catalysts matter the most to the acquisition workforce. Twenty years from now, experience inside the DAW will matter just as much as it did when Congress voted the Defense Acquisition Workforce Improvement Act into law over

20 years ago. The only difference might be that the seam between off-the-job training and on-the-job training will disappear. The warfighting community has already reaped the benefits of a similar transparency. Like few others, warfighters test their experience in warfighting exercises that mimic real-world conditions under fire. The experience they possess grew from what mattered most: They train like they fight and fight like they train. When the acquisition community at large is tested in a similar fashion through intellectual workouts that mimic *their* real-world conditions, performance outcomes will invariably rise.

The acquisition workforce would be well served if it recognizes the importance and influence of all experience catalysts operating in the upper bands and better leverages the confluence of them—even the ones operating in the lower bands. Granted, there are so many variables involved in the experience equation. However, the key in its application depends on whether the workforce

- continuously practices their craft at work in what has long been serving as on-the-job laboratories;
- applies their mettle with challenging work and supervisors close by, and with mentors not far away;
- consistently shares relevant information through a highly collaborative and open knowledge-sharing environment in a wide range of mediums;
- recognizes the necessity and compelling reason for and connection between training and certification; and
- continuously thinks beyond yesterday's truths without getting trapped by competency gaps that could prevent experimentation with more suitable alternatives.

Implementing these collective actions might just energize many of the experience catalysts enough to the point that they all start to behave as experience accelerators. "Experience is the name every one gives to their mistakes" (Wilde, 1892). The DoD's acquisition workforce can least afford any experience shortfall that results in weapon system delays for warfighters serving in harm's way. Warfighters depend on the DAW to get it right the first time, and that's the only "aha" that really matters.

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Program Manager Professionalization: The "Return on Investment" Question

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Dr. Snider has a PhD in Public Administration and Public Affairs from Virginia Polytechnic Institute and State University, a Master of Science degree in Operations Research from the Naval Postgraduate School, and a Bachelor of Science degree from the United States Military Academy at West Point. He served as a field artillery officer in the U.S. Army for 20 years, retiring at the rank of Lieutenant Colonel. He is a former member of the Army Acquisition Corps and a graduate of the Program Manager's Course at the Defense Systems Management College.

Professor Snider's recent publications appear in *American Review of Public Administration*, *Administration and Society*, *Administrative Theory & Praxis*, *Journal of Public Procurement*, *Acquisition Review Quarterly*, and *Project Management Journal.*

Dr. Snider was co-recipient, with RADM (Ret.) Jim Greene, of the 2009 Richard W. Hamming Annual Faculty Award for Achievement in Interdisciplinary Activities. The selection was based on their work in leading and administering the Naval Postgraduate School's Acquisition Research Program. [ksnider@nps.edu]

Abstract

Much of the discourse on defense acquisition reform during the years leading to the Defense Acquisition Workforce Improvement Act (DAWIA) focused on the role of the program manager (PM). A Congressional Research Service report stated, "DoD acquisition problems can be solved only if those charged with responsibility for day-to-day implementation of weapons systems programs are adequately trained, experienced, and motivated" (Lockwood, 1985). This focus was evident in concerns such as

- perceived shortcomings in PM training and experience,
- frequent PM rotations (thus lack of continuity in office),
- absence of a dedicated PM career path, and
- whether a military officer or a civilian is better suited as a PM.

This discourse, together with DAWIA and subsequent workforce policies, presumes that

- an unprofessional (e.g., untrained, inexperienced) PM contributes to poor acquisition outcomes, and
- a professional PM contributes to improved acquisition outcomes.

This research project investigates the validity of these presumptions by addressing the "return on investment" (ROI) issue for public-sector professionalizing policies such as DAWIA. The primary research question is, to what extent does workforce (specifically PM) professionalization contribute to successful acquisition outcomes? The project draws on the private-sector ROI literature that links investments in human capital training and education to firm profitability; the corresponding public-sector literature is sparse. It examines programmatic data (e.g., acquisition program cost and schedule) as well as workforce data (e.g., training and education levels). A major issue is whether an appropriate model may be developed to investigate correlations between the two.

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Panel 21 – Innovative Mechanisms for Improved Acquisition

Thursday, May 12, 2011	
1:45 p.m. – 3:15 p.m.	**Chair: Dr. Fred Thompson,** Professor, Atkinson Graduate School of Management, Willamette University ***Optimal Cost Avoidance Investment and Pricing Strategies for Performance-Based Post-Production Service Contracts*** David Nowicki, Jose Ramirez-Marquez, and Ilona Murynets, Stevens Institute of Technology, and Wesley Randall, University of North Texas ***Prediction Markets as an Information Aggregation Tool for Effective Project Management in Defense Acquisition Projects*** Ricardo Valerdi, Massachusetts Institute of Technology, and Matthew Potoski, Iowa State University ***Game Theoretic Real Option Approach of the Procurement of Department of Defense: Competition or Collaboration*** Marc Rabaey, Belgian MoD, University of Hasselt

Fred Thompson—Grace and Elmer Goudy Professor of Public Management and Policy Analysis at the Atkinson Graduate School of Management, Willamette University. Dr. Thompson is a specialist in the field of tax policy and regulation.

Dr. Thompson is co-editor of the *Handbook of Public Finance*. He was the founding editor of the *International Public Management Journal* and is currently associate editor of the *Journal of Comparative Policy Analysis*. He has been published in numerous scholarly journals, including the *American Political Science Review*, *Public Administration Review*, *Public Choice*, and *Journal of Economic Behavior and Organization*.

In 2000, Dr. Thompson received the Distinguished Research Award of the National Association of Schools of Public Affairs and Administration and the American Society for Public Administration. In 2005 he received the Aaron B. Wildavsky Award for Outstanding Lifetime Scholarly Achievement in the field of public budgeting and financial management of the Association for Budgeting and Financial Management. In 2006 he served on the United Nations Development Program's Blue Ribbon Commission on Macedonia.

Dr. Thompson earned his Bachelor of Arts in Economics and History from Pomona College and his PhD from the Center for Politics and Economics, Claremont Graduate University.

Optimal Cost Avoidance Investment and Pricing Strategies for Performance-Based Post-Production Service Contracts

David Nowicki—Associated Professor, School of Systems and Enterprises, Stevens Institute of Technology (PhD and BS, University of Wisconsin-Madison, MS Virginia Tech). Dr. Nowicki's research focus is on the economic examination of the intersection between system designs and their supporting sustainment infrastructure. His research interests include performance-based logistics modeling, supply chain management, multi-asset optimization, reliability theory, and inventory optimization. He has been published in top-tier academic journals, conducted seminars, and presented at conferences in the United States, Europe, and APAC. Dr. Nowicki has over 15 years of industry experience. [dnowicki@stevens.edu]

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Ilona Murynets—Scientist, Chief Security Office, AT&T. Dr. Murynets recently completed a postdoctoral research appointment at Stevens Institute of Technology. She obtained her PhD in Systems Engineering at the School of Systems and Enterprises, Stevens Institute of Technology, where her dissertation received an Outstanding Dissertation Award. She holds a BS degree in Mathematics and an MS degree in Statistics and Financial and Actuarial Mathematics from Kiev National Taras Shevchenko University, Ukraine. Dr. Murynets' research is in the area of data mining, optimization, and statistical analysis in application to service pricing, malware propagation, spam detection, and mobile and network security. [imurynet@stevens.edu]

Abstract

Performance-based contracting (PBC) is altering the fundamental relationship between buyers and suppliers engaged in the support of capital-intensive systems such as high-speed rail, defense, and power generation. This relationship is shifting from a traditional transactional-based (return on sales) business approach to a collaborative, performance-based (return on investment) multi-year contractual model. With PBC, the supplier is compensated for system performance rather than for each maintenance, repair, and overhaul (MRO) transaction. PBC success lies in the incentive structure. Under PBC supplier profits, system performance and operator costs are improved when smart investment decisions are made that trade year after year MRO costs for upfront investments that reduce total cost of ownership.

This paper develops a decision-theoretic model that determines the optimal contract length and optimal investment and pricing strategies for performance-based, post-production service contracts that simultaneously maximizes the profit to the supplier while satisfying the customer's needs. The model accounts for reliability as a function investment, the average and variance of the cost to perform maintenance tasks, and for customers' willingness to pay for a contract depending on its length. Numerical examples illustrate how optimal strategies depend on potential market size, expected cost per failure, and on other parameters of the model.

Introduction

There is a noticeable paradigm shift in the contractual relationship between suppliers and buyers of post-production support service. Traditionally buyers and suppliers of post-production support for high capital intensive systems (e.g., high speed rail, defense systems, and power distribution systems) have tended to adopt a transactional relationship (Sols, Nowicki, & Verma, 2007). This buyer-supplier strategy is being supplanted by a more avant garde approach where the buyer-supplier relationship is characterized by long-term contracts focused on delivering performance and driving out cost for the buyer while providing satisfactory profit margins for the supplier (Randall, Pohlen, & Hanna, 2010). These performance-based service contracting strategies are referred to by a number of names such as performance-based logistics (PBL), performance-based contracting (PBC) and power-by-the-hour (PBH) with a central theme of providing an incentive structure based on multi-year contracts and shared cost avoidance (Kim, Cohen, & Netessine, 2007).

The traditional approach to post-production service contracts adopts a transactional view where a supplier's revenue and profit is generated with each service transaction. The more transactions, the more revenue and the more profit. In contrast, a performance-based strategy ties the supplier's revenue stream and profit margin to both the system performance and the cost associated with that performance. As costs go down, assuming performance within contract specification, the supplier profits increase.

One industry in which these PBC contracts are increasing is the United States Department of Defense (DoD) industry. Based upon the success of these PBC contracts the DoD has mandated performance-based contracting as the method of choice for post-production support of new systems (Vitasek & Geary, 2008). Currently the DoD is engaged in 76 performance-based contracts with another 95 scheduled in the near future (Geary & Vitasek, 2008). PBC has also been successfully employed in the commercial sector including aerospace, transportation, telecommunications, and power generation industries (Keating & Huff, 2005). By 2005, 50 countries were exploring or implementing performance-based maintenance contracts (National Cooperative Research Program, 2009). Existing practices in PBC proved its efficiency in terms of cost reductions and increases in system performance (Fowler, 2008; Kratz, 2008).

Suppliers using the traditional, transactional-based, post-production service agreements have generated satisfactory profit margins. However, this facilitates an uneasy economic imbalance between suppliers and customers. Alexander, Dayal, Dempsey, and Ark (2002) and Bundschuh and Dezvane (2003) recognize that even though after-sales support using the transactional economic model is a very profitable business for the supplier, the supplier's lack the financial incentive to invest in cost-avoidance strategies such as reliability, maintainability, and supply chain improvements. As a natural consequence of a performance-based contract, the supplier is inherently incentivized to invest in design and supply improvements to reduce out-year costs. As a result, there is often a mutually beneficial effect with the customer's maintenance reduced, the system's operational availability increased, and the supplier's profit margin increased (Kim et al., 2007).

As systems are kept in operation longer, and as support costs increase, the focus on performance-based sustainment strategies is likely to continue to gain momentum. Currently, it is commonly recognized that the operating and sustainment costs of a system often exceed 80% of the total life cycle cost of the system (Fabrycky & Blanchard, 1991). For high capital systems, these costs are substantial. For example, the expected cost to sustain the Joint Strike Fighter exceeds its development and production cost by over $250 billion (GAO, 2008). The commercial sector is equally burdened by the cost to sustain such systems. In the U.S., the airline industry spent $45 billion in 2008 on maintenance, repair, and overhaul (MRO), this is against a calculated $185 billion in revenue (ATA, 2008; Flint, 2007). These costs represent both a significant burden and a significant opportunity.

The opportunity arises from new and innovative post-production performance-based service strategies that conceptualize these sustainment cost streams as investment opportunities for the supplier and their supply chain partners. Customers must provide incentives to the suppliers for the suppliers to invest in cost-avoidance strategies. Central to any successful PBC contract is establishing a long-term relationship between a supplier and a customer (Sanders, Locke, Moore, & Autry, 2007; Sols et al., 2007). A supplier's decision to engage in a PBC with a customer, the amount of money a supplier is going to invest into cost avoidance alternatives, and the price a supplier is going to charge for its post-production services are all highly interrelated and heavily influenced by contract length.

The following fundamental research questions are addressed in our paper. Our research contact with both suppliers and buyers has showed us that these questions represent critical strategic decisions facing suppliers (and buyers) as they consider engaging in a PBC. Frequently, we have been asked to help conceptualize models that allow prediction of the economic viability of transitioning from a traditional to a performance-based service contract. That work has led us to recognize five key variables that impact the profitability, and investment decisions associated with a PBC. Those variables form the following questions.

Research Question 1: For a certain contract length, what is the optimal level of investment in cost-avoidance strategies, and what is the optimal price to charge for the post-production support service contract for an economically mutually satisfying experience for both the supplier and the customer?

Although performance-based contracting has drawn significant attention in the existing literature, most publications focus on qualitative research with a definite lack of quantitative models to assist suppliers and customers in making informed PBC decisions. Keating and Huff (2005) describe current practices in PBC and Kim et al. (2007) discuss advantages of PBC over traditional contracting. Sols et al. (2007) uncover the key characteristics of successful and unsuccessful PBC and further this research through the formulation of multi-dimensional reward and penalty schemes (Sols, Nowicki, & Verma, 2008). Nowicki, Steudel, Kumar, and Verma (2006) developed inventory allocation models in the face of PBC. However, none of the existing research has developed optimal investment and pricing strategies for performance-based contracting. This paper bridges this gap. This paper develops a decision-theoretic model that results in the optimal investment strategy, the optimal pricing strategy, and determines the optimal length of the contract and optimal reliability of the equipment, thus maximizing the supplier's profit and simultaneously satisfying the customer's performance requirements.

The paper is organized as follows. The Literature Review section reviews relevant literature on maintenance contracting, reliability, design, and pricing. The Model section develops the decision-theoretic model for performance-based contracts. The sections Model Notation Assumptions and Optimization derive the optimal investment and pricing strategies of the supplier for a given contract length. The Numerical Analysis section numerically illustrates optimal strategies and the final section concludes the paper.

Literature Review

This section presents a review of relevant literature on performance-based and traditional post-production service contracts, service pricing models, reliability, design, and the intersection of these relatable areas. While performance-based, post-production service contracting has emerged as a successful sustainment strategy in both the defense and commercial sectors (Fowler, 2008; Geary & Vitasek, 2008; Keating & Huff, 2005; Kratz, 2008), academic research in this area is only in its embryonic stage of development. Publications on performance-based contracting (PBC) mostly consist of guidebooks and good practice references found in government-issued guidebooks for suppliers (DAU, 2005a, 2005b). Existing PBC scholarship typically provides qualitative insight into current practices and implications of PBC (Kim et al., 2007; Sols et al., 2007).

The effects of PBC on the aerospace industry are discussed by Keating and Huff (2005) who suggest that PBC shifted risk from the customer to the supplier. The FCS Group for the Office of Financial Management (2005) conducted a literature review and surveyed several agencies and local jurisdictions that have implemented performance-based contracting on the best practices and trends in performance-based contracting. They identified that suppliers had a number of management issues and difficulties related to the implementation of performance-based contracting.

Few quantitative models exist in the general PBC domain and include Sols et al. (2008) who developed an n-dimensional performance model for use in a PBL arrangement. Nowicki et al.'s (2006) research examines inventory allocation under a PBL contract. Kim et al. (2007) developed a principle-agent model to study the implications of performance-based contracts by analyzing performance requirement allocation and risk sharing when a single customer is contracting with a collection of suppliers. We believe our model significantly furthers this effort by simultaneously determining the optimal investment, contract price, and contract length to maximize the supplier's profit while meeting the expectations of its customer base.

The pricing of new products and services is one of the key topics in the marketing literature (Marn, Roegner, & Zawada, 2003; Nagle & Holden, 1994; Rao, 1984). The most popular approaches to establish prices include cost-plus, return-on-investment, and perceived value pricing. The cost-plus approach sets a product's price to cover all costs associated with the product (Hanson, 2006), whereas return on investment pricing sets prices to achieve a targeted return on investment (Pride, Hughes, & Kapoor, 2008). The perceived value pricing approach is the most challenging of the three. It sets the price of a product according to a customer's perception of the product's value and requires surveying customers and inquiring about the maximal price that they are willing to pay for a product of particular quality, so called reservation price (Breidert, 2006). Optimal pricing models developed in the marketing literature are mostly focused on goods rather than on services and to the best of our knowledge there does not exist any model for optimal pricing of performance-based contracts.

Traditional maintenance contracting has been extensively studied in the literature (Levery, 2002; Sherif & Smith, 1987; Stremersch, Wuyts, & Frambach, 2001), however the existing models for traditional maintenance contracting are inapplicable for performance-based contracting since they do not simultaneously optimize pricing and investment strategies and they do not consider varying contracting periods. Murthy and Yeung (1995) used a game theoretic approach to derive optimal maintenance strategies for a customer and an independent service provider. They assumed that the customer determines the time between maintenance services and that the service provider determines the costs and the time to order spare parts. Asgharizadeh and Murthy (2000) and Murthy and Asgharizadeh (1999) use a game theoretic approach to derive their models under an assumption that a customer has to choose whether to accept a contract and to pay a fixed price or to reject the contract and to pay a cost of repair whenever equipment fails. The authors assumed that a service provider controls the price of the contract and the cost of repairs. Jackson and Pascual (2008) considered pricing of maintenance service contracts and determined the optimal number of clients to service in order to maximize the profits of a service provider.

Central to any performance-based contractual arrangement in order to properly sustain the operation of a system over time is the reliability of the system. Reliability is a dimension of quality (Murthy & Blischke, 2006) and it is defined as the probability that the product (system) will perform its intended function for a specified time period when operating under normal (or stated) environmental conditions. In the literature, the notions of reliability and quality are often used interchangeably. The majority of research on investment in product reliability optimizes the inherent trade-off between the reliability of a product and its market entry timing (Lilien & Yoon, 1990). For example, Deshmukh and Chikte (1977) presented a semi-Markov decision model for optimal funding of a product quality improvement project and time of the project termination. The authors assumed that a profit from the product is a function of the final product quality developed in comparison with that of the competing products available in the market on that date. Cohen, Eliashberg, and Ho (1996) developed a multistage model of a product quality improvement process optimizing time to market and a performance target. Levesque (2000) explored the effects of funding and its return on product quality and developed an analytical framework for optimal stopping rules for the development of the new product. Murthy, Rausand, and Virtanen (2009) developed a qualitative framework allowing manufacturers to achieve an optimal trade-off between an investment and the cost of consequences of inadequate product reliability. To the best of our knowledge, there is no research work developing a model for reliability improvement in the context of performance-based contracting.

As evident from our literature review, there is a lack of quantitative models for optimal investment and pricing strategies for suppliers offering performance-based contracts for new systems or for moving from traditional maintenance contracts to performance-based contracts for existing systems. To our knowledge, our paper is the first to develop a decision-theoretic model that optimally determines the periodic price point of a performance-based contract, the amount of money a supplier should invest in improving the reliability of the system it will contractually support, and the length of the contract between the customer and the supplier.

Model

Suppose a supplier offers a system for sale to its addressable market M with each potential customer having the option to engage in a post-production service contract. The salable system has an initial reliability of r_0, however, the supplier has the ability to improve the system design by investing x toward increasing the system's reliability according to $r(x)$, where $r(x) \geq r_0$. A customer purchasing the system is offered a post-production service contract at a fixed periodic fee p in exchange for a full complement of maintenance services. If the customer purchases the post-production contract, then the customer receives the system, with reliability $r(x)$, and the supplier is now responsible for the costs and risks associated with sustaining the proper operation of the system over the length (k) of the contract. A supplier's addressable market consists of M potential customers whose willingness to pay the periodic fee for the post-production service contract directly depends on the reliability of the system $r(x)$ and on the length of the service contract k. Let $w_{r(x),k}(v)$, $v > 0$ be the probability density function of reservation fees, that is, the maximum fee that a customer is willing to pay for the k-period contract if the system reliability is $r(x)$. A customer buys the post-production service contract if the supplier's actual periodic contract fee p is less than or equal to the customer's reservation fee. The fraction of the M potential customers that will engage in a post-production service contract of length k with the supplier is

$$W_{r,k}(p) = \int_{p}^{\infty} w_{r(x),k}(v)dv. \qquad (1)$$

The total profit to the supplier, assuming the supplier invests x into improving the reliability of its system's design, is

$$\Pi(x,p,k) = M\sum_{j=1}^{l}\frac{1}{(1+i)^{j}}(p - f(r(x)))\int_{p}^{\infty} w_{r(x),k}(v)dv - x \quad , \qquad (2)$$

where p is a periodic contract fee, i is an interest rate, and $f((r(x))$ is the total cost of all system failures for a single period within a k-period contract given that the system has a reliability of $r(x)$.

Model Notation and Assumptions

Table 1

M	number of potential customers.
k	length of a contact.
m	number of missions in a single time period of a contract of length k.
r_0	initial reliability of the system for the mission time t_m.
$r(x)$	reliability of the system for a cost avoidance investment of x.
γ	marginal investment parameter.
$f(r(x))$	total cost of all system failures for a single period, given that the system has a reliability $r(x)$.
μ_c	average cost per failure.
σ_c	standard deviation of the cost per failure.
p	periodic contract fee.
i	interest rate.
d	discount per period expected by customers.
λ	maximal fee that customers are willing to pay for the single-period contract if $r(x)$ = 1.
$w_{r(x),k}$	probability density function of customers reservation fees.
$W_{r(x),k}(p)$	fraction of customers that will engage in the k-period contract with the periodic fee equal to p and the reliability of the system is $r(x)$.
$\Pi(x,p,k)$	total profit to the supplier when investing capital x into the system reliability design for a k-period post-production contract with periodic fee p.

The new, decision-theoretic post-production service model developed herein is greatly influenced by the reliability of the system the supplier is contracted to sustain, the cost to the supplier each time a maintenance action is required, the supplier's total ownership cost of a system failure, and the willingness of a customer to engage in a post-production service contract with the supplier. Each of these variables are discussed below, highlighting the defining assumptions and key interrelationships:

Notation

Let us make the following four assumptions, denoted by (A1)-(A4):

(A1) The system reliability r depends on cost avoidance investment x in the following way:

$$r(x) = r_o + (1 - r_o)\left(1 - \frac{1}{x/\gamma + 1}\right) = \frac{x + r_o\gamma}{x + \gamma}, \tag{3}$$

where $\gamma > 0$ is a marginal investment parameter, defined as the marginal investment required to achieve an incremental improvement of system reliability. The function $r(x)$ satisfies the assumption regarding the initial reliability of the equipment ($r(0) = r_0$). The signoid shape of the curve $r(x)$ describes the relationship between system reliability and investment observed in reality fairly well (Levesque, 2000).

(A2) The cost per failure is a normally distributed random variable with the mean μ_c and variance σ_c^2.

(A3) The expected cost of all system failures per period decreases with reliability improvements is $f(r(x)) = cm(1 - r(x))$, where m is the number of missions in a single time period.

(A4) The customers' reservation fees follow the triangular distribution:

$$w_{r(x),k}(v) = \begin{cases} \dfrac{(\lambda(1-d(k-1))r - p)^2}{(\lambda(1-d(k-1))r)^2}, & 0 \le p \le \lambda(1-d(k-1))r \\ 0, & o.w. \end{cases} \quad , \tag{4}$$

where λ is a maximal fee that customers are willing to pay for the contract if reliability of the equipment will be improved to $r(x) = 1$ and d is a discount per period expected by customers if they buy a multi-period contract. The use of a triangular distribution to represent reservation fees is consistent with the current state of the pricing literature (Kirman, Schulz, Hardle, & Werwatz, 2005).

Optimization

The goal of the supplier is to identify an optimal investment x^*, optimal periodic contract fee p^* and optimal contract length k^* that maximize the supplier's expected profit $E[\Pi(x,p,k)]$ from a k-period contract ($k = 1,...,n$):

$$E\left[\Pi(x^*,p^*,k^*)\right] = \max_{k=1,\dots,n} E\left[\Pi(x^*,p^*,k)\right] , \tag{5}$$

where,

$$E\left[\Pi(x^*,p^*,k^*)\right] = \max_{\{x,p\}\in F_{x,p}} E\left[\Pi(x,p,k)\right] , \tag{6}$$

with a set of feasible solutions:

$$F_{x,p} = \{\{x,p\} \mid x > 0, 0 \le p \le \lambda)1 - d(k-1))r\}. \tag{7}$$

where the upper bound for the price follows from triangularly distributed customers' reservation prices. Under the assumptions (A1)-(A4), an expected profit is given by

$$E\left[\Pi(x,p,k)\right] = \begin{cases} \dfrac{MI_k(p(x+\gamma) - \mu_c m(1-r_o)\gamma)(p(x+\gamma) - \lambda D_k(x+r_o\gamma))^2}{\lambda^2 D_k^2 (x+r_o\gamma)^2 (x+\gamma)} - x, & 0 \le p \le \lambda D_k r(x) \\ 0, & o.w. \end{cases} \tag{8}$$

where, $D_k = (1 - d(k - 1))$ and $I_k = (1 + i - (1 + i)^{-k})/i$.

The optimal investment x^* and the optimal periodic fee p^* for the k-period contract are either critical points determined from the first order necessary conditions:

$$\left.\frac{\partial E\left[\Pi(x,p,k)\right]}{\partial x}\right|_{(x^*,p^*,k)} = 0$$

and

$$\left.\frac{\partial E\left[\Pi(x,p,k)\right]}{\partial p}\right|_{(x^*,p^*,k)} = 0 , \tag{9}$$

or belong to the boundary of the feasible set F_{xp}. With Equation 8, Equation 9 reduces to

$$p = \frac{2\mu_c m(1-r_o)\gamma + \lambda D_k X}{3(X-\gamma(1-r_o))}$$

and

$$4M\gamma I_k(1-r_o)\left(X\lambda D_k - cm(1-r_o)\gamma\right)^2 (cm(3X+2(1-r_o)\gamma) + X\lambda D_k) - 27X^3\lambda^2 D_k{}^2(X+(1+r_o)\gamma)^2 = 0$$

where, $X = x + r_0\gamma$. If (x^*,p^*) is a critical point it satisfies the second order sufficient conditions:

$$\left.\frac{\partial^2 E[\Pi(x,p)]}{\partial^2 x}\right|_{(x^*,p^*)} < 0, \quad \text{and} \quad \left.\frac{\partial^2 E[\Pi(x,p)]}{\partial^2 p}\right|_{(x^*,p^*)} < 0, \tag{10}$$

and

$$\left.\frac{\partial^2\Pi(x,p)}{\partial^2 x}\frac{\partial^2\Pi(x,p)}{\partial^2 p} - \frac{\partial^2\Pi(x,p)}{\partial x\partial p}\frac{\partial^2\Pi(x,p)}{\partial p\partial x}\right|_{(x^*,p^*)} > 0, \tag{11}$$

The optimal solution (x^*, p^*) is obtained numerically for all $k = 1,...,n$ and the optimal contracting period k^* follows from Equation 5.

Numerical Analysis

This section analyzes how the optimal investment x^*, optimal contract fee p^*, optimal contract length k^*, reliability $r(x^*)$, and the expected profit $\Pi^* = E[\Pi(x^*,p^*,k)]$ depend on parameters d, λ, μ_c, r_0, M and γ.

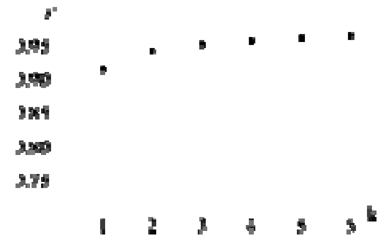
Suppose a supplier of airplane engines plans to introduce a performance-based post-production service option to a market consisting of 60 potential customers (M = 60). The maximal periodic fee that customers are willing to pay for the post-production maintenance service contract is $100,000 ($\lambda$ = 100). Customers expect a 7% discount per period if they subscribe to a multi-period contract (d = 0.07). The initial reliability of the engines is 0.7 (r_0 = 0.7) and at least a $100, 000 investment is required to improve the reliability of the engines up to $r_0 + 1/2(1 - r_0) = 0.85$ (γ = 100). Let the periodic interest rate be equal to 5% (i = 0.05). The expected cost per failure is $20,000 ($\mu_c$=20) and the variance of the cost per failure is $4,000 ($\sigma_c$=4). Assume that a period consists of 10 missions (m = 10). Table 2 summarizes the parameters considered in this example.

Table 2. Baseline Example

Parameter	d	M	**λ**	**r_0**	**γ**	**μ_c**	**σ_c**	**m**	**i**
Value	0.07	60	100	0.7	100	20	10	10	0.05

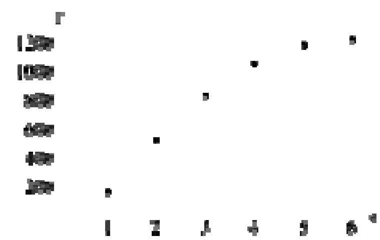
The optimal investment and the optimal contract fee for each k-period contract (k = 1,...,6) are obtained from Figures 1(a) and 1(c). The results, as illustrated through this example, suggest that the longer the contract length, the higher the optimal investment and the lower the optimal periodic contract fee. Figures 1(b) and 1(d) show that a longer contract length results in a system that is delivered with a higher reliability to the customer and provides an even greater profit to the supplier. Herein lies the economic win-win for both the supplier and customer and provides the necessary mechanisms to properly incentivize the supplier to invest in cost avoidance strategies. In this example, a 6-period contract is best with an optimal investment of $751,302 and the optimal periodic contract fee is $25,602. This contract results in reliability equal to 0.965 and the expected total profit of the supplier is $1,227, 210.

(a) Optimal investment (x) vs contract length (k)



(b) Reliability r(x) vs contract length (k)

(c) Optimal contract fee (p) vs contract length (k)



(d) Profit (π) vs contract length (k)

Figure 1. Optimal Investment, Reliability, Periodic Contract Fee and Profit as Functions of Contract Length

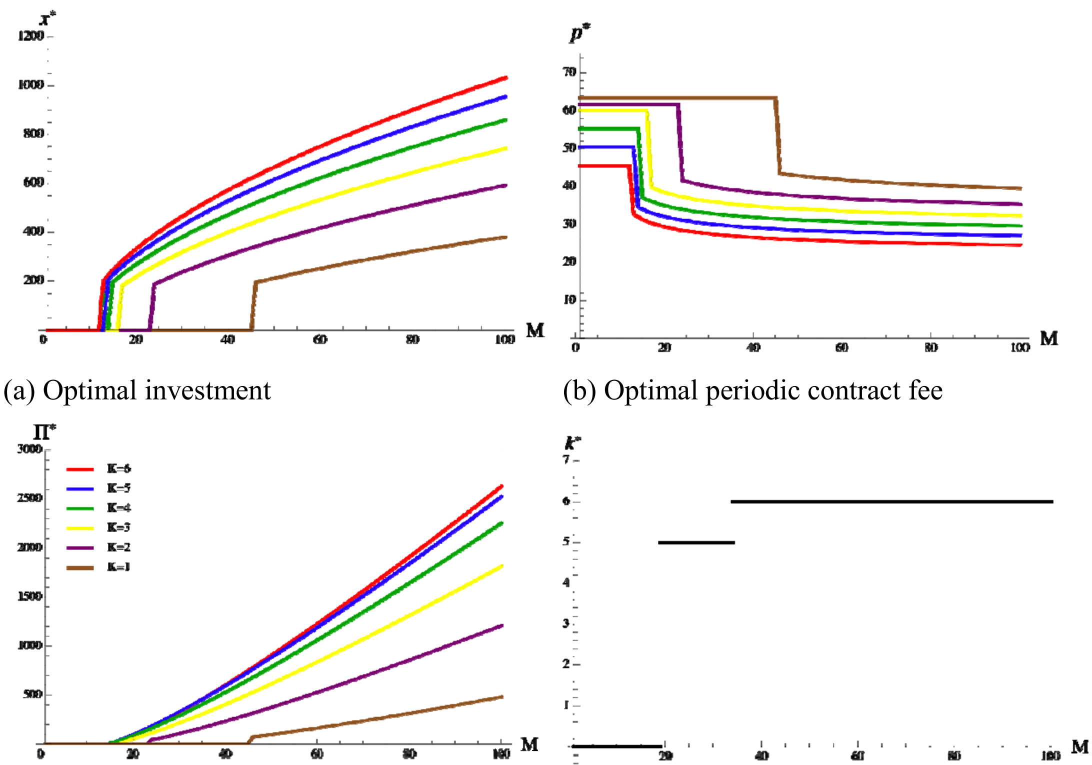
Parameters in Table 2 may vary due to different economic conditions. The remainder of this section discusses the sensitivity of the optimal (for the considered example) results on the parameters of the model. Understanding the sensitivity of these parameters is central to the contractual negotiation process for both the supplier and the customer. Figures 2–7 show x^*, p^*, Π^* and k^* as functions of the discount per period, d; market size, M; customers' willingness to pay, λ; initial reliability, r_0; marginal investment parameter, γ; and the expected cost per failure, μ_c. Table 3 summarizes how the optimal contract's length depends on variations of the parameters $d, M, \lambda, r_0, \gamma, \mu_c$.

Table 3. Sensitivity of the Optimal Contract's Length on the Model Parameters

Parameter	k^*=6	k^*=5	k^*=4	k^*=3	k^*=2	k^*=1	*No contract*
d	[0, 0.08]	(0.08, 0.1]	(0.1, 0.13]	(0.13, 0.18]	(0.18, 0.33]	[0.33, 0.4]	
M	[38, 100]	[20, 38)					[0,20)
λ	[80, 150]	[60, 80]					
r_0	[0.5, 0.9]						
γ	[0,170)	[170,380)					[380,+∞)
μ_c	[0, 34)	[34,40)					

Optimal investment and contract length are increasing functions of the market size, whereas the optimal periodic contract fee is a decreasing function of the market size (see

Figure 2). Moreover, a certain critical market size, which depends on the contract's length, is required for profitability of a contract. For example, it is unprofitable to provide 1-period contracts if the potential market has less than 46 customers and it is unprofitable to provide 6-period contracts if there are less than 14 potential customers on the market, see Figure 3(c). This has the following interpretation. Customers are willing to pay higher fees as the reliability of engines improves. Consequently, the supplier has to invest as much as possible in reliability improvement. However, if the supplier invests large capital in reliability and the market size is small, the supplier may not break even. Thus the optimal investment increases gradually with market size.

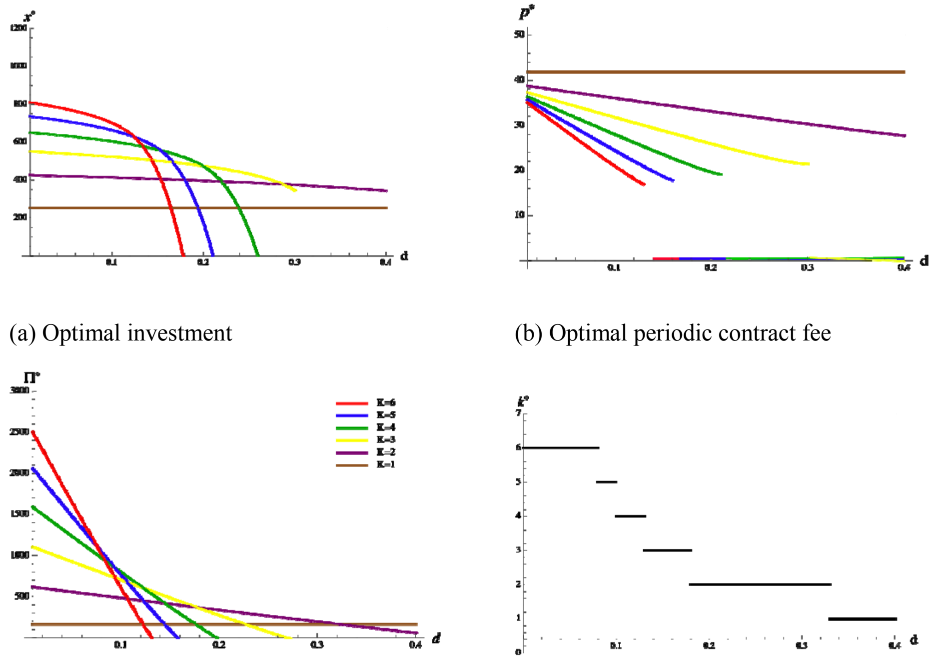


(a) Optimal investment (b) Optimal periodic contract fee

(c) Profit (d) Optimal contract's length

Figure 2. Optimal Investment, Periodic Contract Fee, Profit and Optimal Contract's Length as Functions of the Market Size

The optimal investment, the contract's periodic fee, and length are decreasing functions of the discount per period expected by customers (see Figure 3). Although, in general, longer contracts are more profitable, the supplier should offer shorter contracts if the discount per period is high.



(a) Optimal investment

(b) Optimal periodic contract fee

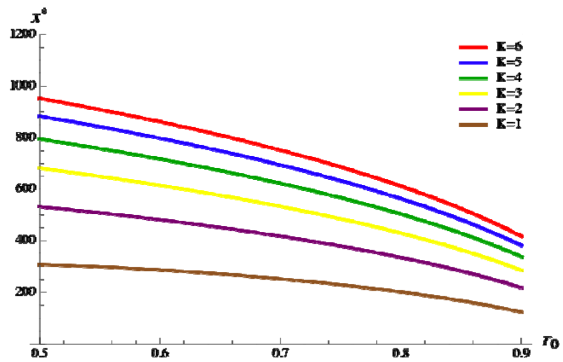
(c) Profit

(d) Optimal contract's length

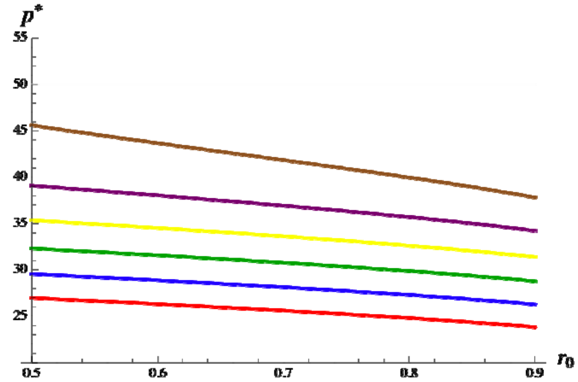
Figure 3. Optimal Investment, Periodic Contract Fee, Profit and Optimal Contract's Length as Functions of the Discount Expected by Customers

The optimal investment, periodic contract fee, and the contract's length are increasing functions of the maximal price that customers are willing to pay for a single-period contract (see Figure 4). In other words, the more customers are willing to pay, the higher fees the supplier should charge.

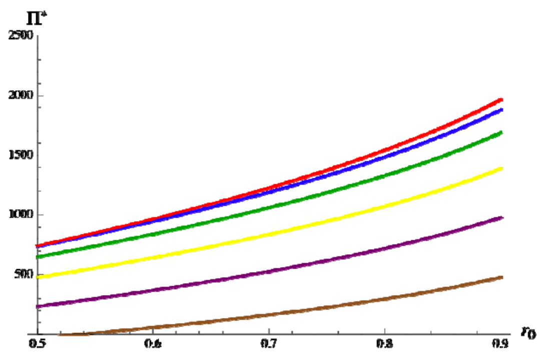
The optimal investment and periodic contract fee are decreasing functions of the initial reliability (see Figure 5). The higher the initial reliability the less the supplier has to invest to achieve a targeted level of reliability and consequently the lower the optimal contract fee.



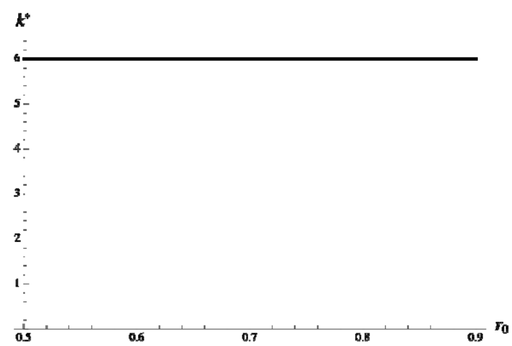
(a) Optimal investment



(b) Optimal periodic contract fee



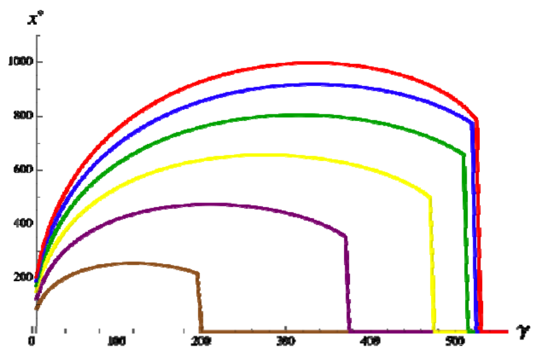
(c) Profit



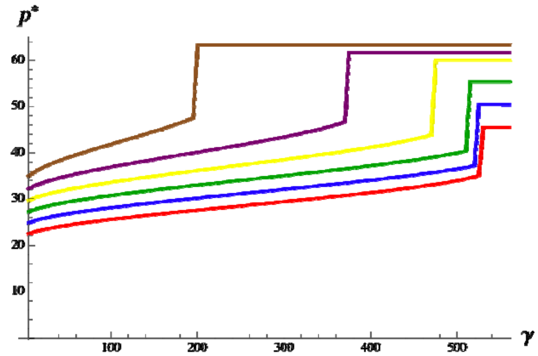
(d) Optimal contract's length

Figure 5. Optimal Investment, Periodic Contract Fee, Profit and Optimal Contract's Length as Functions of the Initial Reliability

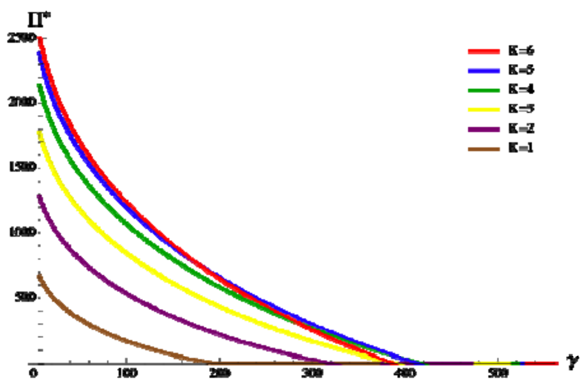
The optimal investment and periodic contract fee increase as the marginal investment parameter increases (see Figure 6). However, for each contract length there exists a marginal investment threshold where it is unprofitable for the supplier to invest in reliability improvement. For example, if γ >200, it is unprofitable to invest in reliability improvements for 1-period contracts and if γ >380, it is unprofitable to invest in reliability improvements for 2-period contracts. Thus, the threshold level rises with the contract's length.



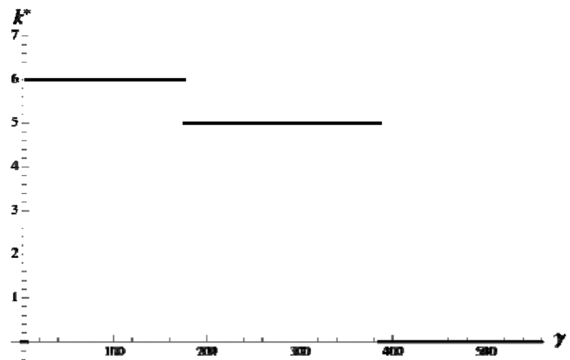
(b) Optimal investment



(c) Optimal periodic contract fee



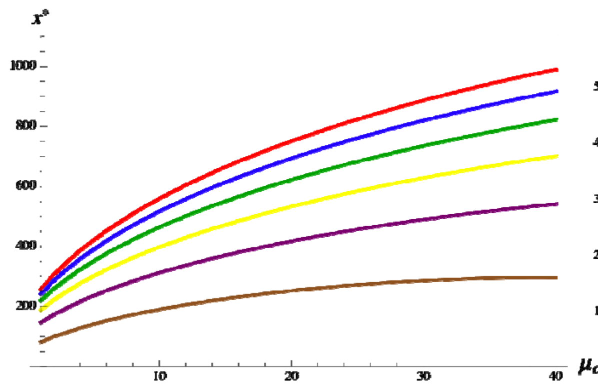
(d) Profit



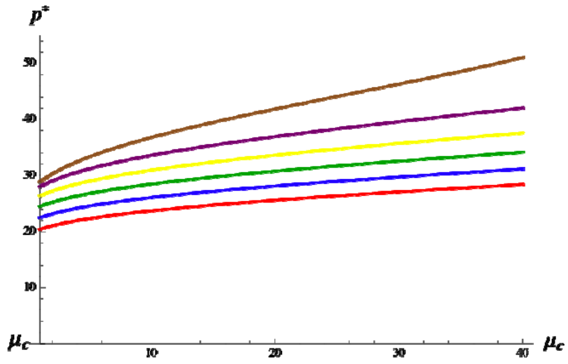
(e) Optimal contract's length

Figure 6. Optimal Investment, Periodic Contract Fee, Profit and Optimal Contract's Length as Functions of the Marginal Investment Parameter

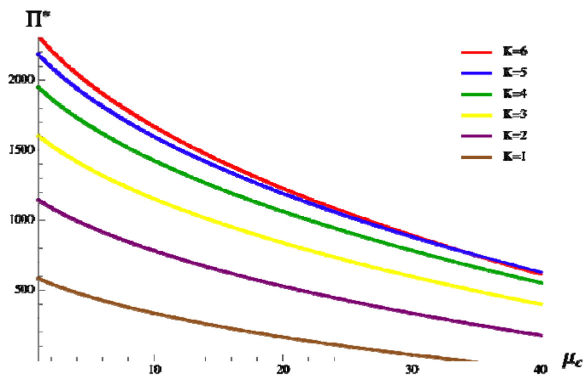
The optimal investment and periodic contract fee are increasing functions of the expected cost per failure (see Figure 7). If the cost per failure is high, the supplier needs to invest in reliability as much as possible in order to reduce the number of future failures and consequently avoid future costs. More failures are likely to occur during longer contracts. Thus, the optimal contract's length is a decreasing function of the expected cost per failure.



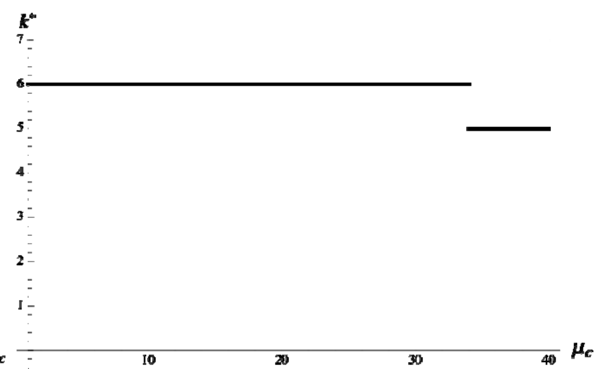
(b) Optimal investment



(c) Optimal periodic contract fee



(d) Profit



(e) Optimal contract's length

Figure 7. Optimal Investment, Periodic Contract Fee, Profit and Optimal Contract's Length as Functions of the Expected Cost Per Failure

In summary, the following conclusion can be drawn:

- The optimal investment is an increasing function of the expected cost per failure, the market size, and the customers' willingness to pay, but it is a decreasing function of the initial reliability.
- The optimal periodic contract fee is an increasing function of the contract's length, the customers' willingness to pay, and an expected cost per failure, but it is a decreasing function of the initial reliability and market size.
- Longer post-production service contracts require higher optimal investments but provide higher system reliability.
- Optimal contract length is a decreasing function of the discount per period, the expected cost per failure, and the marginal investment parameter, and it is an increasing function of the market size and the maximal price that customers are willing to pay for a single-period contract.

Conclusions

As performance-based contracts (PBC) continue to gain momentum, it is important for suppliers to determine the right price to charge in order to capture business to provide service to its own systems or other systems it is capable of sustaining. This paper develops a decision-theoretic model to assist suppliers in defining their investment and pricing strategies for performance-based, post-production service contracts. To our knowledge we are the first to develop, under a PBC, a mathematical model and corresponding solution to determine the optimal investment, contract price, and contract length that maximizes the supplier's profit while meeting the expectations of its customer base.

Of particular interest is gaining insight into the underlying motivation for a supplier to engage in a PBC with a customer, or collection of customers, or a customer's willingness to enter into a PBC with a supplier. Our findings suggest that these decisions are heavily influenced by the contract length, the supplier's level of cost avoidance investment, and the periodic contract fee the supplier offers to its addressable market.

Numerical examples analyze the optimal contract length, investment, system reliability, and optimal periodic fee with respect to the initial system reliability, customers' willingness to pay, the expected cost per failure, and other parameters of the model. The findings from this numerical example suggest that there is a formidable tradeoff space in determining, first and foremost, if a supplier should offer a PBC to its customer base, and if a PBC is offered what price should be offered. The price offering is heavily influenced by the reliability of the system the supplier is offering to service, the length of the contract, and the amount of money the supplier will invest into cost avoidance strategies such as reliability and supply chain improvements.

We believe this is just the beginning of an area of research that focuses on managerial decisions at the intersection of system design, supply chains, and sustainment. Cost avoidance strategies run the gambit of improving the reliability of a system to capital investment into spares to satisfy a customer's requirements. Among other research questions is how to optimally allocate funds among competing cost avoidance alternatives? As it relates to PBC, a future area of research is to determine how to invest in these competing and sometimes complimentary cost avoidance alternatives in order to increase the likelihood of contract capture and to further increase profit.

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Acknowledgements

This material is based upon work supported by the Naval Postgraduate School Acquisition Research Program under Grant No. N00244-10-1-0074.

Prediction Markets as an Information Aggregation Tool for Effective Project Management in Defense Acquisition Projects

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Abstract

A central challenge in defense acquisition is the development of accurate cost and schedule estimates. The lack of discipline in estimating and unrealistic expectations in the early phases of programs have been often cited as common causes for poor performance of large programs (GAO, 2004, 2006). Initial estimates provided by contractors are known to "anchor" expectations (Aranda & Easterbrook, 2005), even when changes in personnel, technology, or budgetary priorities can affect the performance of a program. We examine the use of prediction markets as a tool for generating schedule estimates as a supplement to existing estimation methodologies.

Report Summary

A central challenge in defense acquisition is the development of accurate cost and schedule estimates. The lack of discipline in estimating and unrealistic expectations in the early phases of programs have been often cited as common causes for poor performance of large programs (GAO, 2004, 2006). Initial estimates provided by contractors are known to “anchor” expectations (Aranda & Easterbrook, 2005), even when changes in personnel, technology, or budgetary priorities can affect the performance of a program. We examine the use of prediction markets as a tool for generating schedule estimates as a supplement to existing estimation methodologies. A prediction market provides an environment for traders to buy and sell contracts whose value is tied to an uncertain future event, such as the duration of a weapons system acquisition. Most notably used today for predicting election outcomes, prediction markets are used to forecast product sales, movie box office returns, terrorist attacks, and sporting events (Wolfers & Zitzewitz, 2004).

A prediction market is a means of forecasting some unknown future condition of the world. In a prediction market, buyers and sellers trade contracts and money for contracts whose payoff depends on the future state (Wolfers & Zitzewitz, 2004). If the market is well functioning, contract prices reflect the collective wisdom of the market participants. There are three primary types of prediction markets.[1] Much of the enthusiasm for prediction markets derives from the efficient markets hypothesis. In a truly efficient prediction market, the market price of a prediction market contract will best summarize traders’ beliefs about the probability of the event’s occurrence. Efficient prediction markets should outperform available polls and other forecasting mechanisms.

We anticipate prediction markets to outperform existing defense acquisition estimation techniques (i.e., parametric, analogy, activity-based) for cases in which there is ample “soft,” relative to “hard,” information, and information is broadly and unevenly held by diverse actors. Examples of such circumstances include one-of-a-kind acquisitions in which limited historical information exists, and acquisitions that are prone to performance impacts to external events. Modifications to the design, shifts in program personnel, or changes in the political landscape may have significant impacts on the cost and duration of a program. Existing cost-estimation techniques are not sensitive to these types of changes because (1) most Cost Estimating Relationships (CERs) are based on technical factors, rather than programmatic “soft” factors; (2) cost estimates are not dynamically updated as a program evolves, making the original estimate outdated as soon as the climate changes; and (3) cost estimates are a manifestation of a few decision makers, often under tremendous time pressure, working with limited and, perhaps biased, information.

By shifting the paradigm from estimating by individuals to estimating by groups, we can harness the wisdom of crowds by capturing their collective intelligence. A prediction market facilitates the aggregation of data from diverse and independent sources, yielding more accurate forecasts. The prediction markets’ value is grounded in several factors. First, they provide a way to leverage the wisdom of crowds by aggregating information from diverse sources. Studies have shown that under the right circumstances, prediction markets are quite accurate, and often more so than even the most accurate individual forecasters (Surowiecki, 2005; Griffiths & Tenenbaum, 2006). Second, they mitigate decision biases stemming from pressures to “price to win” and hide information. Third, they enable frequent

[1] The following discussion of prediction market types comes from Wolfers and Zitzewitz (2004).

sampling of information, which makes them more responsive to environmental changes. Finally, prediction markets provide incentives for traders to seek out additional information.

As with any markets, prediction markets may fail—and produce inaccurate forecasts—if not properly designed and executed. Like markets generally, effective prediction markets require a sufficient number of buyers and sellers, well informed about each other and their resources, and a mechanism through which they can exchange resources under fully specified, clear, and enforceable contracts. We briefly discuss some potential challenges in prediction market design before discussing more specific prediction market design principles and the conditions for making them successful.

Game Theoretic Real Option Approach of the Procurement of Department of Defense: Competition or Collaboration

Marc Rabaey—marc.rabaey@gmail.com

Abstract

The real option analysis for investments is well known. In order to make decisions (delay, stop, start up, continue), management is waiting to collect more information, or is waiting for a better environment (market situation, political situation and so on). However this is without taking into account the (inter)actions of the other players in the market. Option games will place the real options into a strategic (game theoretic) context., i.c. DoD for procurement.

In reality, the complexity of real options and the need for the permanent monitoring of the environment make some managers reluctant to introduce it in the enterprise for investment decision-making. A generic framework "Intelligence Base" is being proposed to approach intelligence and game options in a holistic way for the strategy and the investments.

Introduction

The real option analysis for investments is well known. In order to make decisions (delay, stop, start up, continue), management is waiting to collect more information, or is waiting for a better environment (market situation, political situation and so on). However, this is without taking into account the (inter)actions of the other players in the market. Option games will place the real options into a strategic (game theoretic) context.

As we will show, for the strategic interaction with other parties alone, an organization who wants to gain competitive or collaborative advantage, has to screen permanently its environment and its own functioning.

Weeds (2006) points out that to use real options, the real options valuation (ROV) requires a detailed analysis of the full range of possible developments in the future and the probability of success of each one, not just the expected or average outcome. Furthermore, implementation of ROV requires managers to monitor the business environment to assess what should be done with the options. If they cannot bring up the effort to do so, then they are unlikely to achieves the values calculated using ROV. This and the complexity of ROV makes it difficult to implement ROV.

The attentive reader will certainly remark that the effort to monitor the environment of the organization for strategic reasons, can also be used to collect information to implement and maintain the ROV and even more when both are combined in the option games. Therefore, we will propose a generic intelligence system that every organization can instantiate in function of its culture and capabilities.

In what follows we will start from the art of war to develop a forum in which all decisions for investments and procurement can be made. In the next section the process of decision-making for that forum is discussed. In the Intelligence Base section and the Conceptual View on the Intelligence Base section we will propose a generic intelligence system, called intelligence base. The Investments section handles the combination of real options and game theory. Before we conclude, we will give an overview how a department of defense can use the game-theoretic approach of real options in the cases of collaboration and competition and how DoD can determine the possible strategy games for the suppliers (procurement).

From Strategy to Action

The Art of War

To Bernard (1976), there are three principles of the Art of War:

- Balance between Goals and Means,
- Liberty of Action, and
- Economy of Forces.

Regarding the military (Hart, 1991; Bernard, 1976), grand strategy is the art to combine resources of an organization to attain its objectives. This is determined by the first principle of the Art of War, being the balance between objectives and resources. If a company uses too many resources to attain the objectives, then it is not efficient. If too few resources are used, then the company will not be effective and it will not attain its objectives.

As a result of the balance between goals and means, two types of strategy will be derived from the grand strategy: the business strategy and the resources strategy. Examples of resources are human resources, financial resources and ICT.

The business strategy will define strategic objectives that have to be attained by the (core) business units through their processes. Thus, the strategy itself is realized by business processes. These processes may belong to one or more organizations.

The first principle has one rule: the permanent seeking of intelligence, inside and outside the organization. The balance between goals and means is about determination of the right objectives, given the environment and the available and/or possible needed resources related to these objectives. The result is the grand strategy of the entire organization. As a consequence of this balance, two other strategies can be derived: Business and Resources Strategies. The first is focused on the creation and the deployment of the core competences to attain the imposed objectives, while the latter is focused on the means and the processes to support the first (Rabaey et al., 2007a).

The liberty of action is about security: avoiding, preventing as much as possible, hostile actions of other organizations and the assuring of the communication lines (logistics, information; for intelligence). The economy of forces treats the economical and right use of the resources (efficiency and effectiveness).

The deeper in the hierarchy of the organization, the less impact the leaders have on the resources aspects and the scope of their business levels. Therefore, in the ever-faster changing world, the structure becomes less hierarchical, so flexibility is gained. This implies that these leaders (and/or managers) need to have access to more information and have a more extended information system.

Interdisciplinary Forum

Rabaey et al. (2007) define a business process as a logical set of activities that consumes resources to attain its objectives. In the organization of the business processes, we have the second alignment of goals and means. The resource managers and the business unit managers will discuss the operational use of resources (organization) in an interdisciplinary forum—interdisciplinary because of the multitude of functional domains (Rabaey et al., 2007a). The result is the providing of the resources and their service levels (SLA = Service Level Agreement).

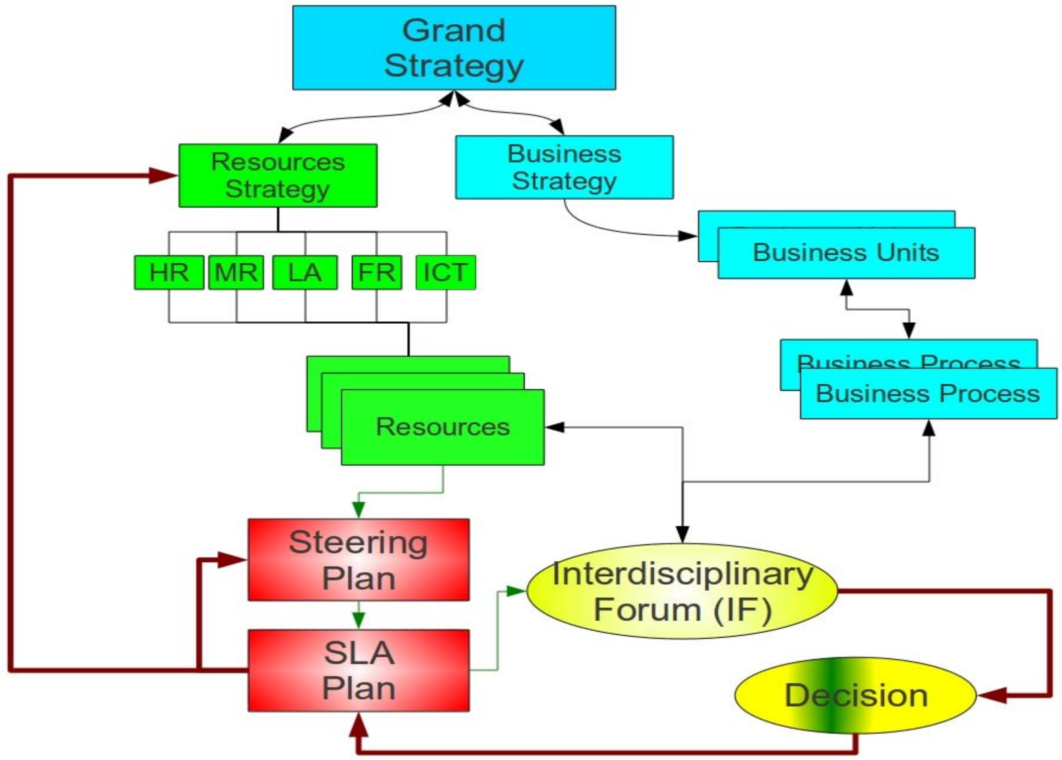

Figure 1. Interdisciplinary Forum

From a business perspective, a resource or service provider will be evaluated on the delivery of the service (SLA) and the quality of service (QoS). The deployment of resources in a business process is the result of a decision process (of the interdisciplinary forum). If software must be able to choose and to deploy itself the resources and the modules of its capability, then it must be capable to understand the characteristics and the purposes to attain its imposed objectives.

Different Games on Different Levels

If we look at an organization as DoD, the organization can play different games at the same time in different domains. So, there is no such thing as a unique strategic game to play.

Moreover, the underlying organizational elements can themselves play different games regarding the mother organization and regarding each other, even for a same project: IT can collaborate with third parties, while human resources are in competition with these parties. If there is no superstructure (like project management or business unit), then contradictory signals are sent to the market.

Thus for the procurement of goods and services the strategy for that project, the chosen strategic game is that of the superstructure. The strategies (games) for the sub-organizational units will be derived from that game. As such, suboptimal strategies are avoided in the request for proposal. It is the interdisciplinary forum that determines the strategy and rules for the procurement for that particular project.

Enterprise Architecture

The strategy of the project itself has to be aligned with the higher strategies and the already made investments (because most of them are irreversible, therefore there are sunk costs). The new project may change the investment plan, thus flexibility and adaptability are demanded. For that reason, real options are very useful.

The changes of investment will reflect on the steering plan (see Figure 1). Since IT performs more and more an important role, it is necessary to have a framework in which IT can be situated in the function of the business. Enterprise Architecture (EA) is such a framework. The Enterprise Architecture Research Forum (http://earf.meraka.org.za/earfhome/) defines Enterprise Architecture as "the continuous practice of describing the essential elements of a socio-technical organization, their relationships to each other and to the environment, in order to understand complexity and manage change." Therefore, Enterprise Architecture should consist of distinguished levels. The naming of the distinguished levels may differ, but in general at least EA should consist of Business Architecture, Information Architecture, Application Architecture, and Infrastructure Architecture (Rabaey et al., 2007a).

Rabaey (2012) proposes to add an additional layer, namely Knowledge Architecture, because IT will become a utility (commodity) and competitive/collaborative advantage will become almost fully dependent from the capability of producing intelligence for decision-making and knowledge management (in systems, processes and human resources). Some investment techniques use knowledge units (Housel & Bell, 2001) or Knowledge Value Added (KVA) to assess investment probabilities (Mun & Housel, 2006).

Decision-Making

Uncertainty and Risk

Real options are used to assess risk (Benaroch, Jeffery, Kauffman, & Shah, 2007) and uncertainty and take the appropriate measures and decisions. Both terms, risk and uncertainty, are interchanged because of the fact that the outcome is the same (expected values; Aven, 2010, p. 55), but semantically they are very different in the approach regarding decision-making.

Organizations have to make important decisions (like investments) without complete information in a complex and fast changing environment. Uncertainty is a state in which the outcomes are unknown and perhaps unknowable; the more distant in time (future), the greater the uncertainty (Funston & Wagner, 2010, p. xxiii).

There is a correlation between the level in the organization and the degree of uncertainty: the higher in the organization, the less explicit information exists, so the more uncertainties exist, and therefore the more intelligence it needs to reduce this uncertainty (see Figure 2).

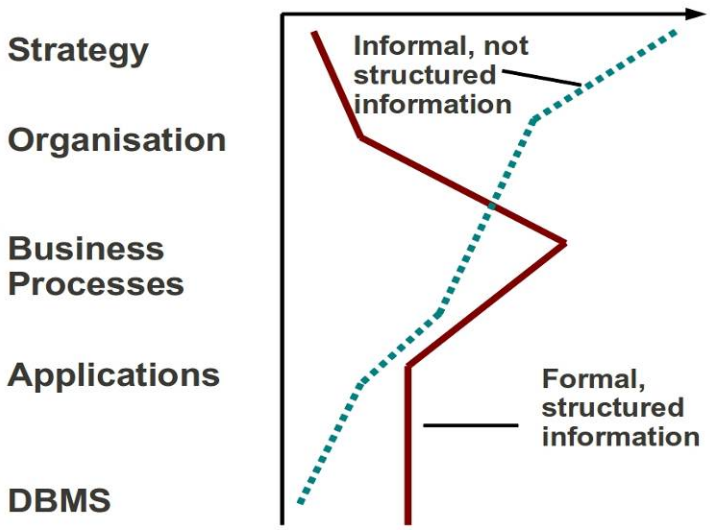

Figure 2. Lack of Formal Information
(Rabaey et al., 2007)

The decision horizon is further at the strategic level than at the operational or tactical levels of the organization. For most of the organizations in this ever-faster changing environment, the time line at the strategic level is from the present until the long term (at least a year), while the operational level is from now until short term (a couple of weeks or months at most).

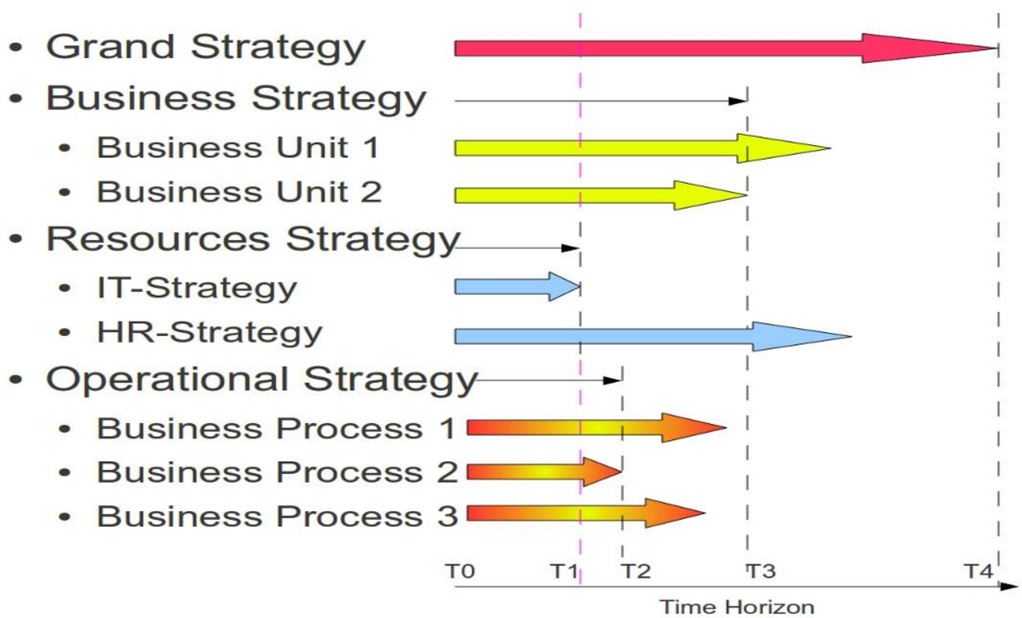

Figure 3. Time Horizon, Uncertainty and Volatility

In Figure 3 the grand strategy determines the long term horizon (T4). The other arrows are indicating the quasi-certain period. For the business strategy business unit 2 determines T3, IT causes T1 for Resources strategy, which may explain the shorter period T2 for the business process 2. The volatility is not a sum of the volatilities of the different units, rather a product. However, as stated above, there are different types of uncertainty, the approach to reduce the uncertainty is in function of the type.

Frank Knight described two types of uncertainty: first, that in which probabilities are known or knowable (so expected), which he called risk. The Open Group defines risk as the probable frequency and probable magnitude of future loss ("Risk," n.d.). The second type is real uncertainty,[1] which is not known or knowable.

So risk is a measurable unknown, while certainty is an unmeasurable unknown. For the former, we can collect information to improve the already existing knowledge, while for the latter, an organization should collect information to "discover" it. The unmeasurable unknown can be divided in the known-unknown (the organization knows that it doesn't know something) and the unknown-unknown (the organization is not aware that something exists).

In any case, be it for risk or uncertainty, an organization should always be collecting intelligence (also the only rule for the first principle of the Art of War). To game theory, unknown-unknown facts can influence the strategy game and strategists are somehow, sometimes aware of it (intuition), while to real options only the known-unknown and risks are taken into account.

OODA

USAF Colonel John Boyd has developed an important concept on decision-making at the strategic, operational and tactical level: Observe-Orient-Decide-Act (OODA). OODA is a decision-making process (see Figure 4). However, Osinga (2007) stresses that OODA-loop is more than a decision-making process; it is a model of an organizational learning and adapting in which the element "Orient" plays an important role in the organizational adaptability. The capability to adapt to uncertainties and risks is one of the parameters to determine the volatility of a real option (Piesse & van de Putte, n.d.).

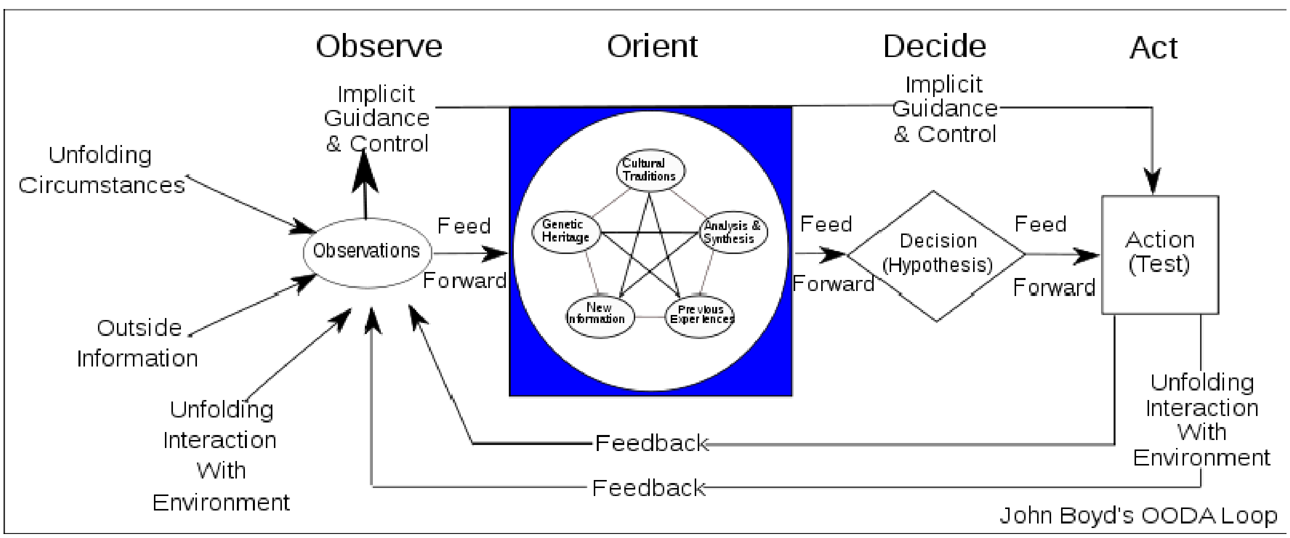

Figure 4. OODA-Loop

[1] Lack of certainty.

Dr. Norma Bubier (personal communication, March 30, 2011) refers to OODA as an organic process. The organization is interacting with its environment and has to interpret it to decide what, when, where, and how to act in function of the new information, culture, previous experiences (skill, knowledge) and organizational structure (genetic heritage). This implies that organization should always monitor the environment and itself to detect risks, and therefore also opportunities.

Translated to the interdisciplinary forum, we can represent OODA as follows (see Figure 5): In an interactive and iterative way the interdisciplinary forum will decide with the superstructure what it should do. The superstructure will then communicate the sub-organizational units (business units, and/or resources-units) what to attain as goals (in a coordinated way). The sub-organizational units will perform then their own OODA-loop to determine the best possible actions on their level. A similar interactive and iterative process for the intelligence cycle will below be discussed.

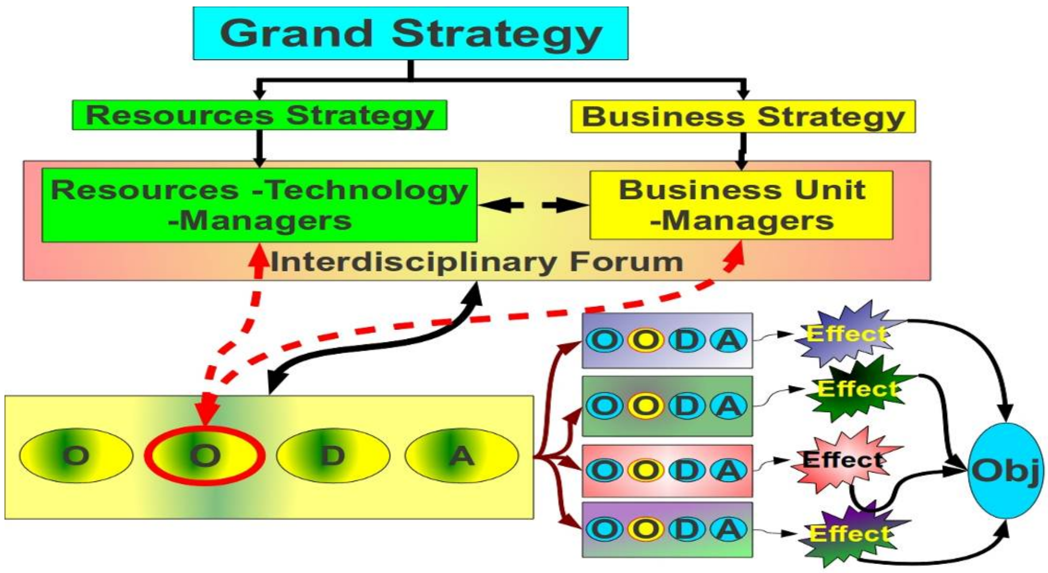

Figure 5. OODA: Unit and Subunits

Predictably Irrational

Game theory explains with success the behavior of humans when they act rationally. However, it does the same for birds or fish, from which we cannot say that they have brains comparable with human brains. Binmore (2007, p. 5) states that rationality in game theory is about consistent behavior, not reasoning. Therefore we may not automatically assume that by using game theory in the procurement domain, we imply that those decisions are made rationally.[2]

Literature on behavioral economics (Ariely, 2009; Montier, 2010), intuitive management (Burke et al., 1999), psychology (Libet, 2011; Pucket & Purdy, 2011), naturalistic decision-making (NDM; Brooks, 2007; Berryman, 2007; Shattuck & Miller, 2006) proves that the decision-making is not always rational. A lot has to do with how people and

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[2] Which, of course, they may be.

their brains are coping with uncertainty and risk. Collecting intelligence can reduce uncertainties and handle better risks, what we will discuss in the next point.

Intelligence Base

Need for Intelligence

At all levels of the organization, uncertainty exists. However, the closer to the strategic level of the organization, the higher the uncertainty. This is because of the decision time horizon. The strategic level of an organization must give the general direction to which the whole organization has to evolve.

It must be noted that uncertainties and risks are not always external the organization but also internal. Techniques such as Baldrige (n.d.) and Common Assessment Framework (CAF, n.d.) are used to assess the internal organization and to improve its working, which comes down to obtaining the right knowledge and information to attain the objectives of the organization and to use, in a rational way, its resources.

In an economical context, rationality has more to do with the ratio of benefits to costs instead of the philosophical meaning of reasoning ("Rationality," n.d.). It is not a surprise that even the first principle of the Art of War is to have the right balance between goals and means to decide which is the best strategic plan to adopt for preserving the best interest of a nation. The only but obligatory rule of this principle is the permanent collection of intelligence (Bernard, 1976). So to reduce its uncertainties to make better decisions, the organization will collect intelligence.

Funston and Wagner (2010, p. xxiii) write the following:

> The risk intelligent enterprise recognizes that risk intelligence and risk management are not ends in themselves but a means toward the ends of creating and preserving value and surviving and thriving in uncertainty. Risk intelligence is an approach to conducting business that improves decision making and judgment in vital areas and initiatives. After all, to be enterprising means to be bold and willing to undertake new initiatives that involve risk.

The Defense Security Service document (DSS, 2005) states,

> Intelligence is the product resulting from the collection, evaluation, analysis, integration, and interpretation of all available information, that concerns one or more aspects of foreign nations or of areas of foreign operations, and that is immediately or potentially significant to military planning and operations.

This is done by the intelligence cycle process. However, not only intelligence is obtained for the decision-making process, also, knowledge can be created with this process. This is not surprising because knowledge is also used to make decisions (Courtney, 2001).

Intelligence Cycle

The intelligence manager has the following resources in the so-called intelligence cycle: the memory (where all acquired information is stored), the network (of sensors) and the analysis capability. The latter analyzes all incoming information and processes it into intelligence that will be stored into the memory. In the scheme of Besson and Possin (2003) in Figure 6, the "unknown" actively drives the intelligence cycle; however, it is the sensors that collect the information, which can be of use to the organization.

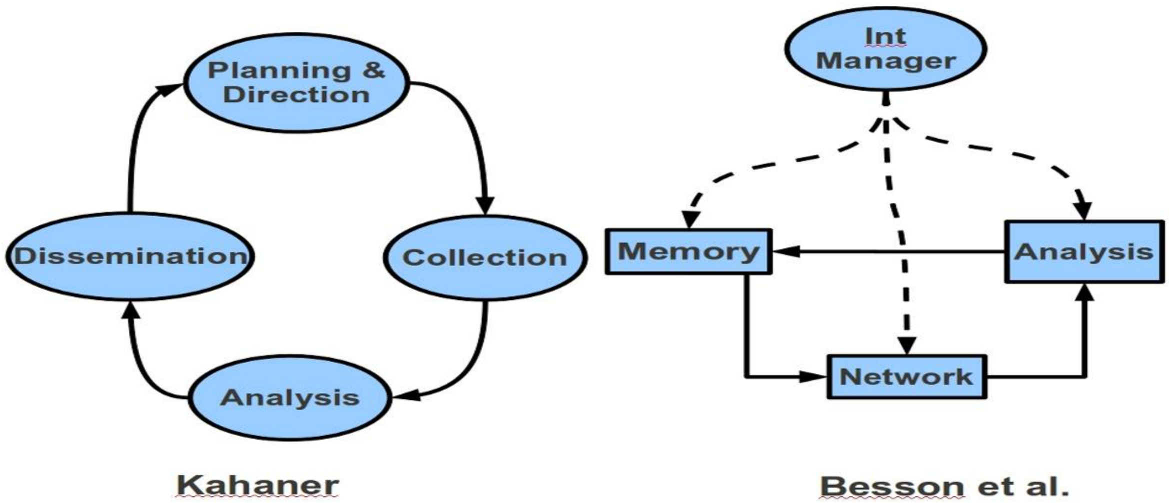

Figure 6. Intelligence Cycles

The most difficult task is to formulate and translate the question into a clear language, which would then lead the organization to the pertinent and relevant information. In other words, it conveys knowledge about opportunities and threats, which the organization (Kahaner, 1997) ignores (Besson & Possin, 2003, p. 22).

Larry Kahaner (1997) sees the intelligence cycle as a process instead of a function. “Therefore it should appear in all aspects of your business as one seamless, continuous activity not relegated to one area, division or unit” (Kahaner, 1997, p. 23). This process has four steps: Planning & Direction, Collection, Analysis and Dissemination (Kahaner, 1997, p. 43).

The step “Planning & Direction” starts with a clear understanding of the user’s needs and includes his time constraints. Once well understood, further intelligence actions are planned. The step “Collection” involves obtaining raw information that can be turned into usable intelligence for the decision-making of an organization.[3] “Analysis” is the process of taking information and integrating it with other information so that intelligence is created. “Dissemination” is distribution of the intelligence towards the client and other organizations that may also be concerned by this intelligence.

Knowledgebase (KnB)

Guida et al. (1994) defines a knowledge-based system (KBS) as a software system capable of supporting the explicit representation of knowledge in some specific competence domain and of exploiting it through appropriate reasoning mechanisms in order to provide high-level problem-solving performance. The knowledgebase stores available knowledge

[3] Mainly two types of information exist: primary and secondary. Primary information comes directly from the information sources. Secondary information is coming from other sources then primary sources, which have altered the “raw facts.”

concerning the domain at hand, represented in appropriate explicit form and ready to be used by the reasoning mechanism.

Is intelligence also knowledge? For Peter Drucker (1998) knowledge is information effective in action so information focuses on results. Sanchez and Heene (1997) define "knowledge as the set of beliefs held by an individual about causal relationships among phenomena. Causal relationships in this definition are cause and effect relationships between imaginable events or actions and likely consequences of those events or actions. Organizational knowledge is then defined as the shared set of beliefs about causal relationships held by individuals within a group."

Therefore, both terms (intelligence and knowledge) are supporting the decision-making process and these terms are sometimes interchanged (Kahaner, 1997, p.21) or confused with information. It is, however, clear that interpreted and integrated information becomes intelligence, which enables the person to make a decision using the inference rules of the concerned knowledge domain.

Yet knowledge evolves, facts stay. Therefore, an organization should store the facts (information) in a "Facts Base" for later re-interpreting the same facts but with other knowledge. Besides tracking the intelligence, an organization should place the intelligence on a dedicated storage "Interpreted Information Base" to assess the quality of intelligence (Besson & Possin, 2001).

Using the same logic as intelligence assessment, the decision-making process can be assessed (Yates, 2003) and thus the knowledge. Sanchez and Heene (1997) define three types of knowledge: factual knowledge (entities, relationships), inferential knowledge (reasoning functions) and strategic knowledge (problem-solving strategies).

Unknown Base

If an organization knows what it knows, then it knows what it does not know but would like to know. The Unknown Base supports the management of the unknown. The whole system of detecting, managing and collecting the unknown is very strategic for an organization. If its competitor/enemy knows what the organization does not know, then the competitor/enemy can take advantage of this. Security is of the utmost importance.

In what follows, the conceptual, strategic and operational level of the Intelligence Base will be discussed.

Conceptual View on the Intelligence Base

Components

The *Dictionary of Military Terms* (DoD, 1999) defines an Intelligence Data Base as "The sum of holdings of intelligence data and finished intelligence products at a given organization." The term "data" is too limited in the context of intelligence (OMB, n.d.); moreover, we have added the management of the Unknown, and therefore we suggest the term "Intelligence Base."[4] The management and the storages of the unknown, the facts and intelligence, and the supporting Intelligence Information system form together the "Intelligence Base" (IntB; see Figure 7).

[4] Section based on Rabaey et al. (2005).

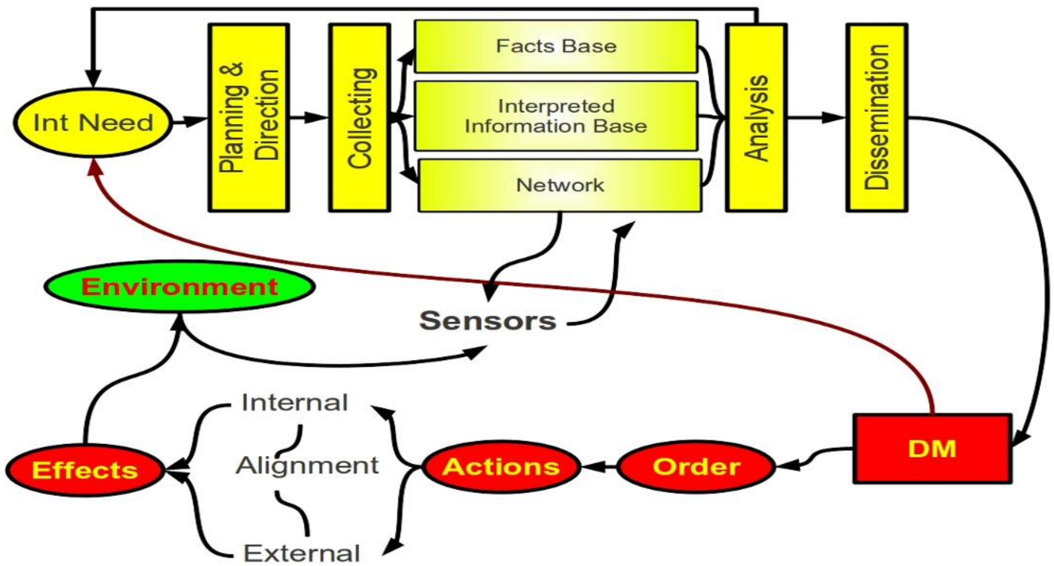

Figure 7. Intelligence Base Concept

Every level of the organization, be it strategic, operational or tactical, interacts with its environment, which gives opportunities to collect information (push or pull, see below) about that environment. The collected information should be transferred via a special and dedicated communication system of the intelligence information system (Int IS), which supports the Intelligence Base.

Figure 8 shows similarities with OODA-loop of the interdisciplinary forum (see Figure 5), which is logic because they are intimately interwoven with each other.

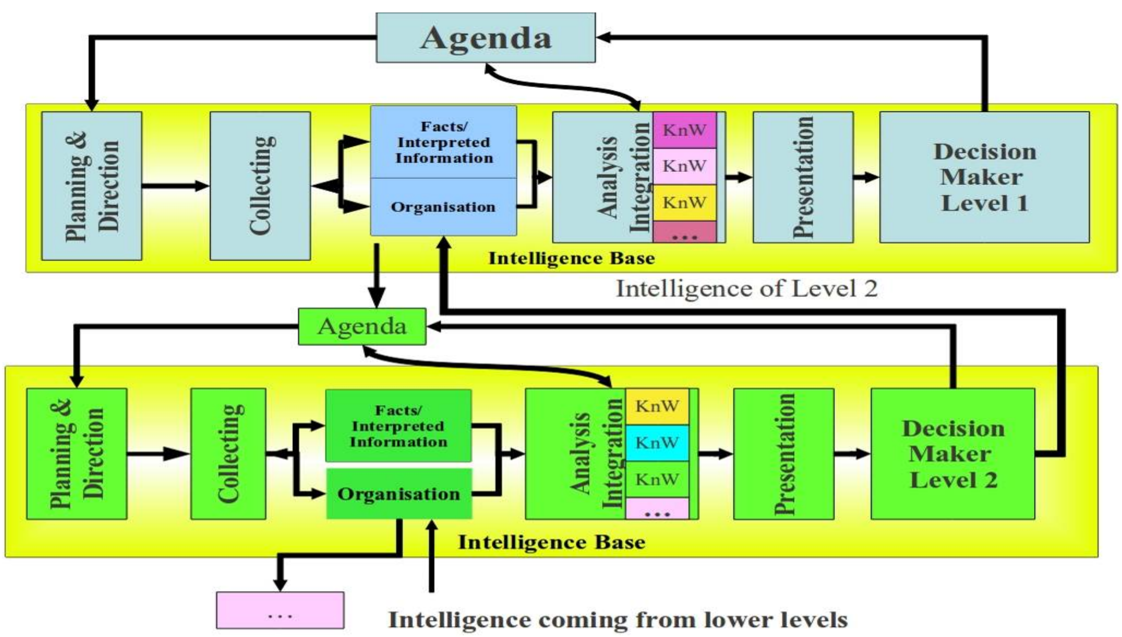

Figure 8. Cascading Intelligence Processes

Decision Making and Intelligence Process

Before handling the triggers, "it is important to always link information to the decision making process. Only pertinent information and information that increases the knowledge base need be processed. All other information may remain unprocessed or discarded." (Morua & Bruns, 2002). In our system the processed information becoming intelligence is placed in the Interpreted Information Base, while the facts (processed or not), went to the Facts Base. The knowledge base is composed of the Interpreted Information Base and Facts Base. How does this information come into the system?

Two events can trigger an interaction between the decision-making process and the intelligence process. Firstly, the decision-maker expresses an intelligence need. The second trigger is the transmission of newly detected facts by the sensors. Of course, the intelligence process can also express intelligence needs.

The case of "Information Pull" is when the decision-maker does not find the necessary intelligence (in the Intelligence Base or outside of it), then he expresses his need to the "Planning & Direction." The latter will then define the needed intelligence actions. The needed information may not be in the Intelligence Base in which case the network has to be instructed (push). The planning of the dynamic search-path is established (Besson & Possin, 2001) and the plan of action is managed in the Unknown Base.

The resulting information (if any) is then analyzed. Additional information may be required if there is not enough information to be integrated into intelligence. Once the intelligence is acquired, then it will be disseminated to the intelligence client. The information and intelligence are stored respectively in the Facts Base and the Interpreted Information Base, and the Unknown Base is updated.

In the case of "Information Push" the sensors are injecting information in the network (push). The transmitted information is then analyzed. If the information can be integrated, then the resulting intelligence is pushed to the concerned people and/or organizations. The information and intelligence (if any) are stored respectively in the Facts Base and the Interpreted Information Base.

Investments

Real Options and Game Theory

The classic investment methodologies like Net Present Value (NPV) and Return of Investment (ROI) are lacking the flexibility that management need to be able to postpone, delay, start, and abandon projects.

Real Option Analysis (ROA) gives management this flexibility, and it tackles the problem of uncertainty and risk related to each investment. Options are the right but not the obligation to execute an action (sell or buy). Translated to real option, it means that management can decide to postpone, stop, start, restart or put on hold a project. The reasons may be because of the lack of relevant information, or to wait for results of some pilot projects.

Although ROA is known in the IT-world, our study of recent literature on Cloud Computing shows that this literature is still referring to ROI and NPV. Besides the reasons mentioned in the introduction, another reason is that most of the books are written by technology people. Therefore, this subject gives the possibility to introduce ROA, also in the philosophy of more technical business environments, like Cloud Computing. ROA, however, has a common drawback, like the classic investment techniques, being the lack of taking into account the interaction of the organization with its environment (market, government, etc.). The solution is to combine ROA with game theory, which resulted in the theory of option games (Rabaey, 2011).

Mono-Game and Multi-Game Options

Game theory on its own analyzes complexities of the equilibriums and the payoffs into detail by determining players' utility functions without any relation to market values. Real options analysis places these payoff values under uncertainty, considering market values and the flexibility of response by the optimal exercise of the options.

However, because the actual actions (and necessary actual decisions) seem to erode partly the value of waiting. This is the main reproach that we can find in the literature on the option games. Our approach brings both theories together in another way.

Real options are a set of chains of future decisions. In order to make decisions (delay, stop, start up, continue), management is waiting to collect more information, or is waiting for a better environment (market situation, political situation and so on). The situation has to be assessed at that moment in the future, but we will place it in a game theoretic context. Our proposal is not only a chain of possible decisions (as in the non-interactive original version of real options), but also a chain of possible interaction situations represented by games.

Every decision node consists of two phases. The first is to assess the situation in which the decision has to be made, in other words the probable payoff matrix of the game. The second phase is to determine the value of the real option based on this payoff matrix.

If the convention is to always take the same game, then we call this the mono-game chain of options. A more complex version is to consider more than one game, and therefore determine the value of the real option for each game (and its corresponding payoff matrix). As a result, each node with multiple games (in the so called multi-game chain of options) will generate more branches than in the case of a mono-game chain of options.

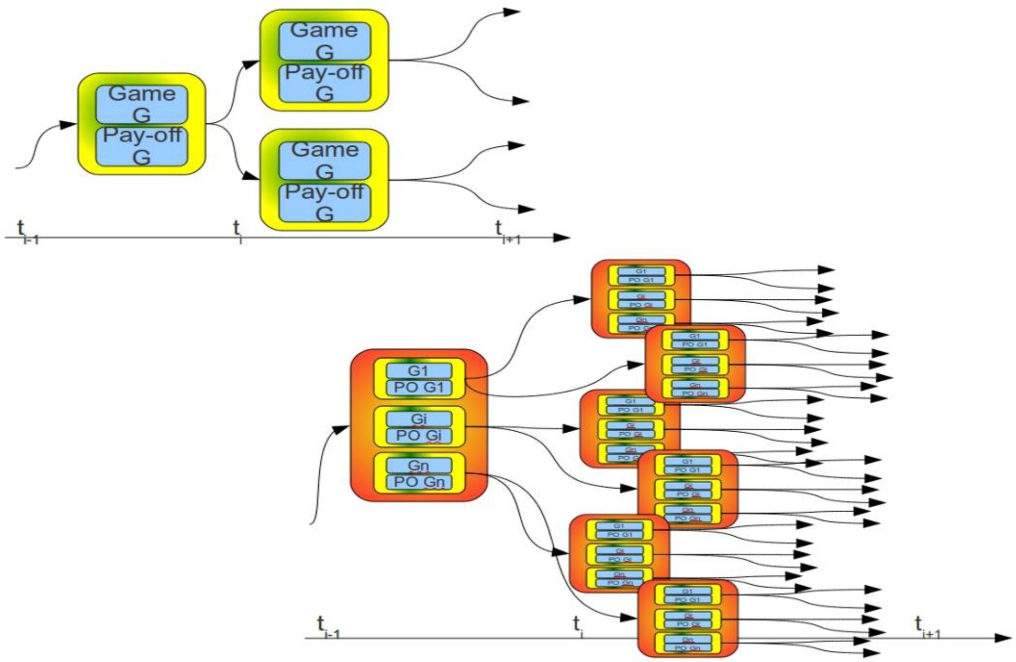

Figure 9. Mono-Game and Multi-Game Options

In the upper part of Figure 9 we see the representation of a mono-game option in a decision tree, while the lower part represents a multi-game option. The latter has a tendency to become a chaotic (although deterministic) system after a certain point in the time horizon.[5] To select the more relevant games, meaning reducing the number of possible games, it is necessary that the organization collects intelligence about the possibilities on collaborating or competing with one or more actors in the market. Otherwise the system will overload itself.

DoD Procurement in Competition and in Collaboration

In general, there are two kinds of situations: competition and collaboration. We will first discuss the competition situation, but before we are referring to Weeds (2006) with the remark that certain urgent events force the organization to act immediately. We will integrate the elements of Weeds (2006) in our discussion. But again it indicates that an organization should permanently screen its environment, and therefore implement an instance of the intelligence base. It must be stressed that even organizations that are not using ROV must implement a similar system, otherwise it will miss opportunities and run more risks.

First or Second Mover

The DoD of a country is in competition with other DoD or government agencies to obtain from the limited number of suppliers, the capabilities to produce goods or to deliver services. In function of the strategic importance, the DoD can chose between a first mover (leader, innovator), or a second mover (follower).

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[5] More research will be done on this subject.

The first mover advantage (FMA) is when the DoD invests first, rather than continuing to delay, and the competitor continues to delay. The invested cost can be seen as a basis investment for further options, while the DoD as first mover has as advantage that there will be a strong alignment of the "new" capabilities on its own strategy. A second advantage is that for a limited time the DoD has a monopoly and can create market conditions for the suppliers and, not to forget, also the customers of the suppliers (see the DoD as Regulator in the Market for Its Own Procurement Environment section). However, it is not without any risk. If it fails, then the competitor who has delayed can take advantage of the mistakes of the first mover (this is an example of a Second Mover Benefit, SMB).

To be a second mover can have many causes.[6] First of all, the DoD had not enough information to reduce its uncertainty or to mitigate the risks. Then, with the information coming from the actions (failure or not) of the competitor, the DoD can reevaluate the situation and improve its payoffs.

The DoD can also consider saving the costs of being the first mover, but it will have to adapt to the solution of the first mover, by sacrificing some of the strategic objectives, or part of it, unless the first mover has failed. In the latter case, the second mover can take the lessons learned to determine a better strategy to obtain the necessary capabilities, as already mentioned previously.

It can even be a strategy that the follower wants the other one (pushed in the role of leader) to move as first, so that the latter can come with a better strategy or products or gain better resources (or methodologies) and hope that the follower becomes the leader.

Weeds (2006) states that FMA tends to conflict with real options because there is a threat of preemption of a rival; however, that is more the now-or-never situation (see below). FMA comes from the strategic (competitive) advantage (opportunity) of that moment. By investing (consuming cash flow), the DoD hopes to create more potential for the future (for attaining the objectives of the political governance) and knows that a possible reaction of the follower can come. In the case of now-or-never, the initiative is not exclusively for the leader.

As for the game-theoretic aspect, the DoD as first mover must be aware that the competitors will react. These reactions can undermine the FMA; therefore, the DoD should not only consider its own actions but also the reactions of the competitors and the influence of these reactions on its own payoffs—in the case of leader-follower game. Therefore, from the point of view of the leader, the DoD will establish two payoffs matrix, one for the case that the follower reacts quickly, and one for the case that the follower continues delaying any action. By creating intelligence (collecting and analyzing information), the organization can better determine the utility functions and the probable reaction of the follower and its impact on its own payoffs.

Now-or-Never

There is a third type of competition in which the DoD is obtaining simultaneously the scarce resources. This is the case when it is strategically important to have a specific system (or goods or services) and therefore has to compete with other agencies. In this the competitive pressures to obtain the resources or goods/services are strong and the cost of

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[6] If the DoD does not have the capabilities to invest (for any kind of reason), then this is obviously not an active strategy, and we can speak of a "mover."

being preempted is considerably high, then waiting can cause considerable damage by losing the investment opportunities to its competitors.

This is a now-or-never opportunity where the option has no value anymore and classic investment techniques can be used. It is not a failure of the system of real options, only strategic (game) considerations oblige DoD to act as soon as possible. Of course, the decision can have significant influence on other projects or investments, of which the option values can change dramatically. Therefore, it is not because of the fact that real options have not been used in an urgent case that the decision nodes along the scenarios tree don't need an ROV anymore.

It must be clear that the DoD has to develop (strategic) scenarios in which not only first and second mover must be taken into consideration but also the now-or-never situations.

Unknown-Unknown

Another situation can be a lack of information on the part of the DoD, resulting in it being unaware of the competition for capabilities of other agencies (silent or secret negotiation phase), so an unknown-unknown situation.

Collaboration

The second situation for DoD procurement is collaboration. It is in a common interest that the DoD of a country collaborates with allies (p.e. NATO). Collaboration does not necessary mean that the DoD is in a less stressful situation. "Missing the boat" to collaborate can be as disastrous as in competition. However, most of the time, the context of collaboration is determined by the higher political bodies of a nation.

In the cases of repeated games, the game theory, linked with the real option analysis, can be used by a DoD of a country to steer the decisions in a best possible way to obtain the strategic objectives. However, this subject is still in the phase of research.[7]

DoD as Regulator in the Market for Its Own Procurement Environment

Regulator

The strategic objectives determine the functional requirements of the goals, where the resource strategy is determining the technical requirements based on standards, policy or doctrine of use. The request for procurement or proposal is then published to the suppliers (market). As seen previously, when the DoD was itself submitted to the market strategic games, the suppliers can be put in two situations: competition or collaboration (coordination).

In this case we don't use the game theory to position the DoD in the market, but as the organization which creates a particular micro-environment for the suppliers, a market regulator for its own procurement. As a matter of fact, the DoD is creating the game theory framework in which the suppliers will interact with each other. We will focus us more on the procurement of IT-related items.

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[7] The research extends also to drama theory and the theory of Bryant (2003).

In the case of competition only, the DoD will enforce its own standards or the market standards. The best possible proposal will be chosen.

Competition followed by collaboration is the particular situation in which the DoD will let different suppliers compete based on the competences (capability), and it creates a short-list for each capability. Afterwards, the DoD creates an environment in which the chosen suppliers are encouraged to chose one or more partners to collaborate so that the main capability can be formed.

This is a more active steering of the formation of collaborative suppliers than the next situation: collaborate and competition. If a project is too big for a single company (supplier) then the interested suppliers will look for themselves to find the best partner to collaborate with. So the market itself will be clustering the different players into ad hoc entities. Once these entities are formed the competition can start.

Collaborate: In the situation in which there are no clear standards for a specific system, this collaboration of interested suppliers will produce and propose standards. Here the DoD can also play an active role to determine the to-be-developed standard(s).

Monopolist of Demand

As a matter of fact, in the "market of (legal) violence" the DoD has the monopoly of demand. The very specific attributes of the defense market of some weapon systems make so that the DoD is confronted on the supply side with a oligopoly (of big players). The subject of oligopoly or duopoly with option games is well documented in the literature. We propose that the DoD use game theory to follow up the "ethical" and "economical" collaborations and competitions (no cartel for instance).

However, because of the globalization of the market, it is possible that in some parts of the market (of "violence") the DoD will lose its monopoly due to the fact that the technology demand has been taken over by commercial companies or other government agents.

Conclusions

Although for strategic reasons an organization should create intelligence to determine the best way to allocate resources to attain its goals, reality shows that besides the complexity, real options are not easily implemented because of the ongoing effort to collect information to maintain the real option valuation.

Therefore, we are proposing two processes, one to obtain intelligence (intelligence base) and one to decide the investments and to maintain the steering plans and service level agreements (interdisciplinary forum). The organization can instantiate from these generic processes their own systems in function of its culture and capabilities.

Since the intelligence base delivers relevant information for determining the strategies (game theory) and for the interdisciplinary forum (real options, other investment techniques), the combination of both, namely game options, can also be supported. However, to exploit effectively game options, some further research has to be done, especially in the domain of collaboration.

In our discussion we also came to the conclusion that it is the situation in which the strategic games are played that determines if real options (game options) are used or not. Some urgent problems in the business environment of the organization may oblige the organization to choose other investment techniques than real options. The organization has the right but not the obligation to use real options (in certain circumstances).

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Acknowledgments

This research was supported by the Faculty of Applied Economics, University of Hasselt, where Marc Rabaey has an on-going PhD. The subject is investment in Cloud Computing (Information Technology).

Panel 22 – Acquisition and Logistics in Support of Disaster Relief and Homeland Security

Thursday, May 12, 2011	
1:45 p.m. – 3:15 p.m.	**Chair: Rear Admiral Kathleen Dussault,** SC, USN, Director, Supply, Ordnance, & Logistics Operations Division, Office of the Chief of Naval Operations ***Strategies for Logistics in Case of a Natural Disaster*** Keenan Yoho and Aruna Apte, NPS ***An Analysis of U.S. Navy Humanitarian Assistance and Disaster Relief Operations (MBA Student Report)*** LT Cullen Greenfield and LT Cameron Ingram, USN ***Financing Naval Support for Humanitarian Assistance & Disaster Response: A Cost Analysis and Planning Model (MBA Student Report)*** LCDR Stephen Ures, USN ***When Disaster Strikes: Is Logistics and Contracting Support Ready?*** Aruna Apte and E. Cory Yoder, NPS

Rear Admiral Kathleen Dussault—Director, Supply, Ordnance and Logistics Operations Division (OPNAV N41). Rear Admiral Kathleen Dussault assumed duties as the director of Supply, Ordnance and Logistics Operations in the Office of Chief of Naval Operations (OPNAV N41) in March 2009. Dussault comes to OPNAV from her most recent assignment as commander of the Joint Contracting Command Iraq/Afghanistan, headquartered in Baghdad, Iraq, with 18 regional offices throughout both theaters.

Dussault graduated from the University of Virginia in 1977 with a Bachelor of Arts in American Government, received her commission through Officer Candidate School in Newport, RI, in November 1979, and graduated from Navy Supply Corps School in May 1980. Dussault has served in USS *Point Loma* (AGDS-2) in the Pacific Area Launch Support Ship for the Trident missile program as supply officer, USS *Concord* (AFS-5) as the assistant supply officer during Operations Desert Shield and Desert Storm, and as supply officer aboard USS *Seattle* (AOE-3), where she served as Afloat Logistics coordinator while deployed to the 5th Fleet operating area.

Dussault's shore tours include assistant supply officer and disbursing officer to the Navy Communications Station, Nea Makri, Greece; Defense Contract Administration Services Region (DCASR), Los Angeles; a negotiator and contracting officer at Naval Supply Center, Oakland, CA; procuring contracting officer for the Sidewinder and deputy for Missile Systems Acquisition at Naval Air Systems Command (NAVAIR); business and financial manager for programs managed by the Space and Naval Warfare Command; and executive assistant to the Deputy Assistant Secretary of the Navy for Acquisition Management within the office of the Assistant Secretary of the Navy for Research Development and Acquisition. In May 2001, Dussault assumed command of Defense Distribution Depot San Diego, and in April 2003 she assumed command of the Office of Special Projects, Arlington, VA. She then served as deputy director of Acquisition Management at Defense Logistics Agency, Fort Belvoir, VA. Prior to her combat assignment, she was assigned as deputy assistant secretary of the Navy for Acquisition and Logistics Management in Washington.

Dussault has earned a master's degree (with honors) in procurement management from Saint Mary's College in Moraga, CA, and a master's degree in national resource strategy from the Industrial College of the Armed Forces. She has achieved the highest levels of accreditation in Acquisition, Financial and Supply Chain Management and Joint Professional Military Education. Dussault is certified in production and inventory management through APICS, the educational society for resource management. She has completed the Executive Education Program at Columbia Business School.

Her decorations include the Defense Superior Service Medal, Legion of Merit, Bronze Star, Navy Meritorious Service Medal with two gold stars, Joint Service Commendation Medal, Navy Commendation Medal, Navy Achievement Medal with gold star and various unit citations, campaign medals and service medals.

Strategies for Logistics in Case of a Natural Disaster

Keenan Yoho—Assistant Professor, Graduate School of Business & Public Policy, NPS. Professor Yoho's primary research activities are in the area of the analysis of alternatives for capital purchases under conditions of resource scarcity, supply chain management, risk analysis, humanitarian assistance and disaster response, and resource management in environments that exhibit high degrees of uncertainty.

Prior to joining the Naval Postgraduate School, Professor Yoho was an operations researcher and principal investigator with The RAND Corporation, a federally funded research and development center (FFRDC) where he led studies for the Army, Air Force, and TRANSCOM to improve the effectiveness of logistics, acquisition, and sustainment operations and to develop policy guidance for supply chain operations.

Professor Yoho has several years of experience teaching and developing master's students and executives in the U.S. and Europe in principles of supply chain management and manufacturing operations. He has served as an Intelligence Analyst for the U.S. Customs Service in the area of international money laundering and has worked large litigation cases representing Lloyd's of London in insurance defense. He was the National Research Coordinator for Manufacturing Skills Standards as part of an initiative funded by the United States Congress to develop national skill standards for the U.S. industrial manufacturing economic sector. He has advised U.S. and European firms for several years in the petrochemical, semiconductor, paper and pulp products, and steel industries focusing on enabling corporate strategy by using the supply chain as a competitive weapon.

Professor Yoho holds a PhD in Operations Management, an MBA in Operations and Information Management, and an MS in Industrial Relations from the University of Wisconsin–Madison. He also holds a BA in Religion with a concentration in Chinese and Japanese Buddhism from Temple University. [kdyoho@nps.edu]

Aruna Apte—Assistant Professor, Department of Operations and Logistics Management, NPS. Professor Apte has successfully completed various research projects, involving application of mathematical models and optimization techniques that have led to over 20 research articles and one patent. Her research interests are in developing mathematical models for complex, real-world operational problems using optimization tools. She values that her research be applicable. Currently her research is focused in humanitarian and military logistics. She has several publications in journals, such as *Interfaces, Naval Research Logistics, Production and Operations Management*. She has recently published a monograph on Humanitarian Logistics (http://dx.doi.org/10.1561/0200000014).

Professor Apte received her PhD in Operations Research from Southern Methodist University in Dallas. She also has an MA in Mathematics from Temple University, Philadelphia. Before NPS she worked as a consultant at MCI and taught at the Cox School of Business, SMU, where she won the best teacher award. She has over 20 years of experience teaching operations management, operations research, and mathematics courses at the undergraduate and graduate levels. At NPS, she teaches mathematical modeling, for which she won the best teacher award, and she has advised over 50 students for over 24 MBA/Masters reports, out of which 10 students have worked and seven more are working in Humanitarian Logistics. She has also advised emergency planners in preparing for disaster response. She is the founding president for a new college (focus group) in Humanitarian Operations and Crisis Management under the flagship academic professional society in her intellectual area of study, Production and Operations Management Society. [auapte@nps.edu]

Abstract

The need to effectively and efficiently provide emergency supplies and services is increasing all over the world. We investigate policy options: prepositioning supplemental resources, preemptive as well as phased deployment of assets, and surge of supplies and services. We hypothesize that there exists a correlation

between these policies and our disaster classification based on localization (dispersed or local) of the disaster and its speed of onset (slow or sudden). We believe that the creation of a matrix and designation of policies based on disaster type will facilitate the policy makers' decision process. Exploring the efficacy of each policy option with respect to several crisis scenarios to assist policy makers to better prepare their disaster response is critical in Humanitarian Assistance and Disaster Response.

Introduction

In 2009 there were "335 natural disasters reported worldwide that killed 10,655 persons, affected more than 119 million others, and caused over $41.3 billion in economic damages" (Vos, Rodriguez, Below, & Guha-Sapir, 2009). The number of natural disasters reported between 1900 and 2007 has increased significantly and with it, the number of requests for aid and humanitarian assistance (see Figure 1). While the trend in the number of disasters reported shows an increase, it is not clear that there has been a commensurate response in terms of preparedness. The United States Agency for International Development (USAID) reports that of all funds used to support disaster operations, 90% are spent for response, whereas 10% are spent on preparedness activities and investments and risk reduction (A. Giegerich, personal communication, 2010). The United Nations estimates that every dollar spent to prepare for a disaster saves seven dollars in disaster response (United Nations Human Development Program, 2007).

Although the objective of all the organizations and agencies involved in humanitarian assistance is to reduce human suffering and casualties, the duration and severity of the human toll during a natural disaster is largely dependent upon the speed and scope of the response, which is often a function of the level of preparedness that has been established prior to the disaster event. While there are no internationally agreed upon metrics by which to judge or measure the effectiveness of a response to a disaster, scholars working in the humanitarian and disaster response research area have found that improvement is desirable (Apte, 2009; Van Wassenhove, 2006). An effective and efficient humanitarian response depends "on the ability of logisticians to procure, transport and receive supplies at the site of a humanitarian relief effort" (Thomas, 2003). In this research we focus on the response to a disaster area in the form of distributing supplies, and strategies that will enhance the effectiveness of such a response.

As part of our investigation, we will explore four policy options: (1) prepositioning supplemental resources in or near the incident location, (2) proactive deployment of assets in advance of a request, (3) phased deployment of assets and supplies, analogous to the "just in time" inventory control philosophy practiced by many commercial manufacturers, and (4) "surge" transportation of manpower and equipment from locations outside the disaster area.

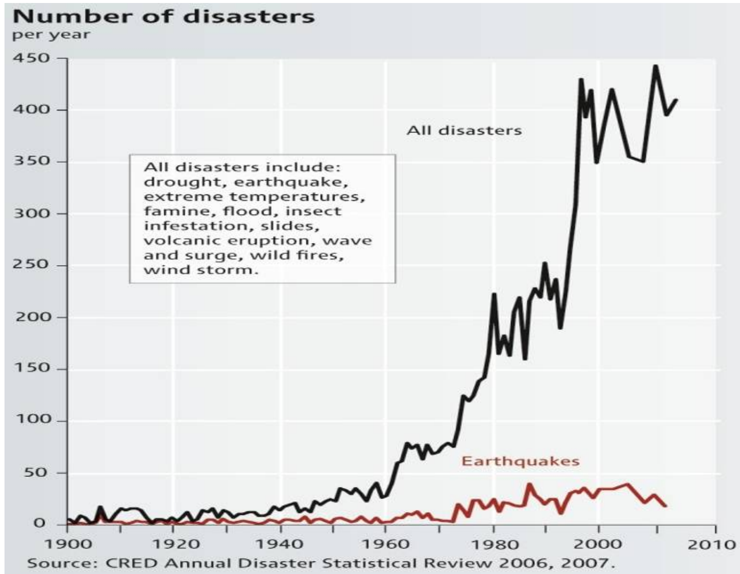

Figure 1. Number of Disasters Reported from 1900–2007
(UNEP/GRID, 2009)

Literature Review

One of the major issues in a response supply chain in case of a natural disaster is to coordinate the operations and relief inventories over a large number of stages, locations, and organizations. This has to be done while providing the emergency supplies and services to the affected population under extreme conditions. Decisions regarding the types of provisions that should be prepositioned, as well as their location, should be made well before a disaster strikes in order to provide quick response. To some extent, without such a high level of uncertainty and an adverse environment, it is similar to the core question in supply chain management of coordinating activities and inventories over a spectrum of stages of the supply chain and facility locations of the inventory (Schoenmeyr & Graves, 2009).

In the private sector, it has been found that if each individual stage in a serial-system of the supply chain operates with a designated base stock policy with service guarantees, then the optimal safety stock strategy is to maintain inventory at certain key locations which results in separating the stages of the supply chain. This allows each stage to operate independently by minimizing the need for communication and coordination amongst players (Simpson, 1958; Graves & Willems, 2003). Models available in supply chain management literature are predominantly with unlimited capacity for storage. In cases where there is unlimited capacity, the amount of safety stock needed is less than the level needed with capacity constraint (Schoenmeyr & Graves, 2009).

Literature discussing strategic inventory placement under evolving or pre-determined forecasts (Graves & Schoenmeyr, 2008; Simpson, 1958) suggests policies for the optimal placement of safety stocks in a supply chain. Graves and Willems (2002) study this problem accounting for uncertain as well as non-stationary demand. This concept can be translated to the response supply chain due to the type of demand in a disaster response (Apte, 2009; Ergun, Heier, & Swann, 2008). There has been much more published work available with stationary demand as opposed to non-stationary demand. Most of the non-stationary demand has been modeled as a Markov–modulated Poisson demand process (Chen &

Song, 2001; Graves & Abhyankar, 2001). One of the primary conclusions for safety stock with non-stationary demand is that an inter-phase optimal policy need not be the same as the intra-phase policy (Graves & Willems, 2002).

In addition to the prepositioning of relief inventories, a disaster response may require the formulation of policies that require the expansion of warehouses, medical facilities, and temporary shelters, while infrastructure preparation may include the provision of airstrips and ramp space at existing airfields (Salmeron & Apte, 2010). Regnier (2008) has explored the relationship between forecasting the time and location of a hurricane landfall and the amount of time necessary to evacuate a high-risk area; as the hurricane gets closer to land, the quality of the forecast increases; however, the time necessary to evacuate decreases. Though evacuation is not the focus of this research, the timing of the evacuation is an important factor when formulating logistics strategies in case of a disaster.

Koavacs and Spens (2007) weigh the difference between traditional commercial logistics and humanitarian logistics. With humanitarian logistics, it is imperative to go beyond the profitability of commercial logistics. Within the domain of humanitarian logistics, suppliers have different motivations for participating, and customers are not generating voluntary demand and will hopefully not create a "repeat purchase." Thus, supply networks must take into account the lack of true demand; demand will be dictated by the relief agencies which are the primary actors within this framework. Therefore, it is the responsibility of the agency to "push" the supplies to the disaster location in the immediate response phase, which is different from the commercial philosophy of pull-based demand. Humanitarian logistics focuses on getting the greatest volume of supplies to the points where they are needed, and there may be lessons learned in the commercial sector that could be used to improve the planning and execution of strategies that could be implemented during a disaster response.

Disaster Life Cycles

The life cycle of a disaster from the perspective of Humanitarian Assistance and Disaster Response (HADR) is divided into three stages (see Figure 2): being prepared in the pre-disaster stage, response as the disaster strikes, and recovery in post-disaster (Van Wassenhove, 2006; Apte, 2009). In order to mitigate the effects of a disaster, one could draw on policies proven to be effective in the private sector (Van Wassenhove, 2006), as well as those in current use by the U.S. military, since many of these policies have been tested and have matured over the years.

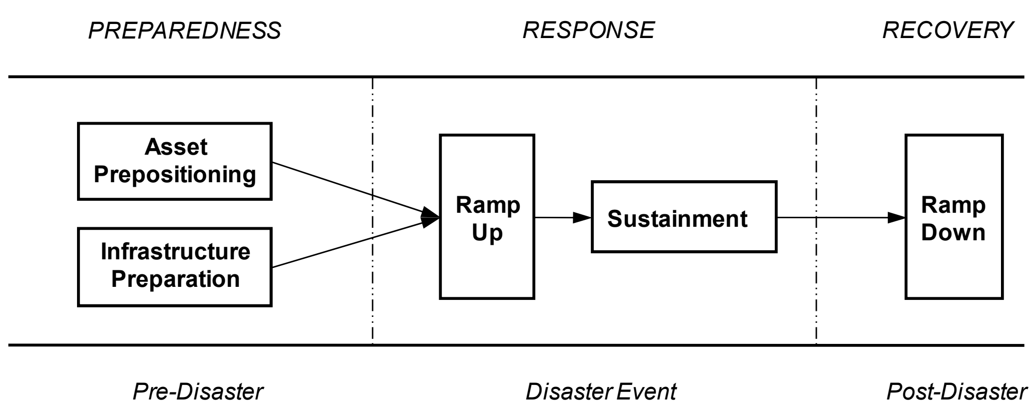

Figure 2. Life Cycle of Disasters
(Apte, 2009)

Disaster preparedness is the first step in mitigating the adverse impacts of any unforeseen catastrophic event. Preparedness on an individual level is defined by the creation of an escape and survival plan, as well as the procurement and storage of supplies that will enable an individual to act on the plan. Preparedness on an organizational or institutional level translates to the planning and pre-establishment of adequate capacity and resources that enable efficient relief operations. Prepositioning of war reserve and contingency stocks, such as that practiced by each of the U.S. Armed Services, has proven an effective means of increasing the speed of response to a conflict (Abell et al., 2000; Button, Gordon, Hoffman, Riposo, & Wilson, 2010; Hura & Robinson, 1991; McGarvey et al., 2010). The private commercial sector, too, has been involved in prepositioning strategic safety stocks in supply chains with evolving forecasts (Graves &Schoenmeyr, 2008), capacity constraints (Schoenmeyr & Graves, 2009), and non-stationary demands (Graves & Willems, 2002, 2008). In addition to the prepositioning of supplies, the U.S. Armed Services have excess capacity in combat, combat support, and combat service support in the form of reserves and National Guard, as well as specialized capabilities needed for crossing rivers, opening ports, and disposing of hazardous and explosive materials.

Disaster response is a function of the preparation that took place prior to the disaster event, as well as the coordination of available supplies and distribution capacity. The first part of the response consists of gaining situational awareness of events and conditions on the ground in the disaster area through the collection of available information, and then using this information and awareness to generate an operational picture that will inform the nature, scale, and timing of the response. The response itself is largely comprised of the tactical activities that must take place to move needed supplies to those parts of the disaster area that are in the most critical demand, given the available resources at hand.

Disaster recovery consists of stabilizing the disaster area and improving the living and economic conditions of those affected by the catastrophic event. The recovery phase will mean different things to different organizations. For the military, the recovery phase will likely signal the beginning of drawn-down or redeployment operations, whereby military personnel and equipment will be withdrawn and responsibility turned over to civil authorities. For non-governmental aid organizations, the recovery phase may consist of establishing semi-permanent camps, aid stations, or warehouses to shelter displaced persons, deliver critical services that cannot be provided by other civil authorities, and coordinate the storage and distribution of supplies that are otherwise unavailable or in short supply to the local population.

Studying the life cycle of recent disasters offers insight into both short-term and long-term consequences. They also provide us with numerous lessons to form effective strategies for mitigating future disasters. However, in order to formulate such strategies we need to understand disasters in terms of their speed and scope, especially since we believe they directly affect operational difficulty in preparedness, response, and recovery.

Disaster Classification

Disasters are often classified based on the speed of onset and the source or cause of the disaster (Ergun et al., 2008; Van Wassenhove, 2006). However, in our research, we focus on four disaster scenarios that are combinations of the geographic dispersion of the disaster (dispersed or localized) and its speed of onset (slow or sudden) as discussed by Apte (2009) and described in Figure 3. The disaster classification suggests that the level of difficulty in the logistics execution is less onerous in the case of localized, slow-onset disasters (depicted in quadrant III of Figure 3), because there may be adequate lead time and local resources to prepare for the response.

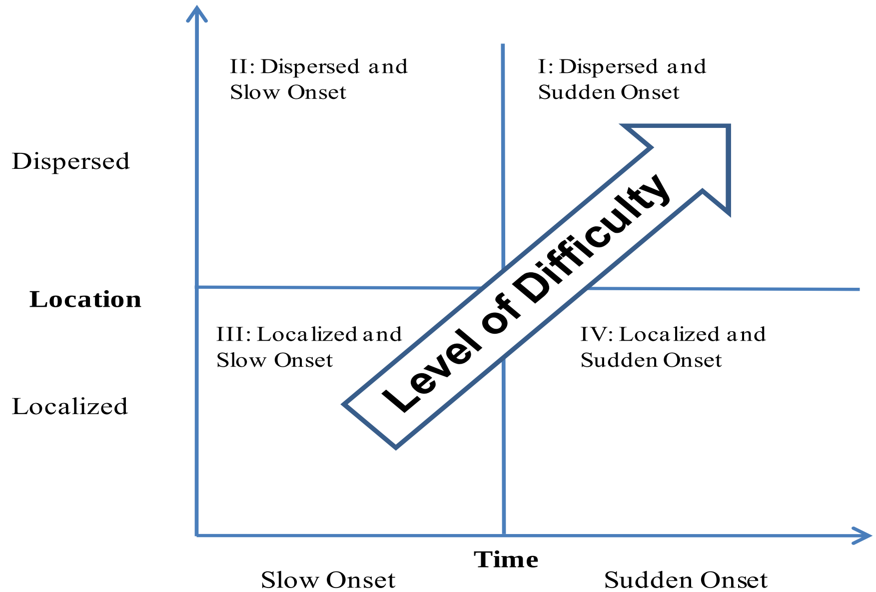

Figure 3. Classification of Disasters
(Apte, 2009)

Dispersed and sudden-onset disasters (depicted in quadrant I of Figure 3) tend to be the most catastrophic in humanitarian terms, because in this case, both a lack of warning and a large geographic region are affected. The recent earthquake and tsunami that occurred in Japan on March 11, 2011, was both rapid in its onset and dispersed in terms of its destruction; the tsunami alone covered a 420 square mile area of coastline, with most of the destruction taking place within an hour of the earthquake (Hirschberg & Richardson, 2011).

Quadrant II describes a context where the onset is slow but the affected area is geographically dispersed. When the disaster area consists of a large or scattered geographical area, it may take substantial planning, resource allocation, and coordination among the military, humanitarian organizations, local, federal, and perhaps even foreign government representatives. The 2009 avian flu epidemic is an example of a slow onset, geographically dispersed disaster involving multiple countries to respond to its effects. Although the numbers of people who have died from avian flu have been modest over the last five years, there remains a significant threat that the disease could mutate into an antibiotic-resistant strain that could eventually kill millions of people worldwide. The sudden-onset disaster, even if localized (depicted in quadrant IV of Figure 3), creates operational difficulties that are greater than circumstances where the onset is slow, but less than if the catastrophe were both rapid in its onset and geographically dispersed. Sudden-onset disasters deny authorities and the public time to prepare for the consequences of the disaster event and therefore tend to exact a much higher human cost.

The disasters with slow-onset provide time for humanitarian logisticians to plan and prepare for relief operations. A disaster that strikes suddenly can pose difficult problems for response since no organization—military or humanitarian—can fully prepare for every need that will emerge during such an event. However, prepositioning strategies such as asset placement, resource allocation, management of disaster relief inventory, and location of such warehouses may help. It is clear that whether the disaster is localized or dispersed over a large geographical area, will dictate the level of difficulty involved in disaster response.

In all these situations, where disasters may be slow-onset or sudden-onset, localized or dispersed, pre-positioning seems to be the policy that will always be more effective and efficient in HADR. The utilization of pre-positioning in private, as well as public sector, suggests that we formulate logistics strategy based on this concept.

Discussion

The unpredictability of the timing of a disaster, as well as the scope of its human and material destruction, raises several serious questions for emergency planners and first responders. For example, how can a state of supply preparedness be established and maintained? How should adequate prepositioned disaster relief inventory be established and sustained over time to include the rotation of perishable stocks? How can information regarding the location, quantity, and condition of prepositioned inventory be shared and what effect would this information sharing have on the total investment of prepositioned stocks? Is prepositioning the best strategy for all types of disasters? How reliable are the potential supply lines if it is determined that supplies should be virtually stockpiled (that is, a detailed list or database of supplies by type and quantity is created and maintained, as well as reliable sources that can provide the supplies quickly)? Should supplies be sourced locally or from outside the disaster zone? Answers to these questions depend on the expected onset speed of the disaster, the volume and weight of supplies to be moved, the expected magnitude of humanitarian relief required, and the expected likelihood of a disaster in the area.

The success of the military in using prepositioned stocks has developed interest in the prospect of using such a strategy to support operations other than war (Brown, Schank, Dahlman, & Lewis, 1997; Salmeron & Apte, 2010). Prepositioning supplemental resources in or near the incident location most resembles the military practice of storing defense inventory ashore to be used in the event of a conflict; the Army-prepositioned stocks in Southwest Asia, as well as those in Korea, are good examples. An alternative to prepositioning would be the early deployment of assets in advance of a local government request. For example, as federal government officials see a hurricane approaching the Gulf of Mexico, they could mobilize food, water, and temporary shelters and stage them close to, but not in, the expected disaster zone so that when these supplies are needed, the lead time necessary to deliver them is reduced. Phased deployment of assets refers to timing the delivery of inventory to a disaster area as it is needed and in the quantity in which it is needed. This disaster response is analogous to "just in time" inventory control practiced by commercial manufacturers, and has the advantage of not committing excess inventory to a specific region before knowing precise types and quantities of supplies needed. Phased deployment also prevents the disaster zone from being inundated or saturated with inbound materiel that might otherwise reduce the overall effectiveness of the disaster response due to inadequate infrastructure or limitations in personnel, material handling equipment, storage space, or some combination of all three.

A surge in transportation of manpower and equipment from locations outside the disaster area is a final alternative that, rather than relying on prepositioned physical inventory, plans for excess capacity to deliver personnel and materiel in case of an emergency; in this instance, the "prepositioning" is with respect to capacity rather than inventory. The organizations involved in humanitarian assistance and disaster response (such as those relevant agencies within the Department of Defense, civil and military agencies, and participating Non-Government Organizations) face issues of information availability, interoperability in communications and equipment, coordination of specialized skill sets, and determination of which organization will lead specific phases of the operation which affect the ability to collaborate and preposition supplies. A preliminary look at the above-mentioned four strategies related to the life cycle of a disaster suggests the assignment of strategies as shown in Figure 4.

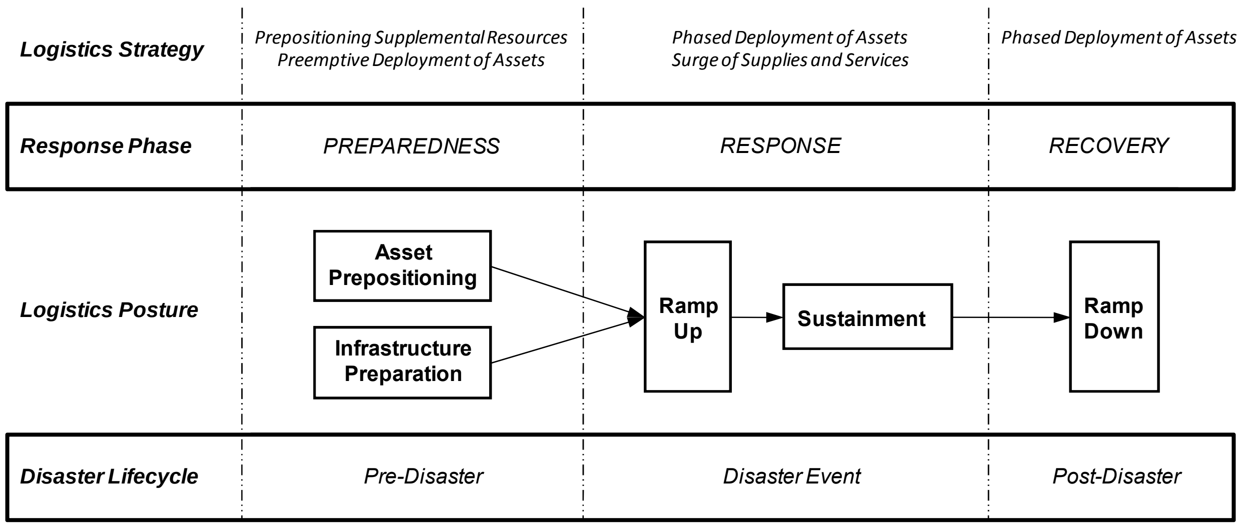

Figure 4. Policies Related to Life Cycle of a Disaster
Note. Figure 4 is adapted from Apte (2009).

Conclusion

The localized, slow-onset and natural disasters are at one end of the spectrum with respect to the level of difficulty for humanitarian logistics, whereas dispersed, sudden-onset disasters are at the other. Classification of disasters and the life cycle of a disaster are our basis for formulating which of the four policies should be used when. The conceptual models we plan to develop in this work will serve as the theoretical base for future empirical work investigating appropriate policy options for different classifications of disasters. We believe the proposed research will create a comprehensive understanding of strategies in logistics for HADR; recommend strategies in logistics that are appropriate to different types of disasters; and recommend strategies in logistics that are appropriate to specific regions of the world.

Way Forward

Utilizing both qualitative and quantitative methods to include process analysis, cost analysis, and case studies, we will introduce four policy options to respond to a disaster or humanitarian relief effort, and explore the efficacy of each one against the backdrop of four different disaster scenarios. Policy options will be developed that correspond to classes of disaster and operational difficulty to improve the decision process of policy makers in terms of resource acquisition and deployment. We plan to pursue the following methodology to achieve this goal.

We will expand upon our current review of the academic literature to identify work that has addressed inventory prepositioning in the public (to include defense) and private sector. We will identify examples of four candidate logistics strategies—prepositioning supplemental resources in or near the incident location; deploying federal assets in advance of a state or local government request; phased deployment of assets, analogous to the "just in time" inventory control philosophy practiced by many manufacturers; and "surge" transportation of manpower and equipment from locations outside the disaster area—in the public and private sector. We will evaluate logistics strategies within the context of the four types of disaster scenarios and develop policy recommendations.

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An Analysis of U.S. Navy Humanitarian Assistance and Disaster Relief Operations (MBA Student Report)

Cullen Greenfield—LT Cullen Greenfield is a Surface Warfare Officer. He was commissioned through the NROTC program at NC State University, where he received a Bachelor of Science. After graduating from the Naval Postgraduate School he will be reporting to Surface Warfare Officer School, Department Head Class 216. He has follow-on orders to USS *Tortuga* (LSD 46) as the Chief Engineer.

Cameron Ingram—Surface Warfare Officer (SWO). LT Ingram graduated from the U.S. Merchant Marine Academy in Kings Point, NY, in 2004 with a degree in Logistics and Intermodal Transportation. After graduation he served onboard the USS *Mitscher* (DDG 57) as the Ordnance Officer and the Main Propulsion Division Officer. His second tour was onboard the USS *Hopper* (DDG 70) as the Training Officer. After the *Hopper* he worked in the Operations Office at U.S. Pacific Fleet Command. He married his wife Autumn in September 2006, and they currently have no children. In his free time, LT Ingram is highly active in the Naval Postgraduate School Foundation and is the Vice President of the Cycling Club. He is an outdoor enthusiast who races in several triathlons, bike races, running races, and swimming events throughout the year. After graduation in June 2010, he will be reporting for SWO Department Head School in Dahlgren, VA, then Newport, RI. After Department Head school, he will be reporting to the USS *Bulkeley* (DDG 84), Norfolk, VA, as the Operations Officer.

Abstract

This project investigates the response of the U.S. Navy (USN) and Military Sealift Command (MSC) to different types of disasters and identifies the types of assets deployed as well as the dwell times for mission support. Using the recent history of U.S. Navy humanitarian assistance and disaster relief (HADR) operations, we explore opportunities to shape the fleet force structure to adapt to the increased mission importance of HADR operations, and we identify current hard power assets that may be effective in achieving soft power goals.

The goal of this project is to act as a guide for the U.S. Navy in its HADR decision-making process. By analyzing disaster characteristics and U.S. Navy platform capabilities, we can determine which assets are better suited for mission requirements brought on by disasters. Knowing the best possible asset to assign to a disaster will improve the DoD's effectiveness in regaining stability, both monetarily and logistically, within the affected region as disasters occur. Knowing which assets are better suited for disaster response will help the USN with future force structure and fleet composition.

Financing Naval Support for Humanitarian Assistance & Disaster Response: A Cost Analysis and Planning Model (MBA Student Report)

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Abstract

The United States Department of Defense (DoD) has recently elevated the priority of military participation in humanitarian assistance and disaster response (HA/DR) to the level of a core mission, equivalent to conventional combat operations. The DoD possesses valuable assets and unique competencies that facilitate operations in dispersed locations without functioning infrastructure. Only the military possesses these capabilities at a sufficient capacity to respond to a major, sudden-onset disaster. Until the DoD provides a cost estimate for services, the DoS cannot gauge the level of service desired from the DoD to support DoS missions. Examining the U.S. Navy's participation in HA/DR following two natural disasters, namely the 2004 Indian Ocean tsunami and the 2010 Haiti earthquake, this research analyzes the effectiveness of a cost model that is currently used by the DoD to budget contingency operations and investigates the potential for a more representative planning tool for future operations.

When Disaster Strikes: Is Logistics and Contracting Support Ready?

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Professor Apte received her PhD in Operations Research from Southern Methodist University in Dallas. She also has an MA in Mathematics from Temple University, Philadelphia. Before NPS she worked as a consultant at MCI and taught at the Cox School of Business, SMU, where she won the best teacher award. She has over 20 years of experience teaching operations management, operations research, and mathematics courses at the undergraduate and graduate levels. At NPS, she teaches mathematical modeling, for which she won the best teacher award, and she has advised over 50 students for over 24 MBA/Masters reports, out of which 10 students have worked and seven more are working in Humanitarian Logistics. She has also advised emergency planners in preparing for disaster response. She is the founding president for a new college (focus group) in Humanitarian Operations and Crisis Management under the flagship academic professional society in her intellectual area of study, Production and Operations Management Society. [auapte@nps.edu]

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Abstract

Recent crisis responses, including the Department of Defense (DoD) and the United States (U.S.) integrated response to the 7.0-magnitude earthquake in Haiti, in which the DoD played a major role, can be examined and analyzed to determine how greater efficiencies and effectiveness may be achieved. Specific examination and analysis of actual logistics and contract capability in real-world response, including the DoD's ability to deliver the right mix of goods and services, when and where they are needed given limited resources, can be utilized to create a more robust capability for future events. This includes the ability to react more effectively and efficiently within the constraints of resources such as budget and manpower if contingency contracting is in place. We examine the planning and management of the DoD's logistics and contracting support for contingency, expeditionary, and crisis response and provide specific recommendations for optimizing response capability for future crisis response.

Introduction

In the last few years, a substantial population of the world has suffered due to disasters, natural or manmade. In 2009, there were "335 natural disasters reported worldwide that killed 10,655 persons, affected more than 119 million others, and caused over $41.3 billion in economic damages" (Vos et al., 2010). Recent crisis responses, including the DoD and U.S. integrated response to the 7.0-magnitude earthquake in Haiti, in which the DoD played a major role, can be examined and analyzed to determine how greater efficiencies and effectiveness may be achieved. Currently, there exists a sub-optimization of capability due to lack of integrated analytical approach creating and executing crisis response. This is manifest in long lead times and high costs in acquisition and delivery of critical supplies and services in areas devastated by disaster. The negative effects of the inefficiencies and ineffectiveness of existing systems include but are not limited to loss of lives and property.

The life cycle of a disaster can be divided into three stages along the time line (Figure 1): preparedness efforts before the disaster strikes, response immediately after the disaster strikes, and recovery in the post-disaster period (Apte, 2009).

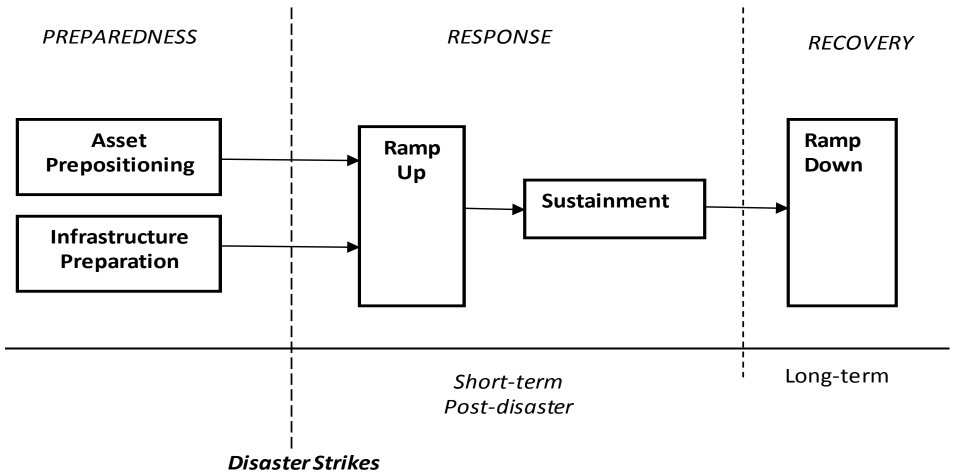

Figure 1. Time Line of Humanitarian Supply Chain
(Apte, 2009)

When a disaster strikes, the response follows: donations and funding are solicited from donors, and sometimes supplies are obtained from pre-contracted vendors. Sometimes the supplies are obtained in advance, especially during the pre-positioning stages. The supplies received from donors and supplies purchased from vendors are then transported by various means to predetermined locations and distributed by emergency responders in the affected areas. The contracting for this transportation should also be predetermined for fast relief. However, the nature of the events creates uncertainties and, again, logistics and contracting have to create an efficient interface. The complexity of humanitarian logistics can be appreciated when the distribution process through this time line, along with the factors and characteristics of this supply chain, are taken into account.

Specific examination and analysis of actual logistics and contract capability in real-world response, including the DoD's ability to deliver the right mix of goods and services, when and where they are needed given limited resources, can be utilized to create a more robust capability for future events. This includes the ability to react more effectively and efficiently within the constraints of resources such as budget and manpower if contingency contracting is in place. Humanitarian logistics is a critical element of an effective and efficient disaster relief process (Apte 2009).

Recent and current examination of DoD crisis response capability indicates that the overall supply chain can be improved (Lodree & Taskin, 2009). Specifically, the response time, coordination of providers, contracting, and the capability to deliver the right mix of goods and services can be enhanced. The Government Accountability Office (GAO) REF indicates that coordination and planning efforts for domestic and international disasters must be improved. This call for improved coordination to improve response extends to the logistics and contracting support communities within the DoD, the Department of the Army (DA), and other services and can be a key enabler for initial response improvement.

In Haiti, devastation caused by the earthquake dramatically impaired the capability of all rapid response efforts. The resulting extreme conditions made it difficult to deliver and transport much needed equipment, materials, supplies, and services to the Haiti earthquake victims and the first responders on the scene. This study will look into how the planners and coordinators utilized DoD contracting and logistics to provide relief to those in Haiti. Additionally, a comparative analysis of recent DoD humanitarian assistance operations will disclose best practices in DoD disaster relief as this study uncovers what went right, what went wrong, and what was learned in the first 100 hours of the Haiti Relief Effort.

In the immediate response phase, the demands of a disaster require an immediate response, and in order to do so, supply chains need to be designed and deployed at once, even though the knowledge of the situation is limited. Relief agencies should react with very little knowledge of the situation, and therefore, supply chains and logisticians need to be flexible and adaptable. Distribution is the most difficult situation, according to the authors. Getting the supplies where they need to be within the affected region is very difficult, and most of the time, these supplies are needed quickly. Distribution networks must be flexible, and this will require an adaptive coordination strategy between the various relief agencies. Decentralization is imperative in order to facilitate this flexibility (Kovács & Spens, 2007). Decentralized networks are more adaptive to the unpredictable effects caused by a disaster; they are less rigid and can be implemented in an area with a lot of unknowns.

Logistics is crucial to the planning stage of disaster relief. Strategic plans should incorporate logistics in order to ensure that the appropriate supplies and provisions are available and properly distributed. Many items needed in a disaster zone are well known and could easily be planned for. Many relief agencies tend to have purchasing agreements with companies that provide many of these disaster relief supplies. However, the gap is within the coordination between the capabilities of logistics agencies and the contracting community.

When disaster strikes, is logistics and contracting support ready? Such a question can only be answered if planning and management of the DoD’s contracting and logistics for optimizing crisis response capability is studied. Further questions that need to be answered include the following: How can initial response time be improved? What will guarantee smooth supply of critical supplies and services? Are existing contracts in place? If not, can and should they be negotiated?

Literature Review

Academic Literature

In light of recent high profile disasters, humanitarian groups and governments have shown a simple lack of preparation in combating the effects of the disaster (McCoy, 2008). Logistical obstacles have created greater suffering and highlighted the ineffectiveness caused by a lack of preparedness. Humanitarian groups have shown a complete lack in inter-organizational coordination and communication; due to the enormous effects caused by disasters, these groups must coordinate their efforts in order to achieve the greatest effect. Sometimes lack of coordination causes further problems where certain areas become overserviced and other areas are underserviced. Information and responsibilities of participants may be redundant. As knowledge management systems are created, surplus operation can be eliminated and response efficiency improved.

Logisticians play a vital role in almost all aspects of society, and especially so in disaster relief zones (Thomas, 2003). Logistics is the life of any emergency aid operation, and without it, lives would be lost. The role of logistics is sometimes overlooked or taken for granted in these zones. Usually, logistics is where many relief operations struggle or even fail. Proper coordination between agencies requires adequate preparation before a disaster, but the lack of specific logistician creates planning inadequacies. Ultimately, humanitarian supply chains are very dynamic and complex, but only a few organizations place logistics high on their agenda. Logistics is viewed as a support function and not a strategic function within these organizations. Inadequate consideration leads to underfunding, which results in inferior logistics provided by the organization. Often times, logisticians are even left out of the planning process and, therefore, resort to reactionary measures and support a constant state of "firefighting" during a crisis. For the logistics function to be a strategic asset, donors and leaders of these organizations must pay attention to it.

Salmeron and Apte (2010) develop a two-stage stochastic optimization model to address shortcomings in current pre-disaster planning for humanitarian logistics. A key strategic issue is the pre-establishment of adequate capacity and resources that enable efficient relief operations. The optimization focuses on minimizing the expected number of casualties, so our model includes first-stage decisions to represent the expansion of resources such as warehouses, medical facilities with personnel, ramp spaces and shelters. Second-stage decisions concern the logistics of the problem, where allocated resources and contracted transportation assets are deployed to rescue critical population (in need of emergency evacuation), deliver required commodities to stay-back population and transport the transfer population displaced by the disaster.

There are substantial differences between commercial logistics and humanitarian logistics. Humanitarian logistics need to have zero lead times, often involve high stakes, and must sometimes utilize unreliable information; many operations are often ad hoc; and there is varying levels of enabling technology (Beamon, 1999). This is due to the unpredictable nature of humanitarian logistics. Logistics must be adaptive and flexible when operating in a disaster area, unlike the familiarity of commercial logistics.

The idea that private sector logistics can and should be applied to improve the performance of disaster logistics, but that before embarking on this, the private sector needs to understand the core capabilities of humanitarian logistics (Van Wassenhove, 2006). With this in mind, this paper walks us through the complexities of managing supply chains in emergency relief operations, as well as the possibilities of getting involved through corporate social responsibility. It also outlines strategies for better preparedness and the need for supply chains to be agile, adaptable, and aligned—a core competency of many humanitarian organizations involved in disaster relief and an area that the private sector could draw on to improve their own competitive edge.

The speed of humanitarian aid after a disaster depends "on the ability of logisticians to procure, transport, and receive supplies at the site of humanitarian relief effort" (Kovács & Spens, 2007). The authors created a framework that distinguishes between the actors, phases, and logistical processes of disaster relief. The authors also defined humanitarian logistics as the different operations at different times that occur to aid and help those affected by various catastrophes, which could be broken down into two fundamental parts: continuous aid work and disaster relief.

Furthermore, they defined disaster management as a process of several stages in order to implement humanitarian logistics. These stages include the following: preparing for the disaster, immediate disaster response, and reconstruction. In the preparing phase, the authors make the argument that while preventing and predicting disasters are nearly impossible, thus creating planning difficulty. Disasters are unpredictable with the exception of possible manmade disasters (e.g., war, terrorism, etc.); however, sufficient preparation can be made due to the likelihood of a disaster , such as preparing for earthquakes in fault zones, preparing for volcanic activity in cities near volcanoes, or preparing for hurricanes in hurricane-prone regions. Although the disaster itself cannot be predicted, the odds can be weighed. Preparedness has been crucial in many of these areas, and the lack of preparedness is evident in those areas not prepared. During their literature review, Kovács and Spens (2007) determined that a significant portion of planning for disasters lacked foresight into logistics and simply focused on reactionary measures such as evacuation routes.

The main operational problem that exists relates to distribution. Balcik, Beamon, and Smilowitz (2008) made the argument for a centralized distribution system consisting of various nodes spread across networks implemented within the affected region. This network would aid in coordination by providing a systematic model of organization for aid distribution utilizing a centralized system. Problems arise during a disaster, with many affecting the infrastructure within an area that oftentimes would be dependent upon during times of need. However, with a lack of such infrastructure, a new solution to move disaster relief supplies around the region would be needed. For the most part, the physical delivery of aid is a non-factor due to the ability to airdrop to even the most remote areas. However, the planning and coordination of the distribution of these supplies is a problem due to the sheer volume and number of relief agencies that may respond to a region. There are several factors and variables that must be taken into account that determine the means and methods of delivery. Thus, a flexible and adaptive plan is required utilizing various mean of tracking and routing. However, the problem with a centralized planning and coordination system is whether or not one will gain participation among the various actors within the region. Centralization depends on factors that are interrelated. Therefore, if certain parts of the distribution fail, there exists a possibility that the entire plan may collapse.

Balick and Beamon (2008) created a model of a centralized distribution system for humanitarian relief operations. A centralized system would generalize the overall disaster and be completely contrary to the very nature of most disasters. If a centralized distribution system could be implemented, it would solve a majority of the problems associated with logistics within a disaster area. However, due to the complex nature and lack of information pertaining to the disaster, it is incredibly difficult to implement such a plan. Ad hoc networks combined with proper pre-planning would achieve the necessary flexibility in order to logistically respond to a natural disaster. Unlike traditional commercial chains with pre-established logistical operations and can regularly are planned well in advance; humanitarian networks do not have this luxury.

Numerous case studies point out the importance of logistics as well as criticality of coordination among agencies that are downstream or upstream from the logistics in the entire supply chain. A 7.9-magnitude earthquake struck Gujarat, India, during a holiday in 2001. This earthquake was massive and widespread; the regions lack of codes and general unpreparedness for the earthquake caused more damage than was necessary. The earthquake's scale made implementation of any logistics plan difficult. There was significant use of an "IPT-like" team consisting of engineers, sanitation experts, earthquake specialists, and health experts set up to assess the damage and needs of the resulting humanitarian mission (Samii, Van Wassenhove, Kumar, & Becerra-Fernandez, 2002). This is an excellent model due to the varying levels of certain disasters; it is imperative to have a group of knowledgeable experts to provide real data to the relief organizations in order to implement the correct actions for the distribution of aid.

Samii et al. (2002) stress the importance of logistics. The logistics unit for this disaster had recently gone through a conversion. They were well-organized and versed in all aspects of logistics, including not only purchasing but also warehousing, supply chaining, management, and reporting. They also had two separate groups, which divided logistics between field activity and resource management. This seemed to work well. Additionally they had specialists pertaining to planning, coordination, and reporting. They also had a distribution specialist. The Red Cross had focused on their disaster management capability. Over the years, the IRFC had developed three main mechanisms and tools to respond to emergencies, which consisted of a funding mechanism, an assessment mechanism, and a mobilization mechanism. All three mechanisms allowed the IRFC to raise funds, quantify a disaster area, and react by distributing aid. The IRFC maintains a network of supplies throughout the world as well as numerous well-stocked donation centers in order to rapidly deploy resources in the event of a disaster.

By the end of its six-month mandate in Afghanistan, the United Nation Joint Logistics Center (UNJLC), an interagency emergency response coordination mechanism administered by the World Food Program (WFP), had accomplished its goals (Samii & Van Wassenhove, 2003a). It had supported humanitarian logistics planners in their efforts throughout the 2001–2002 Afghan winter and addressed cross-border and in-theater logistic bottlenecks. However, four months after the fall of the Taliban regime, the scale of the humanitarian crisis remained significant and the need for another year of operations was clear. The UNJLC, which had never been deployed for longer than six months, was asked on an extraordinary basis to continue its operation for one more year. The UNJLC utilized a pre-planned strategy that consisted of three prongs involving pre-positioning of aid, ensuring corridor accessibility, and developing contingency airlift capacity. The UNJLC took the entire potential factor within their region and developed an effective strategy to managing the crisis. They concluded that corridor access was the most important. They had to take into account the needs and constraints of the various regions and implement decisions based on transportation and pre-positioned stocks. UNJLC also used innovative thinking when they employed locals to participate with clear access via snow-blocked passes. This effort provided two factors for the people: cash and open access to relief aid and other types of communication and travel.

Relief efforts were organized to combat the effects of a quick succession of floods in Mozambique (Samii & Van Wassenhove, 2003b). The logistical constraints imposed by the floods made airlifts the only viable means of transportation. It was also the most expensive method. Given the great demand for air assets, there was a pressing need to enhance the efficiency and cost-effectiveness of the overall humanitarian relief effort. But, which humanitarian UN agency or NGO was to coordinate the use of the available air assets? The UNJLC was made up of a group of humanitarian logistics expert who formed a sort of logistics "IPT," and they were tasked with coordination and communication among the various aid agencies within the affected region. They became the center point for all operations within the region. This reduced the confusion and redundancy of multiple agencies trying to provide aid.

Official Documents

Recent disasters and the ability to effectively and efficiently respond has spawned several official published works related to disaster response. Of note are those from the Congressional Research Service (CRS), the Government Accountability Office (GAO), the United Nations (UN), the Federal Emergency Management Agency (FEMA), the RAND Corporation, and U.S. military commands including the Naval Postgraduate School (NPS).

The RAND Corporation published a comprehensive, albeit interim, work on response capabilities and organizations responsible for response and recovery efforts. (Moore et al., 2010). The RAND Report Number TR-764 found that federal funding supports preparedness initiatives across cabinet departments as well as grants to states and certain major metropolitan areas. At the local level, multiple agencies are grappling with a patchwork of federal funding streams and associated grant requirements. The RAND study determined that despite clear recognition, most disasters occur locally—or at least start that way—and most attention to date seems to have been on "top-down" planning from the federal level, representing stovepipe initiatives from different federal agencies. With that in mind, the Office of the Assistant Secretary of Defense for Health Affairs (ASD[HA]) in the DoD saw an opportunity to strengthen local level disaster preparedness planning by military installations and their civilian counterparts—local governments and local health-care providers, especially the Department of Veterans Affairs. The report examined the national policies for preparedness planning, examines preparedness utilizing a notional "risk-informed, capability-based" planning framework, and examines local civil and military preparedness and local support networks. RAND intends to continue research in this area in an effort to create and test a "concept of operations" for more coherent response capability. The proposed model will be specifically tailored to U.S. domestic response capability, but, the lessons from the work may prove valuable in creating international response capability as well.

Another RAND Corporation publication, *Analysis of Risk Communication Strategies and Approaches with At- Risk Populations to Enhance Emergency Preparedness, Response, and Recovery*, examines the key role of communication in preparedness and response (Meredith et al., 2008). This published working paper represents results of a one-year study and assessment that involved review of the literature on emergency preparedness risk communication and public health messaging strategies; the compilation of educational and outreach materials for emergency preparedness communication with at-risk populations; and site visits in three states and the Washington, DC, area to identify gaps in the practice of risk communication with at- risk populations. The study emphasizes that community involvement in preparedness and response, to include key stakeholders and the media, improves capability in pre-event, event, and post-event disaster response.

The Government Accountability Office in March 2011 published "Measuring Disaster Preparedness: FEMA Has Made Limited Progress in Assessing National Capabilities," a statement by William O. Jenkins Jr., Director of Homeland Security and Justice Issues (GAO, 2011). According to the testimony presented in the report, since 2002 Congress has appropriated over $34 billion for homeland security preparedness through grant programs to enhance the capabilities of state, territory, local, and tribal governments to prevent, protect against, respond to, and recover from terrorist attacks and other disasters. Additionally, Congress enacted the Post-Katrina Emergency Management Reform Act of 2006 (Post-Katrina Act) to address shortcomings in the preparation for and response to Hurricane Katrina that, among other things, gave FEMA responsibility for leading the nation in developing a national preparedness system. The Post-Katrina Act requires that FEMA develop a national preparedness system and assess preparedness capabilities—capabilities needed to respond effectively to disasters—to determine the nation's preparedness capability levels and the resources needed to achieve desired levels of capability. Mr. Jenkins' testimony states that in September 2007, the DHS issued the National Preparedness Guidelines that describe a national framework for capabilities-based preparedness as a systematic effort that includes sequential steps to first determine capability requirements and then assess current capability levels. According to the Guidelines, the results of this analysis provide a basis to identify, analyze, and choose options to address capability gaps and deficiencies, allocate funds, and assess and report the results. This proposed framework reflects critical practices we have identified for government performance and results.

The report is significant in that it emphasizes the need to have measurable and demonstrable metrics to determine the state of preparedness and the capability to respond effectively and efficiently. Figure 2 highlights the concept presented, indicating the response capability of local, state, and federal responses over time and the theoretical gaps that can occur.

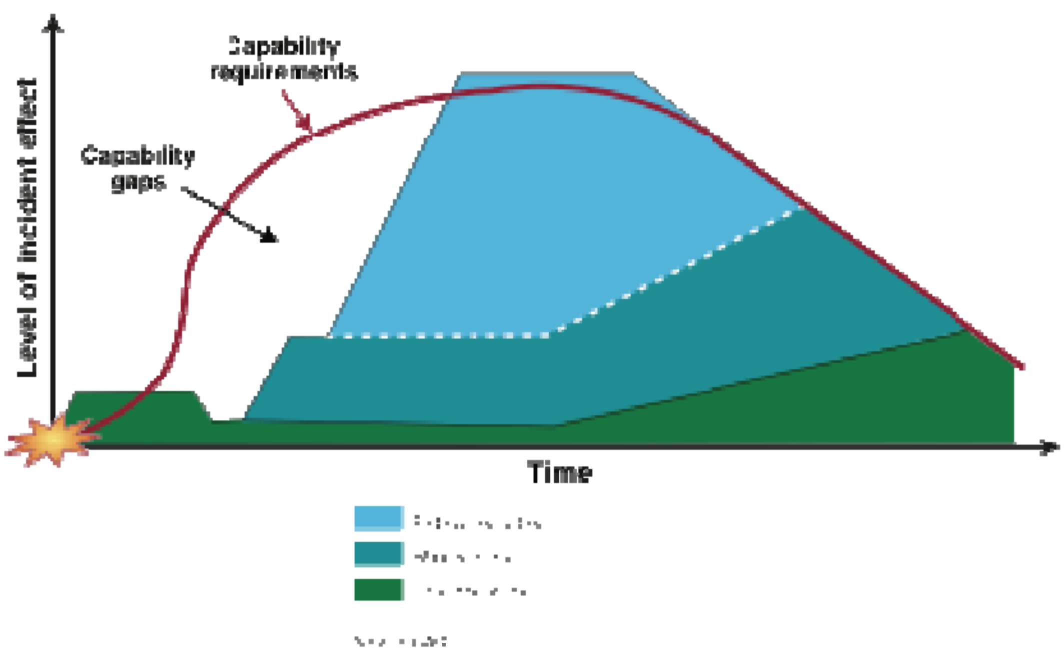

Figure 2. Capabilities Requirements and Gaps
(GAO, 2011)

The Government Accountability Office also published *Hurricane Katrina: Planning for and Management of Federal Disaster Recovery Contracts*, which presented the testimony of William T. Woods, Director of Acquisition and Sourcing Management, and specifically addressed the planning and conduct of contracting in relation to Hurricane Katrina (GAO, 2006). The testimony report discussed how three agencies—the General Services

Administration, the Federal Emergency Management Agency (FEMA), and the U.S. Army Corps of Engineers (the Corps)—conducted oversight of key contracts used in response to the hurricane. The GAO found three primary and specific deficiencies. First, there was inadequate planning and preparation in anticipating requirements for needed goods and services. Second, there was a lack of clearly communicated responsibilities across agencies and jurisdictions to ensure effective outcomes. And third, there were insufficient numbers and inadequate deployment of personnel to provide for effective contractor oversight. Mr. Woods recommended several actionable items to remedy the deficiencies, including but not limited to the need to have competitively awarded contracts in place prior to the event against which orders can be placed as needed and better pre-planning and communications with other agencies prior to the alignment of responsibilities among the key officials in managing the award and oversight of contracts. This is but one of the many GAO published reports on the Hurricane Katrina response. In total, there are well over a dozen reports, and most indicate a lack of planning, coordination, and communication as key problems in effective response capability.

Recognizing the complexities of interagency communication and coordination of a wide array of agency and service cultures, the Department of Homeland Security published *Risk Steering Committee DHS Risk Lexicon, 2010 Edition*, dated September 2010 (DHS, 2010). Risk management and analysis supports specific homeland security missions and determines how homeland security functions can be best used to prevent, protect, mitigate, respond to, and recover from hazards to the Nation. The ability to communicate precise concepts and meanings is essential for effective risk-informed decision-making. Clear communication allows information to be used consistently to support decisions about the nature, cause, and severity of risks. This ability to communicate homeland security risk information with precision is critical to support decision-making at all levels throughout the DHS. While this document is primarily geared for the DHS, it's clear to the researchers that a universally recognized lexicon can prove beneficial to all agencies and services, particularly in communicating for logistics and contracting and developing sound business practices.

The Department of the Army and the U.S. Marine Corps' *Field Manual 100-19 Domestic Support Operations* (DA & USMC, 1993) is a primary document in the force structure, planning, and conduct of domestic operations, including disaster response capabilities on U.S. soil. The manual includes comprehensive chapters on concepts of operations, roles and responsibilities, legal considerations, logistics and support operations, community assistance, and training and education in domestic support. Its Chapter 5, entitled "Disasters and Domestic Emergencies," is a comprehensive guide on interagency roles and responsibilities, stages of response, and associated capabilities. According to the chapter summary, the Army and the DoD provide military support to civil authorities, especially in disaster assistance operations. The DoD is a supporting agency, providing military support to other lead federal agencies. The Secretary of the Army (SA) is the DoD's executive agent, and the Director of Military Support, or DOMS, is the SA's agent for disaster assistance support. In most cases, the Army will participate in disaster assistance operations as part of a DoD effort managed by the DOMS serving as a joint staff and commanded by a supported CINC. The Army is committed to providing timely and effective disaster assistance support to other federal agencies and the American people (DA & USMC, 1993). Despite being authored in 1993, the Army still utilizes this manual. The researchers contend that since many changes have occurred in statutes and policies, including revisions to the Stafford Act, this publication should be revised to reflect those changes and to include recent recommendations on logistics and contracting as required.

The Congressional Research Service (CRS) has published several reports on disaster response and disaster assistance. Of particular interest is the CRS report titled *The Use of Federal Troops for Disaster Assistance: Legal Issues*. (Elsea & Mason, 2008). Since the military is often called upon to provide logistic and contracting assistance in domestic disasters, the legal framework for the apportionment of active-duty military units is examined in relation to the Posse Comitatus Act and the Stafford Act. While these statutes deal with the use of armed military personnel involved in security and peacekeeping in domestic operations, the aftermath of Hurricane Katrina, and the lack of observed law and order in New Orleans, in particular, and under special provisions can allow the use of active duty military for response. This report defined the legal framework in understandable language and is useful for any logistic and contract planner and executor.

The Naval Postgraduate School, primarily through its Acquisition Research Program, has published several research studies and working papers of interest. Of particular use for this research effort is *Phase Zero Operations for Contingency and Expeditionary Contracting–Keys to Fully Integrating Contracting Into Operational Planning and Execution* (Yoder, 2010). This sponsored research paper, published in August 2010, demonstrated a synergy that may occur when personnel credentialed in accordance with the author's recommendations are integrated into strategic operations planning and execution specifically for contract integration into all operations plans. The author contended that when the right mixes of personnel, platforms, and protocols are in place and utilized prior to an actual humanitarian crisis event, in phase zero, activities can be much more prepared for response in the event of an actual crisis.

The *Defense Contingency Contracting Handbook*, published by the Defense Procurement and Acquisition Policy and the Air Force Logistics Management Agency, provides a solid and fundamental guide for all DoD practitioners for humanitarian and expeditionary operations. In particular, Chapter 9, titled "Domestic and Overseas Disaster Response," is wholly dedicated to the topic. Within the text, the unique roles of various federal agencies, including FEMA and the DoD, are addressed. The chapter also provides an overview of FAR Part 18 Emergency Acquisition Authorities. Mr. Shay Assad, Director of Defense Procurement and Acquisition Policy, endorsed this handbook for use in all DAU CON 234 Contingency Contracting courses and that delivery equivalent credential.

Forward Direction for This Research Effort

The researchers will continue to investigate and analyze information and data pursuant to providing solid findings, conclusions, and recommendations to further improve the efficiency and effectiveness of logistics and contracting in responding to crisis.

This effort will result in additional chapters to include the following:

- Data collected
    - *Response supply chain*
    - *Contingency contracting*
- Analysis
    - *Deficiencies in each area*
    - *Gap between the two*
    - *How do we fix it?*

- Conclusion
  - *Summary of what we did*
  - *Recommendation*
  - *Way forward*

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Panel 23 – Engaging Small Business in Defense Acquisition

Thursday, May 12, 2011	
3:30 p.m. – 5:00 p.m.	**Chair: Rear Admiral Seán F. Crean,** USN, Director, Office of Small Business Programs, Department of the Navy **Discussant: David Lamm,** Professor Emeritus, Graduate School of Business and Public Policy (GSBPP), NPS ***Strategic Sourcing with Small Business in Mind*** Lora Gross, Department of Veterans Affairs, Acquisition ***Implementation of the Department of Defense Small Business Innovation Research Commercialization Pilot Program: Be All You Can Be?*** Max Kidalov, Kevin Hettinger, and Mario Gonzalez, NPS

Rear Admiral Seán F. Crean—Director, Office of Small Business Programs, Department of the Navy. Mr. Crean serves as Chief Advisor to the Secretary on all small business matters. He is responsible for small business acquisition policy and strategic initiatives.

Mr. Crean joined the Secretary of the Navy Staff as a member of the Senior Executive Service in January 2010 and has over 30 years of federal service. Prior to receiving this appointment, he served as Deputy Assistant Secretary of the Navy for Acquisition and Logistics Management during a two-year military recall to active duty as a Rear Admiral in support of Operation Iraqi Freedom.

Mr. Crean's previous experience includes serving as the senior procurement analyst for the U.S. Small Business Administration's Office of Government Contracting Area I (New England) for 19 years. In this role he was the principal advisor to the SBA's six regional district offices and congressional delegations on procurement issues. He provided acquisition strategy analysis for over 20 buying activities throughout the region, supporting both DoD and Civilian federal agencies. He first entered federal civilian service as the Deputy Supply Officer for Naval Air Station Brunswick, ME, where he was also appointed the activity small business specialist.

Mr. Crean's combined military and civil service careers have provided complimentary and extensive leadership responsibilities in service to the country. As a member of the reserve component, he has attained the grade of Rear Admiral (two-star) and is currently assigned as Deputy Commander, Naval Supply Systems Command. He holds a Bachelor of Science degree in business management and marine transportation from State University of New York Maritime College and a Master of Business Administration degree from New Hampshire College's graduate school of business.

He has a number of personal and command decorations, including two Legion of Merit awards. He is a member of the Defense Acquisition Corps and is DAWIA Level III Contracting certified.

David Lamm—Professor Emeritus, Graduate School of Business and Public Policy (GSBPP), NPS. Dr. Lamm served at NPS as both a military and civilian professor from 1978 through his retirement in January 2004, teaching a number of acquisition and contracting courses, as well as advising thesis and MBA project students. During his tenure, he served as the Academic Associate for the Acquisition & Contracting Management (815) MBA Curriculum, the Systems Acquisition Management (816) MBA Curriculum, the Master of Science in Contract Management (835) distance learning degree, and the Master of Science in Program Management (836) distance-learning degree. He created the latter three programs. He also created the International Defense Acquisition Resources Management (IDARM) program for the civilian acquisition workforce throughout the country. Finally, in collaboration with the GSBPP Acquisition Chair, he established and served as PI for the Acquisition Research Program, including inauguration of an annual Acquisition Research Symposium. He also developed the Master of Science in Procurement & Contracting degree program at St. Mary's College in Moraga, CA, and served as a Professor in both the St. Mary's and The George Washington University's graduate programs.

He has researched and published numerous articles as well as written an acquisition text entitled *Contract Negotiation Cases: Government and Industry* (1993). He served on the editorial board for the *National Contract Management Journal* and was a founding member of the editorial board for the *Acquisition Review Quarterly*, now known as the *Defense Acquisition Review Journal*. He served as the NPS member of the Defense Acquisition Research Element (DARE) from 1983–1990.

Prior to NPS, he served as the Supply Officer aboard the USS *Virgo* (AE-30) and the USS *Hector* (AR-7). He also had acquisition tours of duty at the Defense Logistics Agency in Contract Administration and the Naval Air Systems Command, where he was the Deputy Director of the Missile Procurement Division.

He holds a BA from the University of Minnesota and an MBA and DBA both from The George Washington University. He is Fellow of the National Contract Management Association and received that association's Charles A. Dana Distinguished Service Award and the Blanche Witte Award for Contracting Excellence. He created the NCMA's Certified Professional Contracts Manager (CPCM) Examination Board and served as its Director from 1975–1990. He is the 1988 NPS winner of the RADM John J. Schieffelin Award for Teaching Excellence.

Strategic Sourcing with Small Business in Mind

Lora Gross—Acquisition Fellow, Department of Veterans Affairs Acquisition Academy. Ms. Gross is a member of the National Contract Management Association (NCMA). Prior to joining the Department of Veterans Affairs (VA), she wrote commercial contracts for the Bureau of National Affairs, Inc. (BNA), where she was the lead Contract Specialist, primarily working with law schools to better promote BNA brand usage throughout the law school community. Prior to working at BNA, Ms. Gross spent several years in retail management. She has a bachelor's degree in psychology from Towson University and is currently pursuing her MBA at the University of Maryland. [Lora.gross@va.gov]

Abstract

In 2005, the Office of Management and Budget (OMB) issued a memorandum to federal agencies to identify three routinely purchased commodities that could be more effectively and efficiently acquired through the use of an acquisition approach called Strategic Sourcing. The memorandum requires agencies to implement Strategic Sourcing efforts to save the government money and improve performance on the more than $500 billion spent through contracting each year.

In an effort to save millions of dollars of agency funds, concern has been raised by small business advocates that Strategic Sourcing efforts may narrow their opportunities and create bundled requirements which they are not able to meet. Strategic Sourcing concepts generally require national coverage for product or service provisions that may fall beyond a small businesses capability. Additionally, the Obama administration has called for a reduction of contracts awarded non-competitively; however, single award requirements are still within federal acquisition guidelines. If these requirements are procured under a single award effort, Strategic Sourcing can limit competition at the task and delivery order levels without incentivizing vendors to further reduce prices.

This paper discusses ideas for how the government acquisition workforce can leverage small business participation through the use of subcontracting goals.

Introduction

In 2005, the Office of Management and Budget (OMB) issued a memorandum to federal agencies to identify three routinely purchased commodities that could be more effectively and efficiently acquired through the use of an acquisition approach called Strategic Sourcing. The memorandum requires agencies to implement and report annually to the OMB on their Strategic Sourcing efforts to save the government money and improve performance on the more than $500 billion spent through contracting each year. Under the Strategic Sourcing approach, agencies consolidate requirements to leverage their buying power to take advantage of quantity discounts/lower pricing and obtain "best customer" status in terms of higher quality performance.

Strategic Sourcing is defined as a "collaborative and structured process of critically analyzing an organization's spending and using this information to make business decisions about acquiring commodities and services more effectively and efficiently" (Johnson, 2005). Its use requires standardization of procurement processes and fosters a reduction of overhead expenses. Further, Strategic Sourcing is meant to "[help] agencies optimize performance, minimize price, increase achievement of socio-economic acquisition goals, evaluate total life cycle management costs, improve vendor access to business opportunities, and otherwise increase the value of each dollar spent" (Johnson, 2005).

To illustrate the power of Strategic Sourcing, the United States (U.S.) Air Force has implemented a Strategic Sourcing initiative for information technology (IT). According to an article appearing in the Acquisition Solutions Advisory, the Air Force's Information Technology Commodity Council program successfully reduced 1,000 IT contracts to seven. This program alone has yielded dollar savings of $65.1 million and a "cost avoidance of more than $155 million between fiscal year (FY) 2004 and FY 2008" (Mather & Costello, 2009). Additionally, leveraging buying power for this effort improved the quality of performance in the following ways:

1. Decrease the workload of their contracting departments,
2. "Influence suppliers to include security offerings in software licenses,
3. Increase spending toward small businesses, and
4. Ensure compliance with the network and increase enterprise security" (Mather & Costello, 2009).

The OMB memorandum states that this process would not only enhance the performance and costs, thereby increasing the value of each dollar spent, but also notes the "increased achievement of socio-economic acquisition goals [and] improved vendor access to business opportunities"(Johnson, 2005). However, recent data shows that Strategic Sourcing may actually be limiting contracting opportunities for the small business community.

Small business performance is considered an indicator of the strength of the U.S. economy. According to the U.S. Department of Commerce (DoC), in 2007 small business accounted for little more than half of the U.S.'s private sector workforce and paid "44 percent of the total U.S. private payroll" (Kobe, 2007). Small businesses further support the U.S. economy through job creation. The DOC's report details that small businesses "generated 64 percent of new jobs over the past 15 years" (Kobe, 2007). Additionally, small businesses out-produce large businesses in terms of innovation. For commodities and services small businesses apply for patents 13 times more per employee than large firms (Kobe, 2007).

Because Strategic Sourcing initiatives are usually large in scope or volume with geographically dispersed customers and high in dollar value, small businesses may not have the capacity and capability to satisfy all of the government's requirements. So, how does a Contracting Officer balance Strategic Sourcing practices (that make really good business sense) with the competing demands of small business public policy objectives? This paper discusses the importance of small businesses to our national economy and innovative spirit while examining the challenges of balancing Strategic Sourcing with the achievement of socioeconomic goals. This paper also presents innovative ideas for how the entire government acquisition workforce can leverage small business participation through subcontracting goals by (1) incorporating agencies' small business subcontracting goals into the contract; (2) using past performance as an evaluation factor; (3) using performance-based incentives; and (4) leveraging contract option clauses contingent on compliance with subcontracting goals; and, separate from subcontracting compliance, (5) through the use of 100% Set-Aside Government-wide Acquisition Contracts (GWACs).

Relationship Between Consolidation and Bundling

Strategic Sourcing maximizes opportunities for consolidation and is a program that if not managed properly can bring about challenges with small business goals and bundling that could increase the risk of reduced contracting prospects for small business. Consolidating requirements takes previously performed actions by either large or small businesses under two or more separate contracts and combines them into one contract or order. Consolidating reduces the number of available contract opportunities by narrowing the potential pool of vendors from hundreds to dozens or less. The benefits to consolidating must be documented, justified, and approved prior to being implemented.

Consolidation should not be confused with bundling. Per the Federal Acquisition Regulation (FAR) Part 2.101, bundling consolidates

> two or more procurement requirements for goods or services previously provided or performed under separate, small contracts into a solicitation of offers for a single contract that is unlikely to be suitable for award to a small business concern due to (1) the diversity, size, or specialized nature of the elements of the performance specified; (2) the aggregate dollar value of the anticipated award; (3) the geographical dispersion of the contract performance sites; or (4) any combination of the factors described herein. (FAR, 2009)

The FAR does not exclude Contract Officers (COs) from bundling; however, bundling requirements do make it hard for small business participation on any acquisition because of the demand for multiple specialties or the resulting dollar amount.

There are multiple and conflicting statistics on contract bundling in the federal government. While most of all reports about contract bundling were published between FY 1992 and FY 2001, it continues to be of concern for small businesses. Articles published in 2008 reference these reports and state that bundling is one issue preventing small businesses from receiving new contract awards. An article by Aaserund (2008), reports that new contract awards to small businesses experienced a 56% decline between 1991 and 2000. Similarly, an article by Murphy (2000) reports a statistic from the Small Business Administration (SBA) noting that during FY 1992 through FY 2001, for every 100 bundled contracts, 60 individual contracts are no longer available to small businesses. Further, for every $100 awarded on a bundled contract, there is a $12 decrease to small businesses (Murphy, 2000). In searching for statistics on contract bundling, more current information shows that bundled actions actually decreased between FY 2005 and FY 2006 by 6%; however, the total dollars under these bundled actions increased by almost 42% for this period ("National Association of Small Business," 2008). This data clearly reflects the adverse impact of bundling, and perhaps Strategic Sourcing, if not properly implemented, to the small business community.

The FAR addresses multiple requirements for COs to take prior to beginning an acquisition effort that involves bundling. Regulations at FAR 7.107 state that the bundling action must have measurable substantial benefits that include (1) improved quality, (2) cost savings, or (3) better terms and conditions and provide written justification of such. Specific to cost savings, for contracts valued at less than $86 million, the benefits of bundling must be equivalent to 10% of the contract value, including options. For those greater than $86 million, the benefits must be equal to 5% of the contract value, including options, or $8.6 million, whichever is greater.

In addition to these requirements, agencies considering a bundled procurement must provide 30 days notice to the affected small business community. The FAR provides that agencies must consult with a representative of the Small Business Administration (SBA) on their acquisition strategies prior to the start of procurement under a bundled effort to protect the interests of the small business community.

Impact on Small Businesses

According to Elizabeth Newell (personal communication, December 17, 2009), a reporter for the *Government Executive*, the White House and the OMB will continue to issue directives to find other opportunities for Strategic Sourcing during President Barack Obama's administration. In choosing the top commodities to consider for Strategic Sourcing, agencies are focusing on high dollar requirements to realize immediate, impactful cost savings. Services such as wireless devices and commodities like office supplies for which the government spends millions of dollars annually are being awarded to businesses that can prove capability, reliability, and dependability. This brings one to question if any small businesses can perform requirements worth $100 million or more per year? Further, if a small business were deemed capable of performing the requirement and produced earnings in excess of the small business dollar threshold set by SBA's North American Industry Classification Systems Codes, they would no longer be considered a small business for future government business. Is this a goal of the SBA and would similar future needs of the government have to be awarded to other small businesses to help them continue to meet their requirements?

An article appearing in *Contract Management* reports that an end goal of Strategic Sourcing is to "limit the number of vendors and … [offer] exclusivity of contract as a means of aggregating volume in return for lower prices" (Fox, 2006). This process essentially narrows the pool of awardees to a finite number of vendors considered "best value" through evaluation and pricing comparison. Vendors proving that they are responsive and responsible will be awarded the contracts.

This method will exclude all other businesses, including locally owned small businesses that may have been performing the requirement prior to award. An article in the *Washington Report* supports this by stating,

> Strategic Sourcing is nothing more than an effort to limit the number of sellers of goods and services to a very select few, none of which, if present trends continue, will be small, independent office products dealers. In essence, it's simply a more severe version of contract bundling and that's bad news. (Miller, 2007)

This type of relationship tends to see prices gradually increase over time as the agency becomes dependent on the vendor to continue supplying their needs.

Single Award Sourcing

In its contracting form, Strategic Sourcing often resembles an Indefinite Delivery/Indefinite Quantity (IDIQ) contract method that allows agencies to define a minimal quantity of the needed commodity or service without knowing or committing the government to a maximum order beyond such. Under this contracting method, agencies may make multiple awards to vendors who can provide best value to their need and to maintain competition throughout the period of need; however, single awardees can be justified.

Though there are negative aspects to doing so, Strategic Sourcing initiatives can currently be justified for sole source and single awardees. Congress imposed a statute in 2008 requiring the award of multiple awardees where the aggregate contract value of an

IDIQ contract will exceed $100 million. This was enacted to ensure that there will be adequate competition in awarding the task and delivery orders for large IDIQ contracts (Jensen & Herzfeld, 2008). Agencies still must notify Congress of a decision to make a single award IDIQ contract within 30 days of the determination. Per FAR 16.504(c)(1)(ii)(D), the following exemptions apply:

- the tasks under the contract are so integrated that only a single source can perform them;
- only one contractor is qualified;
- the contract provides for award of only firm-fixed priced orders; or
- exceptional circumstances justify an exception in the public interest.

Some examples of negative aspects of single award sourcing includes limited competition at the task and delivery order levels, this process is not in alignment with President Obama's agenda towards competition and limited potential for innovative solutions.

Perhaps most important, single award sourcing limits competition at the task and delivery order level and does not promote incentives for further price reductions from the vendor. The General Services Administration (GSA) and the National Aeronautics and Space Administration's Solutions for Enterprise Wide Procurement (NASA SEWP) contracting programs are both examples of a Government-wide Acquisition Contract (GWAC) vehicle with multiple awardees enabling agencies to seek further competition at the task and delivery order levels. This not only benefits the agencies to make a better determination of price reasonableness, but also assists COs to write a best value determination based on competition. Further, having multiple awardees under a Strategic Sourcing vehicle encourages competition over the life of the contract. Contractors will be less likely to force price increases and non-scheduled delays onto agencies with other vendors appearing on the contract. This level of competition will ensure continuous delivery of best value to the government.

Second, single award sourcing is not in alignment with President Obama's acquisition agenda toward competition. In his memo dated March 4, 2009, Obama notes that "noncompetitive contracts place agencies in the position of having to negotiate contracts without the benefit of a direct market mechanism to help establish pricing" (Field, 2009). Further, a memo dated July 29, 2009, from the Executive Office of the President Office of Management and Budget (OMB) calls for a 10% reduction of dollars obligated through new contracts in FY 2010 that are awarded non-competitively and authorizes OMB oversight on any non-competitive contract awards (Orszag, 2009). The remainder of the March 4 memo is dedicated to providing guidance from the Office of Federal Procurement Policy (OFPP) to agencies in order to promote maximum competition and best value, further emphasizing the importance of this issue.

A third issue created by single awardees under a Strategic Sourcing initiative concerns the lack of innovation a single source can provide. With several vendors offering solutions for an agency's need, there is a greater likelihood to find a better way to achieve government objectives. Also, variety will be available to customers within the agency. Perhaps one vendor's idea of solving an issue would be ideal for one customer within the agency, but another customer in a different location would benefit from a totally different solution with a different vendor. Several ideas would be lost to the government under a static relationship from a single award Strategic Source contract.

A Better Way

While small businesses experienced a record setting increase of 12% in prime contract awards from FY 2007 to FY 2008, only eight of the 15 cabinet-level agencies met the government-wide goal of 23% of total contracted dollars going to small business (Hubler, 2009). While there are challenges in meeting small business goals with existing approaches to Strategic Sourcing, there are innovative ideas being used to ensure continued small business participation. Strategic Sourcing can be better utilized by leveraging small business subcontracting goals with large businesses and through continued use of 100% set-aside IDIQ contract vehicles.

Leveraging Small Business Participation in Strategic Sourcing Effort Through Subcontracting Goals

As previously stated, the goal of Strategic Sourcing is to leverage government purchases by consolidating existing procurements into a larger requirement. This concept typically will push the total cost of performance for a contractor into the multi-millions of dollars and will include all of the geographical areas that fall within the agency. This total cost of business with the government may hamper a small business from being qualified as a responsible bidder whose annual income must be below a certain dollar threshold in order to qualify for small business status. Similarly, small businesses are not geographically dispersed across the country and therefore wouldn't be considered as responsible bidders in that regard. From the standpoint of capacity and capability, large businesses would have to be considered when using a Strategic Sourcing procurement strategy.

Small businesses will have a difficult time meeting government Strategic Sourcing requirements. So, how do we balance these competing priorities and how can we ensure that small businesses are truly given the opportunity for this work? Four approaches are as follows:

1. **Incorporate the agency's small business subcontracting goals into contract.**

According to FAR 19.702, for any purchase over the simplified acquisition threshold, contractors must agree to include small businesses[1] to the maximum extent practicable. The Small Business Subcontracting Plan clause found at FAR 52.219–9 further instructs contractors to submit contracting plans that clearly define the percentage and total dollars they are planning to set aside for subcontracting with a small business. This is important for COs to understand because if these statements are not specifically made in their proposal, the government has nothing to hold them to for compliance and they technically do not have to give any work to small businesses.

Several agencies are taking their own initiatives to provide small business concerns with more subcontracting opportunities. The Department of Veterans Affairs (VA) published a Final Rule in the December 8, 2009, edition of the *Federal Register* to better leverage their ability to ensure service-disabled veteran-owned small business (SDVOSB) and veteran-owned small business (VOSB) participation in subcontracting opportunities. In it the VA authorizes extra evaluation credits for those contractors providing subcontracting plans that incorporate the use of an SDVOSB or VOSB concern. Further, if procurements are not set

[1] This reference of small businesses includes veteran-owned small business, service-disabled veteran-owned small business, HUBZone small business, small disadvantaged business, and woman-owned small business concerns.

aside for SDVOSB and VOSB's, including those using the Federal Supply Schedule, the VA Acquisition Regulation (VAAR) clause 852.215–70 for SDVOSB and VOSB Evaluation Factors must be used authorizing VA CO's to evaluate the status of the offerors, providing them with the following merits during proposal evaluation:

a) full credit for SDVOSB status,

b) partial credit for VOSB status, and

c) some credit for offerors proposing to use SDOVSB or VOSB businesses as subcontractors.

Additionally, VAAR 819.704 states that subcontracting plans incorporating SDVOSB and VOSB's must have a goal that is at least commensurate with the annual VA SDVOSB prime contracting goal for the total value of planned subcontracts.

The Department of Treasury is another agency that is promoting small business participation through subcontracting. Their FAR supplement, Department of Treasury Acquisition Regulation (DTAR), provides for an incentive to offerors of a bonus score, not to exceed 5% of the relative importance assigned to the technical or management factors when proposals include a mentor-protégé arrangement with a small business (Department of Treasury, 2010).

2. Leverage past performance as an evaluation factor relative to the prime contractor's ability to comply with its proposed small business subcontracting goals on prior contracts similar in size, scope, and complexity.

One of the many challenges of a subcontracting requirement for large business is with regard to their efforts to follow through on their commitments. Another way of ensuring that prime contractors reach their subcontracting goals is by requesting and evaluating certified letters from previous contracts as part of their past performance evaluation. Agencies can require this as evidence to enhance the contractor's rating for any past performance evaluation factors.

According to Melissa Starinsky, former Vice-Chancellor of the VA Acquisition Academy, by giving more weight to this evaluation factor, the government can also significantly increase contractors' compliance with small business subcontracting goals. If agencies take this approach government-wide and meaningfully weigh this evaluation factor, large prime contractors will start taking the importance of small business programs more seriously. Historically, the government has approached this issue as merely a pass/fail test by incorporating the small business subcontracting plan requirement into the solicitation. All that is required in the award selection decision is that the contractors make a good faith effort with presenting its plan to satisfy the government's small business subcontracting plan goals. In reality, what actually happens during contract administration is that the government doesn't have the resources to appropriately monitor compliance with these goals and loses leverage in getting the large contractor to comply. A lack of contract administration on the part of the agency often leads to poor oversight of the prime contractor's efforts to fulfill these obligations. Alternatively, given the current shortage and workload of 1,102 series professionals, agencies should consider hiring a contractor to evaluate and audit the actual performance of subcontractors as provided in the primes' proposal.

Leveraging small business subcontracting plan compliance through past performance as a meaningful evaluation factor will go a long way in attaining compliance from the prime contractor. But, all agencies across the government need to do this for the full benefits to take effect. Also, the agency should require the contractor to certify and submit, as an annual deliverable (possibly with certification from their small businesses) that they have lived up to the goals (personal communication, M. Starinksy, January 7, 2010).

3. **Use performance-based contracting and performance incentives.**

Contract Officers can further be proactive with subcontracting accountability by withholding a small percentage (as much as 1%) of the total subcontracting dollars (versus total contract) from the contractor until they provide evidence of their subcontracting efforts. Certified letters from subcontractors can be submitted as proof that the goals were met at the end of the initial period of performance. CO's will have to ensure that this amount can be funded at the end of the period of performance in order to avoid anti-deficiency act issues.

4. **Leverage contract option clauses contingent on compliance with small business subcontracting goals.**

Similar to withholding final payment from the prime contractor, COs could decide to withhold the exercise of options until the contractor submits certified evidence that they met their subcontracting goals for the preceding period of performance as stated in their proposals. This places the onus on the contractor for reporting and deliverables because it is a challenge for COs to monitor their performance. This requirement should be built into the solicitation along with a clearly defined time period by which the government will accept evidence to support their outcome. Perhaps as part of the deliverables, the contractor could be held to an annual presentation to demonstrate their results for subcontracting goals.

100% Set-Aside Government-Wide Acquisition Contracts

While small businesses set a record in earning prime federal contracts in 2008, collectively, agencies are not reaching their combined goal of 23% (Hubler, 2009). In an effort to reach small business goals, several agencies have successfully launched Government-wide Acquisition Contracts (GWAC's) that are 100% set aside for small businesses. GWAC's are similar to Strategic Sourcing contract vehicles in that they are competitively awarded multiple award contracts that take the form of an IDIQ contract method and permit ordering from other agencies.

In 2006, the SBA published a report stating that these contract vehicles are increasing the total percentage of contracting with small businesses. As GWAC spending increases amongst all federal agencies, the percent of small business participation has been 32% between FY 1995 and FY 2004. Further, the SBA determined that "in FY 2004, approximately one out of every three GWAC dollars was spent through small firms" ("Impact of Government-Wide", 2009).

Conclusion

In conclusion, the Obama administration continues to look for ways to decrease the baseline contract spending for existing contracts and acquisition practices by 7% by the end of FY 2011 (Orszag, 2009). While Strategic Sourcing was formally introduced in 2005, trends are pointing toward further spending analyses in order for agencies to further reduce contract costs, yet continue to procure needed commodities and services more efficiently and effectively. In striving to become the "best customer," the federal government can consolidate requirements to leverage their buying power in order to negotiate better pricing and performance. If managed appropriately, agencies can meet their socioeconomic goals and avoid contract bundling, all the while maximizing competition to its fullest extent possible.

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Implementation of the Department of Defense Small Business Innovation Research Commercialization Pilot Program: Be All You Can Be?

Max Kidalov—Assistant Professor, Procurement Law & Policy, NPS, and Member, Small Business Advisory Council, U.S. Department of Energy. Mr. Kidalov graduated with a BS (cum laude) and JD from the University of South Carolina. For over three years during his prior service as Counsel for Procurement, Innovation, and Oversight Matters at the U.S. Senate Committee on Small Business & Entrepreneurship, then chaired by Senator Olympia J. Snowe (R-ME), Mr. Kidalov's responsibilities included oversight of federal small business contracting and subcontracting programs, as well as oversight of U.S. international trade agreements related to government procurement that affected small businesses. He also was a law clerk to the Honorable Loren A. Smith, formerly chief judge of the U.S. Court of Federal Claims.

Kevin Hettinger

Mario Gonzalez

Abstract

In Section 252 of the National Defense Authorization Act for Fiscal 2006, Congress adopted four wide-ranging reforms to the Department of Defense Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) programs in order to increase the effectiveness of SBIR and STTR for both the DoD and the defense industry. First, Section 252 directed closer alignment between R&D and acquisition goals of SBIR and STTR. Second, Section 252 authorized and funded creation by the Department of Defense (DoD) and the military Services of the Commercialization Pilot Program (CPP) to facilitate transition of SBIR technologies into the acquisition process. Congress conditioned the use of CPP funds on detailed evaluative reporting to Congress. Third, Congress codified into statutory law President George W. Bush's Executive Order No. 13329, which incentivized manufacturing technologies through the SBIR and STTR programs. Fourth, Congress clarified the authority to conduct testing and evaluation of SBIR and STTR technologies in SBIR and STTR Phases II and III. The implementation requirements were specified in the text of Section 252 and the Congressional Guidance Letter issued by the House and the Senate Small Business Committees.

This study analyzes the implementation of Section 252 by the Secretaries of Defense, the Army, the Navy, and the Air Force. It reflects the results of literature review and a survey of SBIR and STTR program executives. The study questions are based on Section 252 text and the Congressional Guidance Letter, as well as on best practices identified in relevant academic and professional literature. The study finds that although the DoD and the military departments have begun implementation of the DoD SBIR CPP program and other Section 252 reforms, progress is uneven. Specifically, agencies are not implementing Section 252 CPP incentives and R&D alignment requirements to the fullest extent possible. The study recommends clarifications of legislative requirements and additional review of Section 252 implementation.

Introduction

The U.S. Department of Defense spends close to $1.5 billion a year on competitive R&D set-asides under the Small Business Innovation Research (SBIR) and the Small Business Technology Transfer (STTR) programs, established under 15 U.S.C. § 638. These competitive set-asides are designed to help small firms investigate ideas for new technologies (Phase I) and develop prototypes (Phase II). Congress intended that new technologies will be commercialized either through the federal procurement process or in private markets. To encourage return on SBIR and STTR investment, Congress directed federal agencies to purchase products and services developed through SBIR and STTR to the maximum extent practicable, and authorized government agencies to buy SBIR and STTR technologies from SBIR and STTR awardees (or their successor firms) on a sole-source basis. In recent years, however, both Congress and industry have grown increasingly frustrated with the low utilization of SBIR and STTR-developed technologies in DoD acquisition, especially in major defense acquisition programs.

In Section 252 of the National Defense Authorization Act for Fiscal 2006, "Research and Developments Efforts for Purposes of Small Business Research," Congress adopted four wide-ranging reforms to the DoD SBIR and STTR programs in order to increase the effectiveness of SBIR and STTR for both the DoD and the defense industry. First, Section 252 directed closer alignment between R&D and acquisition goals of SBIR and STTR. Second, Section 252 authorized and funded creation by the DoD and the military Services of the Commercialization Pilot Program (CPP) to facilitate transition of SBIR technologies into the acquisition process. Congress conditioned the use of CPP funds on detailed evaluative reporting to Congress. Third, Congress codified into statutory law President George W. Bush's Executive Order No. 13329, Encouraging Innovation in Manufacturing, which incentivized manufacturing technologies through the SBIR and STTR programs. Fourth, Congress clarified the authority to conduct testing and evaluation of SBIR and STTR technologies in SBIR and STTR Phases II and III. The implementation requirements were specified in the text of Section 252 and the Congressional Guidance Letter, issued by the House and the Senate Small Business Committees.

This paper analyzes the implementation of Section 252 by the Secretaries of Defense, the Army, the Navy, and the Air Force. It reflects the results of literature review and a survey of SBIR and STTR program executives The study questions are based on Section 252 text and the Congressional Guidance Letter. Study questions also rely on best practices identified in relevant academic and professional literature, in innovation programs of other federal agencies such as NASA, and in practices of our NATO partners such as the United Kingdom and France. The study finds that while the DoD and the military departments have begun implementation of the DoD SBIR CPP program and other Section 252 reforms, progress is uneven. Specifically, agencies are not implementing section 252 CPP incentives and R&D alignment requirements to the fullest extent possible. The study recommends clarifications of legislative requirements and additional review of Section 252 implementation.

The following section, Background of the SBIR and STTR Programs, gives general background information about SBIR and STTR. The section describes the programs objectives. It also describes firms' eligibility requirements to participate in the each program. A list of participating government agencies is also in this section. A description of each of the three phases for the programs is given at the end of this section.

Next, the section titled Background of FY06 NDAA Section 252 delves into specific background of Section 252, including details from National Academies Symposium, *SBIR and the Phase III Challenge of Commercialization*. Following that symposium, "the Senate Committee on Small Business & Entrepreneurship proposed legislation that called for a commercialization pilot program" (NAS, 2005, p. 29, footnote 23). The purpose of this section is to give the reader an idea of the SBIR and STTR program conditions prior to Section 252 by putting it in context. After reading this section, the reader should understand the reasons why Congress adopted Section 252.

A survey was conducted, directed primarily at SBIR and STTR program managers and administrators within DoD agencies and military Services, that attempted to ascertain how Section 252 has been carried out within these specific agencies. The Survey Methodology section describes in detail the methods we used. This section clearly states the survey questions that were given to participants. This section also describes limitations identified by the survey administrators.

The analysis section the paper describes results from this survey. All of the respondents' answers for each question are analyzed and compared with the Section 252 legislation, the Congressional Guidance Letter, as well as with additional sources. The survey answers, in many cases, showed inconsistencies with the intent of the legislation as well as with announced practices.

Finally, the paper concludes with answers to the research questions and the authors' recommendations.

Background of the SBIR and STTR Programs

The DoD SBIR program awards contracts to qualifying small businesses that display the promise of producing cutting-edge technology for military or dual-use applications. The technology may show promise, but that technology may still be too risky for private investment due to various reasons such as a relatively low technological readiness level and no past performance history for the company (Wessner, 2007). Therefore, an SBIR contract can act as initial funding to get what amounts to an idea developed into a product or service. The SBIR program began pursuant to the Small Business Innovation Act of 1982. The STTR program began pursuant to the Small Business Technology Transfer Act of 1992. SBIR and STTR have no permanent reauthorization, but have been periodically reauthorized since then. The main difference between SBIR and STTR is that SBIR contracts are open solely to small businesses, defined as businesses with less than 500 employees, and STTR contracts are open to small businesses that collaborate with not-for-profit research organizations such as universities and federally funded research and development centers ("SBIR and STTR Policy Directives," 2002a, 2002b).

As stated in the Small Business Innovation Act (1982), the SBIR and STTR programs have four goals:

1. to stimulate technological innovation;
2. to use small business to meet federal and development needs;
3. foster and encourage participation by minority and disadvantaged persons in technological innovation; and
4. to increase private sector commercialization derived from federal research and development. (p. 1)

The forth objective, commercialization, is defined by the U.S. Small Business Administration as “the process of developing marketable products or services and producing and delivering products or services for sale (whether by the originating party or by others) to Government or commercial markets” (“SBIR and STTR Policy Directives,” 2002a).

Federal agencies with extramural R&D budgets of at least $100 million are required to participate in SBIR. Federal agencies with extramural R&D budgets of at $1 billion are required to participate in STTR. Participating agencies are required to set aside 2.5% and 0.3% of their R&D budgets for SBIR and STTR programs, respectively.[1] Within the DoD, each military department as well as the Defense Advance Research Projects Agency (DARPA) and the Missile Defense Agency (MDA) administer their own SBIR/STTR programs. Seven agencies under the Office of the Secretary of Defense (OSD) administer the SBIR programs, but not STTR, including the Defense Logistics Agency (DLA), the Defense Microelectronics Activity (DMEA), the Defense Technical Information Center (DTIC), the Defense Threat Reduction Agency (DTRA), the Chemical and Biological Defense Program (CBDP), the Special Operations Acquisitions and Logistics Center (SOALC), and the National Geospatial-Intelligence Agency (NGA).

The DoD SBIR/STTR awards processes are divided into three phases. In Phase I, small businesses compete on SBIR/STTR topics that are published by the DoD. The DoD announces SBIR topics three times a year and STTR topics twice a year. Small businesses that earn Phase I contracts can generally be awarded up to $150,000[2] while participating in SBIR and up to $100,000 while participating in STTR (“SBIR and STTR Policy Directives,” 2002b). The purpose of Phase I is “for determining, insofar as possible, the scientific and technical merit and feasibility of ideas that appear to have commercial potential, as described in subparagraph (B), submitted pursuant to SBIR program solicitations.”[3] Phase I awardees can be awarded up to $1 million for SBIR and $750,000 for STTR in a Phase II contract. The purpose of Phase II is “to further develop proposed ideas to meet particular program needs, in which awards shall be made based on the scientific, technical, and commercial merit and feasibility of the idea, as evidenced by the first phase and by other relevant information.”[4]

Phase III is considered the commercialization phase. This is the step in which only non-SBIR/STTR funds, typically from private-sector investment or defense acquisition funds can be used to develop an actual product or service. In some cases, enough work can be completed in Phase I or II to satisfy a program office.

> Phase III refers to work that derives from, extends, or logically concludes effort(s) performed under prior SBIR funding agreements, but is funded by sources other than the SBIR Program. Phase III work is typically oriented towards commercialization of SBIR research or technology” . . . but may also include continuation of R&D. “Phase III work may be for products, production, services, R/ R&D, or any combination thereof.” “For Phase III, Congress intends that agencies or their Government-owned, contractor-operated facilities, Federally-funded research and development centers, or Government prime contractors that

[1] The Statute is 15 U.S.C. 638.

[2] *Federal Register*, Volume 75, page 15,756.

[3] U.S.C., Title 15, 638.

[4] U.S.C., Title 15, 638.

> pursue R/R&D or production developed under the SBIR Program, give preference, including sole source awards, to the awardee that developed the technology. In fact, the Act requires reporting to SBA of all instances in which an agency pursues research, development, or production of a technology developed by an SBIR awardee, with a concern other than the one that developed the SBIR technology." "This notification must include, at a minimum: (a) The reasons why the follow-on funding agreement with the SBIR awardee is not practicable; (b) the identity of the entity with which the agency intends to make an award to perform research, development, or production; and (c) a description of the type of funding award under which the research, development, or production will be obtained." SBA may appeal that decision. Other cases, SBIR/STTR projects cannot cross the funding "valley of death" between Phase II and commercialization. (NAS, 2005, pp. 5–6)

Background of FY06 NDAA Section 252

The purpose of Section 252 of the National Defense Authorization Act for 2006 was to reform SBIR and STTR. Section 252 mostly addresses issues within the SBIR program, but does refer to STTR. The reason why the Congressional and Senate Small Business Committees are concerned with the state of SBIR and STTR is they believe that leveraging the innovation of small businesses is vital for the U.S.'s national security. They also view Phase I and Phase II contract awards as investments of taxpayer dollars. Attempting to reform SBIR and STTR Section 252 added the following subsections to Section 9 of the Small Business Act: (x) Research and Development Focus; (y) Commercialization Pilot Program, language concerning Implementation of Executive Order No. 13329; and subsection (e)(9) language supporting testing and evaluation of SBIR and STTR technologies. Each of these subsections is meant to address challenges that have been identified within the SBIR and STTR communities by the National Academies Symposium on SBIR commercialization and other inputs from government and industry. These challenges include SBIR and STTR topic alignment, expediting the commercialization of SBIR and STTR projects and assurance that Executive Order No. 13329 is being implemented.

Reform 1: SBIR Topics Generation

Subsection (x) Research and Development Focus mandates that the Secretary of Defense (SECDEF) will engage in a Quadrennial SBIR/STTR Review in order to revise and update the criteria and procedures utilized to identify research and development efforts that are suitable for SBIR and STTR programs at least once every four years. According to the Congressional Guidance Letter, subsection (x) "addresses the need for a strategic, DoD-wide review of the SBIR and STTR program (conducted not less than quadrennially) based on the latest research, science, and technology plans of the DoD," and based on the Joint Warfighting Science and Technology Plan, the Defense Technology Area Plan, and the Basic Research Plan. Each of these plans has a specific emphasis: joint warfighter operations, DoD-wide acquisition program priorities, and strategically disruptive/revolutionary technologies. Together, these plans were to focus research and development efforts within the DoD SBIR and STTR to specific areas previously identified of strategic importance to warfighting efforts. At the same time, subsection (x) also mandates that program managers and program executive officers be included during topic generation. If an SBIR/STTR project is not aligned with an acquisition program to fill in technological gaps, then it is unlikely to attract those kinds of funds. Therefore, early involvement from program offices is essential.

Reform 2: Commercialization Pilot Program

Next, subsection (y) authorizes the Secretary of Defense and each military department secretary to create a Commercialization Pilot Program (CPP). The CPP's stated intent is to "accelerate the transition of SBIR technologies into Phase III including acquisition process." If a department decides to create a CPP, then the department must adhere to all the requirements within subsection (y). These requirements include that the SECDEF and the secretary of each military department must identify SBIR projects that show potential for rapid transition into Phase III and certify in writing that the identified projects will meet high priorities within that military Service. Each military department is authorized to use up to 1% of available SBIR funds to administer the CPP, but cannot be used to award Phase III contracts. Subsection (y) also mandates that the SECDEF must provide an evaluative report to the Committee on Armed Services and the Committee on Small Business and Entrepreneurship of the Senate and the Committee on Armed Services and the Committee on Small Business of the House of Representatives. This report must contain an accounting of funds, description of incentives and activities performed under the CPP, and results achieved under the CPP.

The origin of the CPP came from the 2005 National Academies SBIR Transition Symposium. This symposium was a gathering of leadership from government agencies, large defense contractors (prime contractors), and small businesses. During the symposium, representatives from each discussed challenges of commercialization from their own point of view. Policy reform recommendations at the symposium generally fell within two categories: (1) "possible changes in agency program management, including better use of incentives for managers, roadmaps, and greater matchmaking, and (2) ways in which small businesses and the prime contractors could better align their work to improve Phase III outcomes" (NAS, 2005, p. 23).

While focusing on the "incentives for better management" the intent was to incentivize program managers and program executive officers to introduce new technologies that can result not only in substantial time, cost, or performance benefits, but also can present some risk of disruption to program costs and schedules if the technologies failed. Leading government officials, industry executive, and policy experts proposed various incentives for better SBIR program management. For example, incentives were proposed in the following areas:

- **Alignment.** Entering the SBIR company into a program with which the program executive officer was already engaged is one way to better focus SBIR projects on outcomes that directly support agency programs (and program officer) objectives. As noted by some speakers, this could allow SBIR projects to connect with Phase III activities already under way.
- **Reliability.** This involves identifying technologies that have been operationally tested and need little if any modification. This suggestion by a participant reflected widely held views that program executive officer involvement was critical in bringing SBIR technologies to the necessary readiness level.
- **Capacity.** As Dr. Michael McGrath, Deputy Assistant Secretary of the Navy for Research, Development, Testing, and Evaluation, noted, SBIR firms need

to take steps to convince program executive officers not only that the SBIR technology works, but also that the small business will be able to produce it to scale and on time.

- **Budget Integration.** Some participants noted that program executive officers needed to see that the SBIR set-aside will be used to further their own missions. This calls for building SBIR research into the work and budget of program offices. By contrast, the Air Force's program offices submit a budget based on independent cost estimates. SBIR awards are then taken as a 2.5% tax out of that budget.
- **Training.** Major Stephen noted that training program executive officers to help them understand how SBIR can be leveraged to realize their mission goals is necessary. However, Mr. Carroll of Innovative Defense Strategies noted that SBIR training had been part of the general program executive officer training curriculum for one year, but had since been deleted.
- **Partnering.** As described by Carl Ray, the SBIR program at NASA is forming partnerships with mission directorates aimed at enhancing "spinin" — the take-up of SBIR technologies by NASA programs.
- **Emphasizing Opportunity.** Dr. McGrath noted that the Navy's SBIR management attempts to provide a consistent message to program executive officers and program managers—that "SBIR provides money and opportunity to fill R&D gaps in the program. Apply that money and innovation to your most urgent needs." (NAS, 2005, pp. 23–24)

With respect to the roadmaps, "some participants emphasized the need to coordinate small business activities with prime contractor project roadmaps." This is due to the complexities involved in integrating subsystems that are SBIR candidates into large weapon systems that prime contractors act as lead integrators.

> Lockheed's Mr. Ramirez noted that "to make successful transitions to Phase III, SBIR technologies must be integrated into an overall roadmap." Lockheed Martin uses a variety of roadmaps to that end, including both technical capability roadmaps and corporate technology roadmaps. The Raytheon representative added that roadmaps are important because it is necessary to coordinate the technology transition process across the customer, the supply chain, and small businesses. Coordination should include advanced technology demonstrations, which could be used to integrate multiple technologies into a complex system. (NAS, 2005, pp. 24–25)

Ultimately, all symposium participants agreed that the transition to commercialization needed to be reformed. SBIR technologies need buy-in from program managers and prime contractors, and the attitude of SBIR being a "tax" on acquisition and R&D programs funding needed to change. Statements at the NAS Symposium provided examples of incentive strategies needed to effect such a change. Mr. Robert McNamara of the Navy, Program Executive Officer for PEO Submarines, described himself as an advocate of small business and said that the centerpiece of his advocacy was the SBIR program. In his Requests for Proposals (RFPs), he incentivizes primes to subcontract certain percentages of the work to small business.

For example, he contracted with General Dynamics on the Virginia-Class Program, demonstrating that small businesses are a high priority, and offered a million-dollar "bounty" per hull as an additional incentive fee for contractors who met small business subcontracting goals. The Navy owes it to the large prime contractors, he said, to provide real incentives for a policy considered truly important (NAS, 2005, p. 142).

Col. Stephen, U.S. Air Force, suggested that in order to gain buy-in, the program should be sure to focus not only on research but also on the results that program managers need—outputs that directly support agency objectives. Dr. Parmentola agreed, saying that program managers want technologies that have been operationally tested and require little, if any, modification. Section 252 makes provisions for testing and evaluation. Opening the SBIR program to test and evaluation is an incentive for PMs because results from T&E may be used to gauge the TRL of a SBIR project. As stated by participants, the TRL is more important to PMs than ongoing research.

This need for meaningful incentives was also reiterated by prime contractors. Prime contractors represented at the conference stated that they have focused management attention, shifted resources, and assigned responsibilities within their own management structures to capitalize on the creativity of SBIR firms and promote greater testing and evaluation (NAS, 2005, p. 28). Lockheed Martin also intended to build more formal business relationships with its small businesses, which are critical to successful Phase III transitions. This process must begin with joint visits to customers, when both sides can discuss product discriminators, areas for further investigation, and collaboration within Lockheed's own Independent Research and Development (IR&D) and Cooperative Research and Development Agreement (CRADA) technology culture. These relationships would also help integrate the SBIR technologies and firms and allow Lockheed to demonstrate its successes and build formal partnerships.

During the symposium, Dr. Kidalov, from the Senate Small Business Committee, lead a panel discussion on incentives for contracting with SBIR firms. Dr. Kidalov noted that in his experience, large prime contractors needed a champion, a corporate strategy, and incentives to continue using SBIR firms. He noted that these incentives need to go beyond the competitive advantages they provide. Dr. Kidalov asked the question of whether or not the panelists saw value in a system that would allow for recognition of efforts to contract with SBIR firms, perhaps from Congress and the government agencies. All panelists agreed.

Specifically, in response, a Boeing representative pointed out that incentives are built into contracts when agencies award them for many reasons, such as schedule and budget. He was pointing out that it should be possible to include similar incentives, such as those for working with SBIR firms. An ATK representative agreed that incentives were essential because primes, like PMs, were risk adverse by nature. Incentives would encourage them to take those risks.

A Raytheon representative was more specific in response to the question posed by Dr. Kidalov. He stated three incentives that would help the case to use SBIR firms. First, to streamline and otherwise optimize the SBIR process, which in turn would ensure the development of many technologies needed for the long term. Second, an assurance that customers have realistic plans to support the transition from Phase II through Phase III. Third, was an incentive that SBIR firms help meet the requirement to work with small disadvantaged businesses (NAS, 2005, p. 82).

Reform 3: Encouraging Innovation in Manufacturing

Section 252 mandates the full implementation of Executive Order No. 13329. The impact of Section 252 is that future presidential administrations cannot ignore this order.

Executive Order No. 13329 was issued on February 24, 2004, by President George W. Bush. The goal of the order is outlined in the Introduction section, which stresses the importance of the federal government's role in encouraging technological innovation in the U.S. economy. As part of that encouragement, the order specifically tasks the SBIR and SBTT programs with "helping to advance innovation, including innovation in manufacturing, through small businesses" (Executive Order No. 13329, 2004, section 1). The executive order required that heads of departments and agencies that have an SBIR or STTR program "give high priority within such programs to manufacturing-related research and development" (Executive Order No. 13329, 2004, section 2). The order places on department and agency heads a requirement to provide an annual report to the Small Business Administration and to the Director of the White House Office of Science and Technology Policy in which they are to report on their efforts in meeting this order.

An impact of the executive order issuance was that the U.S. Small Business Administration proposed amendments to the SBIR Policy Directive on May 19, 2005, to incorporate the goals of the executive order. Although the amendments to this policy directive were not finalized, the agencies themselves established their own implementation plans.[5]

Reform 4: Enhanced Testing & Evaluation

In order to address another issue that impairs SBIR projects from transitioning to Phase III, Section 252 clarifies the definition of what constitutes a commercial application. The clarification was necessary in order to remove barriers imposed by overly restrictive interpretations of Phase II and Phase III requirements. Therefore, the definition of a "commercial application" was expanded to include test and evaluation of products, services, or technologies for use in technical or weapons systems, and, further, awards for testing and evaluation of products, services, or technologies for use in technical or weapons systems may be made in either the second or the third phase of the SBIR and SBTT programs.[6]

Survey Methodology

Survey Goals

In order to access effectiveness of efforts designed to increase Phase III implementation success rates, especially in regard to the development of Commercialization Pilot Projects (CPP), input was sought from program managers and experts within the military departments who are involved with the Small Business Innovation Research (SBIR) program. We asked 102 individuals to complete an online survey. The aim of the survey was to document the agency implementations and practice in regard to the Commercialization Pilot Program and other Section 252 reforms. With this information, it was then possible to identify what was being done to implement Section 252 and how each agency worked to meet the congressional intent of the CPP.

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[5] For example, the Air Force, Navy, and Army have all issued directives for implementation.

[6] See Section 252 of H.R 1815.

Survey Design

The survey focuses on seven main research questions from the Congressional Guidance Letter to USD(AT&L) Kenneth J. Krieg.

1. How did the DoD implement the new requirement in Section 252(a) for research focus of its SBIR and STTR programs?
2. How did the DoD and each military department plan to involve acquisition program managers and program executive offices in SBIR/STTR topic selection and management to ensure that SBIR/STTR is integrated into the DoD's mission and its acquisition framework, as contemplated in Section 252(a), SBIR Commercialization Pilot Program, and Section 252(c), inclusion of testing and evaluation works as part of SBIR/STTR commercialization activity?
3. How did the DoD and each military department's acquisition program managers and program executive officers plan for post-SBIR/STTR funding, through the Program Objective Memoranda and other vehicles, to utilize SBIR/STTR technology resources in their acquisition process, as stated in Section 252(a), SBIR Commercialization Pilot Program?
4. How did the DoD and each military department plan and implement the SBIR Commercialization Pilot Program, and specifically what processes did these military Services and defense agencies develop and implement to ensure identification of optimal SBIR/STTR Phase I–II projects for accelerated transition through this pilot program?
5. What acquisition incentives and activities did the DoD and each military department deploy to accelerate the transition of SBIR/STTR technologies into the acquisition process though the pilot program?
6. What specific reporting requirements did the DoD and each military department impose on acquisition program managers, program executive officers, and prime contractors as part of the annual evaluative report to Congress, as outlined in Section 252(a)?
7. How did the DoD and each military department implement Executive Order No. 13329, Encouraging Innovation In Manufacturing, codified into law as part of Section 252(b)?

Survey Scoring

Respondents were asked two types of question: those requiring a positive or negative response or those requesting a response using a rating scale.

Respondents were also given the option of choosing, "Don't Know" or "Not Applicable."

Survey Subjects

All DoD agencies and departments participating in SBIR and STTR were asked to participate in the survey. Each point of contact was sent an e-mail with a request to participate in the survey and a link to the SurveyMonkey.com website where the online survey was posted. To refresh respondents recollection, the survey was supplemented with the text of the act and a copy of the Congressional Guidance Letter, issued jointly by the Chair and Ranking Minority Member of the Senate Committee on Small Business and Entrepreneurship and the Chair of the House Committee on Small Business. Point of contacts may have assigned additional respondents within their agency. Respondents were asked to identify their agency. Respondents' names and position within their agency were not collected.

Survey Limitations

The survey was primarily intended to ask responsible agency officials to identify practices and polices related to the reforms adopted by Congress and outlined in Section 252.

The data collected in the survey is therefore the primary source of the conclusions presented. No respondent actually completed the survey in total. This was partly by design, as a large number of the survey questions were only presented to the respondent depending on the previous answer.

The conclusions discussed in the following sections are based on results obtained when multiple responders provided the answers to the question being asked supplemented by reviews of publications and academic literature.

Survey Results and Analysis

Response Rate and Background Results

Organizations Participating and Background

We asked 102 individuals to complete the online survey. Of those 102, 19 responses were received, with the largest number of participants identified as being from Air Force organizations.

Partly as a result of the design of the survey to adjust the questions asked depending on the response to previous questions, no one participant completed all 30 questions within the survey.

The organizations responding and their response rates are shown in Table 1.

Table 1. Response by Organization

Invited Participant Organization	Participated?	Number of Responses
Office of the Secretary of Defense/Office of Small Business Programs	No	0
Army	No	0
Navy	Yes	3
Air Force	Yes	4
Missile Defense Agency	No	0
National Geospatial Intelligence Agency	Yes	1
Joint Science and Technology Office for Chemical and Biological Defense	No	0
Defense Advanced Research Projects Agency	No	0
Defense Microelectronics Activity	No	0
Defense Logistics Agency	No	0
Defense Threat Reduction Agency	No	0
Office of the Deputy Under Secretary of Defense (Science and Technology)	No	0
U.S. Special Operations Command	No	0
Commercialization Pilot Program Implementing Contractor – Army	No	0
Commercialization Pilot Program Implementing Contractor - Navy	No	0
Total Responses	3	8

Organizational Alignment of Regulations, Policies, and Procedures With SBIR and STTR Research Focus

Alignment of SBIR/STTR Topics With DoD Research Plans

Given an opportunity to respond to a question regarding the adoption of regulations, policies, or procedures necessary for compliance with the requirement in Section 252 for alignment of SBIR and STTR research topics with those set forth in the Joint Warfighting Science and Technology Plan, the Defense Technology Area Plan, and the Basis Research Plan of the Department of Defense, 50% of the respondents for the organization responded that their organization was not in alignment with the plan (Figure 1).

Of the respondents, 37.5% gave an affirmative response that their organization was in alignment with the plan.

There were 12.5% of the respondents who answered that they did not know if they had institutionalized SBIR/STTR topic alignment with the Section 252–identified DoD research plans in their organization.

When the results are broken down by organization (Figure 2), the Navy response indicated that it was more in compliance than any other agency, and the Air Force the least. Overall, all responding organizations indicated that they did not have the topic alignment required by Section 252, as was outlined previously in this paper.

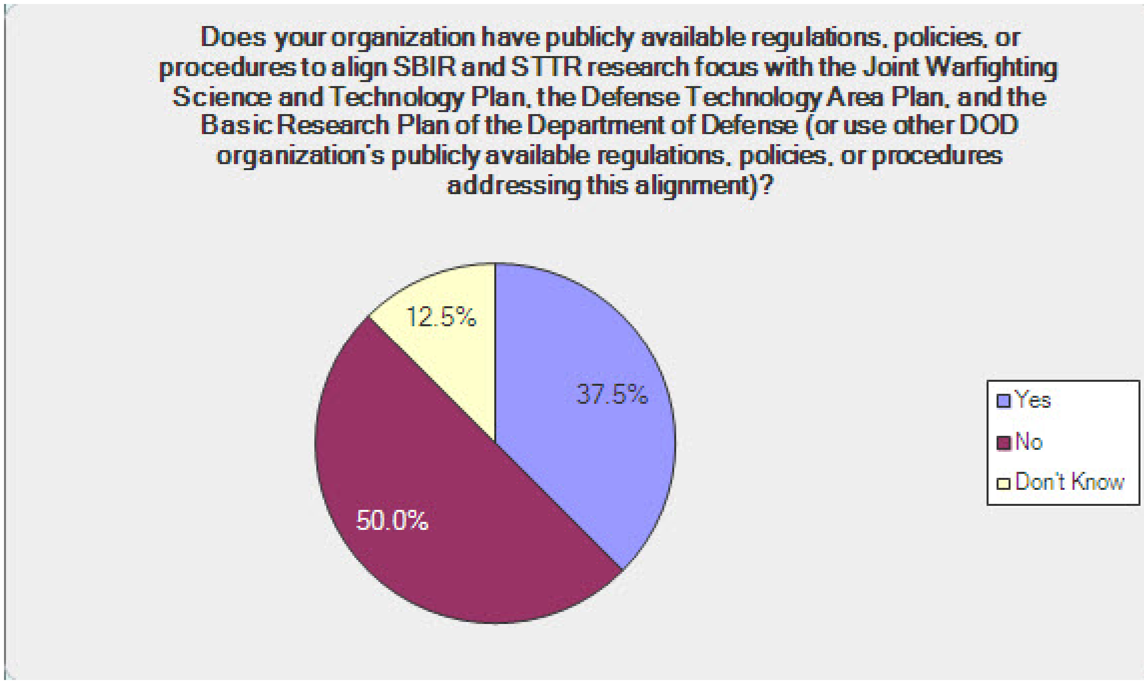

Figure 1. SBIR/STTR Policy Alignment With DoD Research Plans

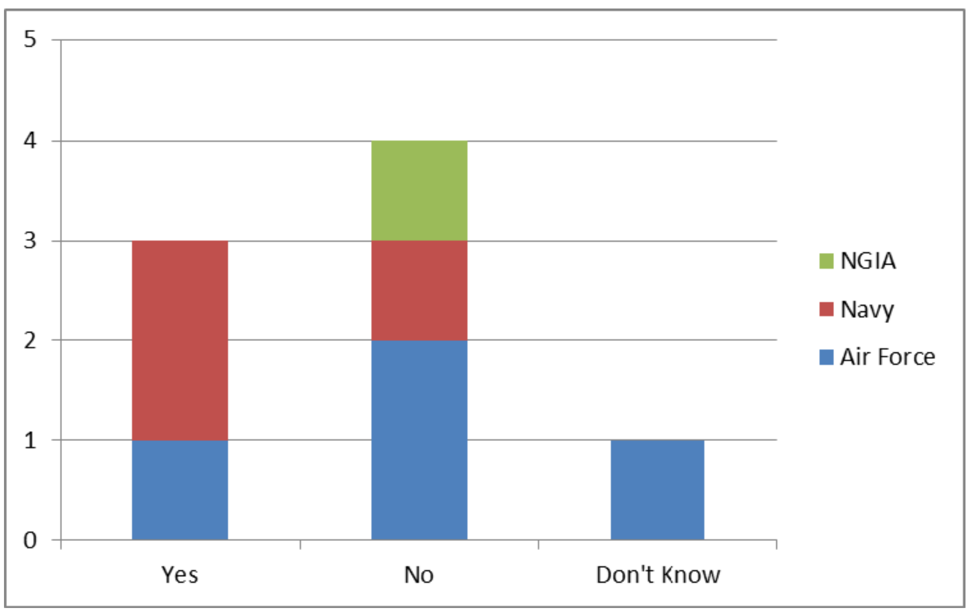

Figure 2. SBIR/STTR Policy Alignment With DoD Research Plans Response by Organization

Analysis. This finding is surprising as the Research Development Testing and Evaluation communities control the selection of SBIR/STTR topics in the Air Force (with some exception for space-related systems; GAO, 2010, p. 9), and Army, while the Navy approaches topic generation by the program offices (DoDIG, 2009). The Army and Air Force labs should be well aware of the defense science plans that are required for topic generation and the statutory requirements for generating those topics.

The conclusion that can be drawn from this data is that either the organizations are uninformed regarding the statutory alignment requirement, or they are aware but do not put the requirements in place. Further research would have to be conducted to determine which of the two conclusions is correct.

Alignment of SBIR/STTR Topics With DoD Research Plans—Program Manager/PEO Input

With a response of 50%, most respondents answered with a "not applicable" to the question as to whether there were regulations, policies, or procedures in place to provide for the input of program manager and/or program executive officers to determine the SBIR and STTR research and development (R&D) focus areas (see Figure 3).

In contrast, 37.5% of the respondents answered positively that there were regulations, policies, or procedures in place to provide input of program managers and/or program executive officers, as required by Section 252. There were 12.5% who answered that they did not know.

As shown in Figure 4, the response by organization to this question again shows the Navy indicating its compliance with Section 252, which calls for the input of program managers and program executive officers in the identification of areas of research and development of SBIR and STTR program areas of research.[7] These results mirror those of the previous question.

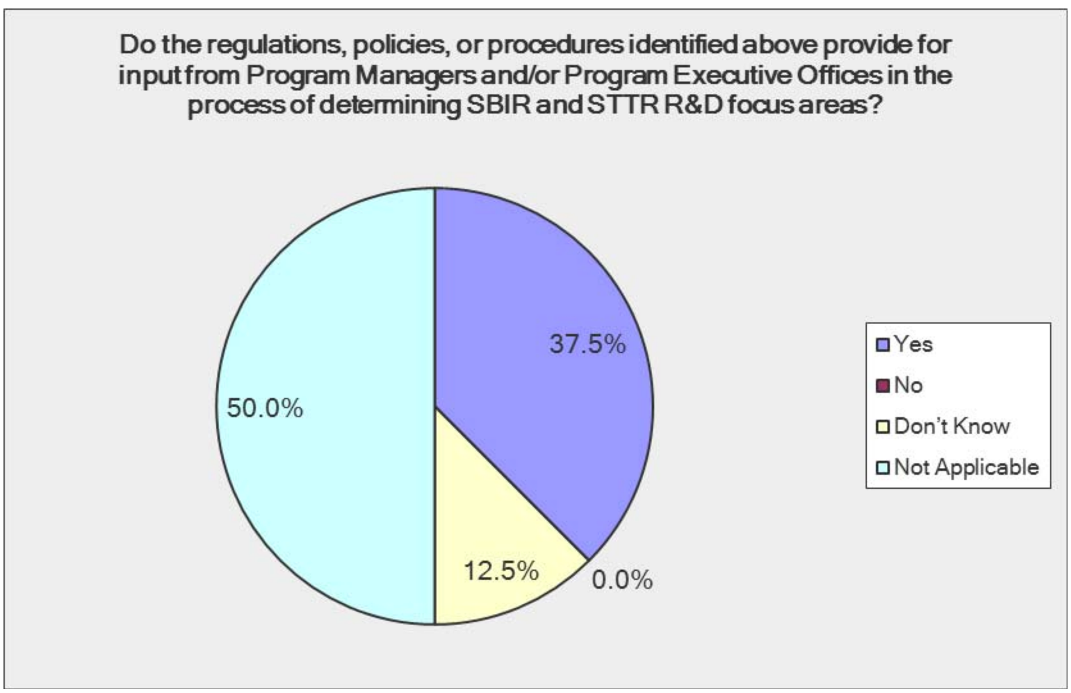

Figure 3. Program Manager/Executive Officer Input Into SBIR/STTR Focus Areas

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[7] This requirement is also more fully developed within paragraph 3 of the Congressional Guidance Letter.

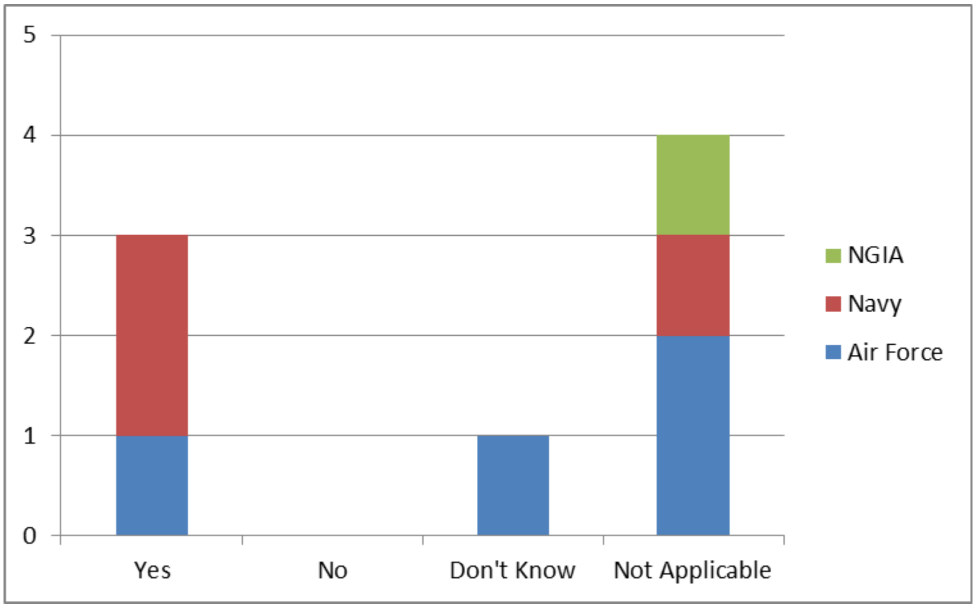

Figure 4. Program Manager/Executive Officer Input Into SBIR/STTR Focus Areas Response by Organization

Analysis. However much the response of the Navy organization shows its understanding of this section of the legislation, the overwhelming response by all organizations indicated that the involvement of program managers and program executive officers in determining focus areas was not applicable to their SBIR/STTR program implementation.

This finding is also surprising, especially since a 2006 memorandum from the Office of the Under Secretary of Defense (AT&L) issued the SBIR policy requiring "at least 50% of SBIR topics have acquisition community endorsement or sponsorship" (Krieg, 2006). As reported in the DoDIG report of January 30, 2009, which related the results of a Navy 2007 SBIR symposium, it was noted that the Navy writes SBIR topics that are closely aligned with the needs of the acquisition community for easier transitions of technology projects. As a result, Navy topics are less risky, and they transition to commercialization (Phase III) more easily then the topics developed by other means (DoDIG, 2009, p. 9). In addition to the success reported by the Navy, involvement of the acquisition community in topic generation was also recommended as a best practice in a congressionally mandated SBIR study conducted by the National Academy of Sciences (2009).

As was also noted in the DoDIG report, this requirement for involving the acquisition community members in the development of topics for SBIR/STTR projects may pose a problem for DARPA because their focus is not on "urgent needs and requirements" but rather on "radical innovations that may take years to prove feasible" (DoDIG, 2009, p. 10). Consequently, an area of further research may be how should an organization with a focus such as DARPAs participate in SBIR/STTR topic generation, and what guidelines should be provided to smooth Phase III transitions for organizations that have a similar focus?

Again, additional research would have to be conducted to determine the reasons behind these responses were (i.e., ignorance of the requirement, or disregard).

Alignment of SBIR/STTR Topics With DoD Research Plans—Quadrennial Strategic Review

With a combined response rate of 75%, most respondents answered with a “don’t know” or “never participated” response to the question as to whether there was organizational participation in a Quadrennial Strategic Review of SBIR and STTR programs in accordance with the regulations, policies, or procedures that align topics with DoD research plans and program manager/program executive officer inputs to the same (see Figure 5).

Only a quarter, 25%, indicated that in either “most instances” or in “some instances” their organization participated in these reviews as required by Section 252 (a)(1).

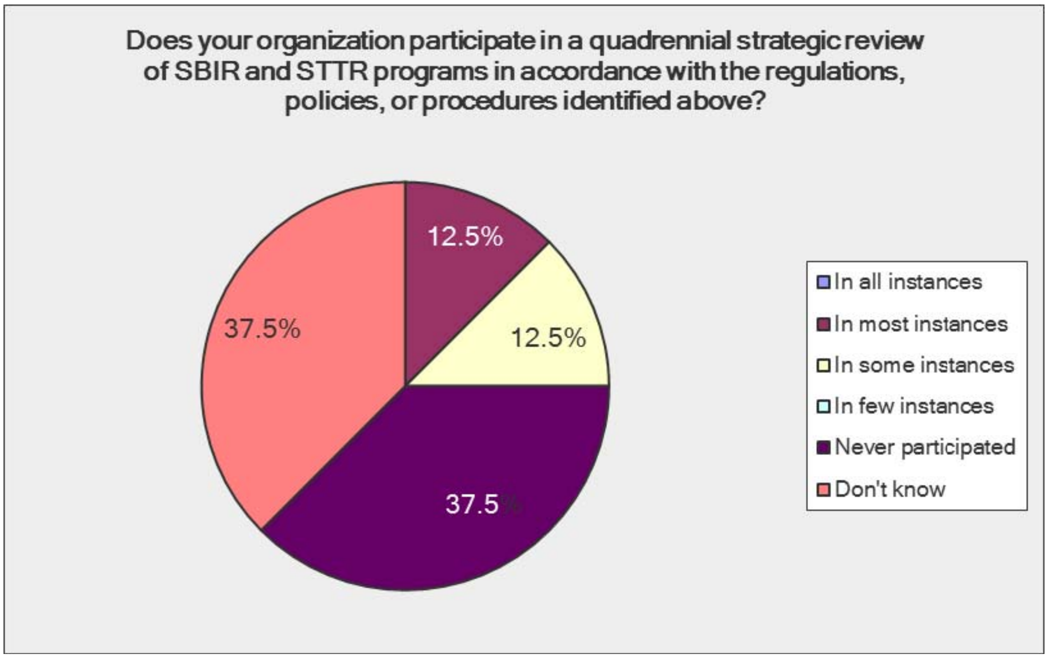

Figure 5. Response to Quadrennial Review

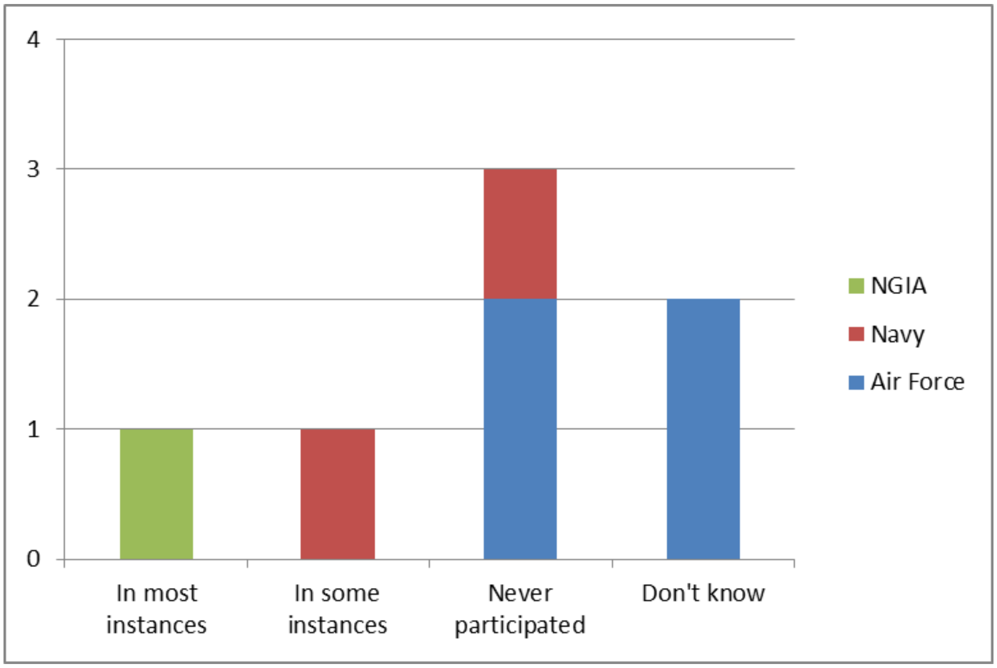

Figure 6. Response to Quadrennial Review by Responding Organization

Analysis. The organizational responses to this question were interesting. The Air Force responders either did not participate or didn't know if their organization participated in the Secretary of Defense Quadrennial Strategic Review. The Navy split between one respondent indicating that the organization had participated in some instances, and the other respondent indicated that the organization had never participated. One other Navy respondent did not provide any answer to the question.

Of interest also was the response from the NGIA, which responded that their organization participated in most instances. This response seemingly contradicts the responses from the previous questions in which they answered either in the negative or not applicable to those parts of the legislation that required alignment with DoD research plans and program manager/program executive officer input to the Quadrennial Strategic Review.

In any case, one can conclude from these results that the participation of the DoD organizations in the Secretary of Defense's Quadrennial Strategic Review of SBIR/STTR is low. Furthermore, during literature review for the purposes of this report, no information was found regarding the SBIR/STTR Quadrennial Strategic Review. This may be due to the nature of the review itself or—what is more likely in the opinion of the authors—that the Review has not been conducted as the legislation stipulates. The fact that since Section 252 was adopted, there have been two Quadrennial Defense Reviews, one in 2006 and the other in 2010, neither of which apparently had a Quadrennial Strategic Review conducted thereafter.

Creation of the Commercialization Pilot Program (CPP)

Creation of the Commercial Pilot Program (CPP)

Paragraph (y)(1) of Section 252 gives the Secretaries of Defense, Army, Navy, and Air Force the authority to create a Commercialization Pilot Program with the stated goal to "accelerate the transition of technologies, products, and services developed under the Small Business Innovation Research Program to Phase III, including the acquisition process." With a response of 62.5%, most respondents answered with an affirmative to the question as to whether their organization created the Commercialization Pilot Program (CPP; see Figure 7).

However, 25% of the respondents answered in the negative that their organization had not created the CPP, while 12.5% answered that creation of the CPP was "not applicable" to their organization.

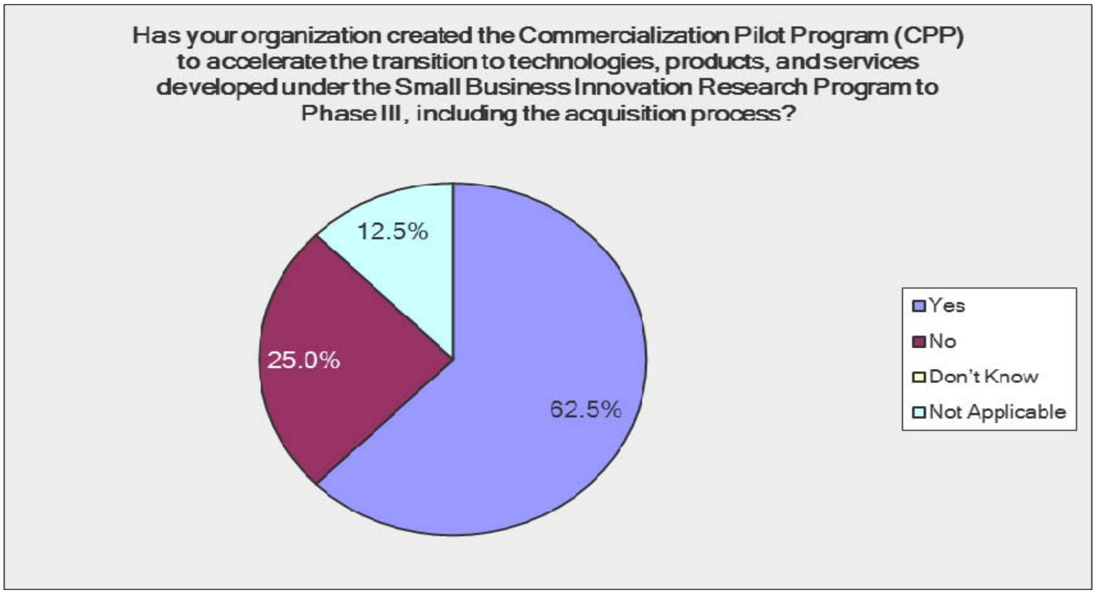

Figure 7. Response to Creation of the Commercial Pilot Program (CPP)

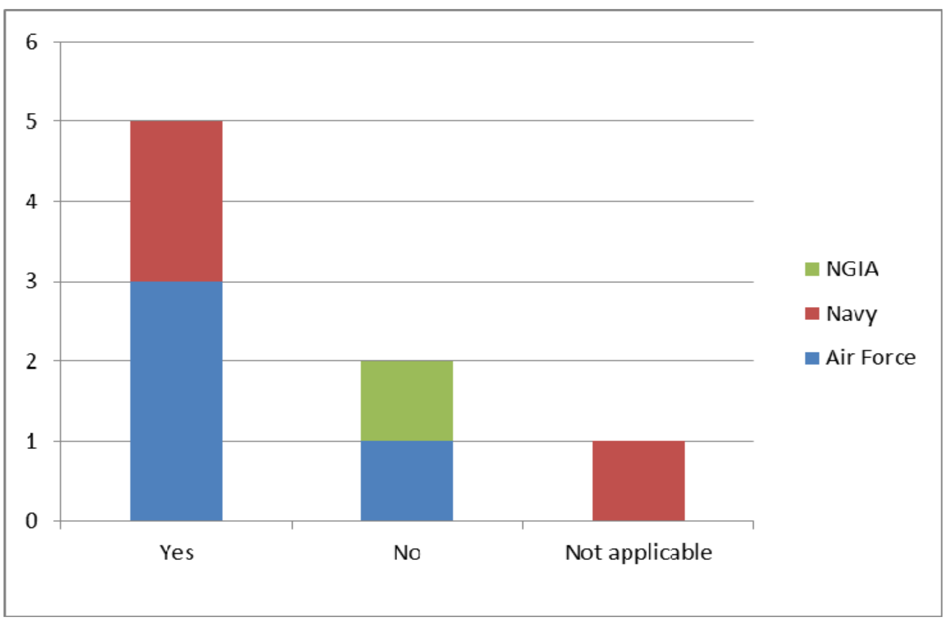

Figure 8. Response by Service to Creation of the Commercial Pilot Program (CPP)

Analysis. The majority of the military departments represented by the survey respondents indicated that they had created the Commercialization Pilot Program (CPP), with the Air Force slightly more responding in the affirmative then the Navy respondents (Figure 8).

The legislation's language allowed the departments to create this program; they were not required to do so by the legislation. However, if they did choose to create the CPP program, there were specific requirements that had to be followed because the CPP is self-funding. Whether the requirements were followed forms the basis for the next questions in this section.

In the case of the Navy, whether the CPP was created as a separate program is a subject of some conjecture. In a report done by the Navy SBIR program office titled *A Report on the Navy SBIR Program: Best Practices, Roadblocks, and Recommendations for Technology Transition* and released in 2008, it was stated, "One could argue that the Navy's SBIR program already meets the intent of the CPP legislation and we should continue business as usual" (Navy Small Business Innovation Research Program Office, 2008, p. iii). That study stated that the Navy's Transition Assistance Program (TAP) assists SBIR/STTR participates and helps to meet knowledge and support gaps by providing support to these program participants within Phase II in order "to help the SBIR firm delivery [sic] a technology product to DoD and the Navy" (p. 35).

In any case, the Navy does have what it calls "Phase II.5," which includes the TAP and refers to it as a CPP program (http://www.navysbir.com/cpp.htm). It utilizes self-funding set-asides for the CPP to pay for the Transition Assistance Program and has the System Command (SYSCOM) SBIR transition manager making the determination as to which firm gets invited to participate. In addition, each SYSCOM has its award structure and requirements to receive be selected for Phase II.5.

This paper does not attempt to make any determination as to whether the Navy SBIR program with the TAP and Phase II.5 component included does or does not meet the definition of the CPP; it is clear from the evidence presented previously that the Navy believes that this is the case. Rather, the presence of the TAP program may be confused with the CPP, which is why the Navy response seems to contradict itself. This, however, is not a sematic issue, as Section 252 has specific conditions on the usage of CPP funds.

In addition to the Air Force and Navy creation of the CPP, the Army, the Missile Defense Agency, and the Joint Science & Technology Office for Chemical and Biological Defense (JSTO–CBD), created CPP programs.

Commercial Pilot Program (CPP)—Identification of Projects for Rapid Transitioning Through CPP

With a response of 62.5%, most respondents answered with an affirmative to the question as to whether their organization had formal processes or procedures for the identification of optimal SBIR Phase I or Phase II projects for rapid transitioning and related assistance through the Commercialization Pilot Program (CPP) into Phase III and the acquisition processes, as required in Section 252 (y)(2) (see Figure 9).

Conversely, 25% of the respondents answered in the negative that their organization did not have the processes or procedures in place, and 12.5% answered that creation of the processes or procedures was "not applicable" to their organization.

The breakdown of the respondents to this question (Figure 10) mirrored that of the previous question: namely, the Air Force led the Navy in answering affirmatively to this question; the one NGIA and one Air Force respondent answered negatively; and the one Navy respondent answered as not applicable to their organization.

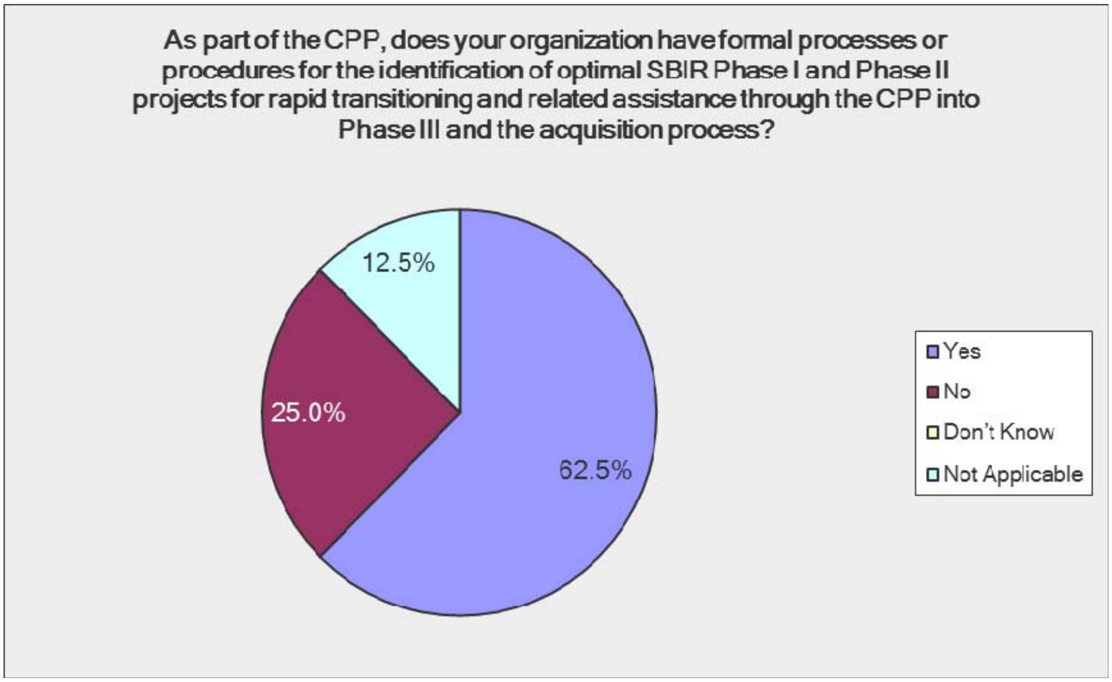

Figure 9. Response to Commercial Pilot Program (CPP) Identification of Projects for Rapid Transitioning Through CPP

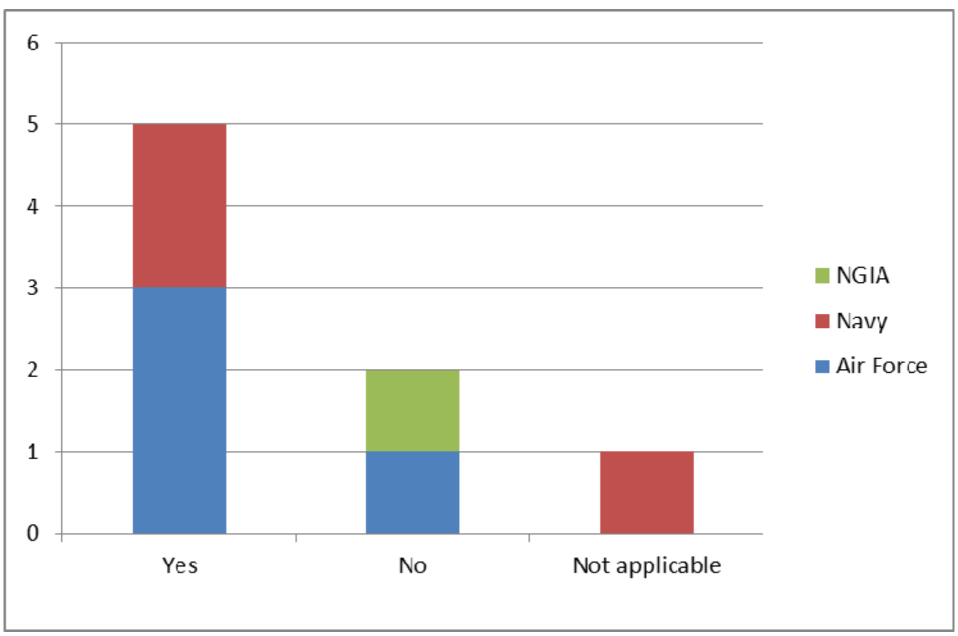

Figure 10. Response by Service to Commercial Pilot Program (CPP) Identification of Projects for Rapid Transitioning Through CPP

Analysis. On the whole, it can be concluded that most agencies that created the CPP came up with some sort of process for the identification of projects for rapid transitioning into the Commercialization Phase of the SBIR/STTR program. The negative responses to this question need to be viewed in the context of the previous question, namely that the respondents either did not create the CPP program in their organization, mixed up the CPP with other transition assistance programs, or were not clear about the legislative requirement.

To understand these results, one must look at the various CPP programs for their approach to identification. The Air Force approaches SBIR project identification for its CPP program using two approaches: technology needs identified by an Air Force acquisition organization and technology needs identified by a single major contractor. In both approaches, "data mining" of DoD Phase II databases occurred by Air Force experts at the various Air Force Product Centers and Air Force Research Lab. The experts look for promising candidates based on program executive office needs. The results of the search are then provided to major contractors of Air Force acquisition organizations, which then conduct interviews with the various small businesses during Industry Interchange Workshops. Then, the technical points of contact and the major contractors identify promising SBIR projects for inclusion into the CPP (Flake, 2007).

The Navy approach involves the program executive office and the System Command SBIR program manager and a technical monitor to decide which Phase II programs get included into their CPP program. Each System Command has its own identification processes relating to their areas of interest (http://www.navysbir.com/cpp.htm). Since 2008 the Navy has also participated with the Air Force in Joint DoD Component Industry SBIR CPP Technology Interchange Workshops, although recent resource constraints make Navy attendance in the future questionable.[8]

The responses also relate to how each Service conducts initial topic selection for the SBIR program. In earlier studies conducted by the RAND Corporation and reported in a 2009 DoDIG report, the approaches to topic generation—and, as a result, projects—of the various military departments was discovered and analyzed. According to the report, the Air Force and the Army "generated a majority of their topics in laboratories, whereas the Navy generated a majority of its topics through the acquisition program offices" (DoDIG, 2009, p. 10). The DoDIG's report also concurred with the 2007 National Research Council report titled *SBIR and the Phase III Challenge of Commercialization* that the Navy approach to topic generation "expedited the transition to commercialization" (p. 9). Based on the current approach of the Army and Air Force, while there may have been improvements in the transition process of the respective CPP programs, the Navy model appears to provide for greater acquisition program input with regard to generating topics that will be successfully transitioned into DoD acquisition phases.

Commercial Pilot Program (CPP)—Certification of Technology Projects for Assistance by Department Secretary

With a response of 50%, most respondents answered that they did not know whether their organization required that SBIR Phase I and Phase II projects be certified by the Secretary of Defense or by the secretary of a military department that the project's

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[8] Fact sheet available at http://www.wpafb.af.mil/library/factsheets/factsheet.asp?id=15879.

successful transition to Phase III and into the acquisition process is expected to meet high priority military requirements of the relevant department as a precondition for receiving assistance under the CPP (see Figure 11).

More than a third, 37.5%, responded that their organization never required the certification. Only 12.5% stated that their organization frequently requires the certification.

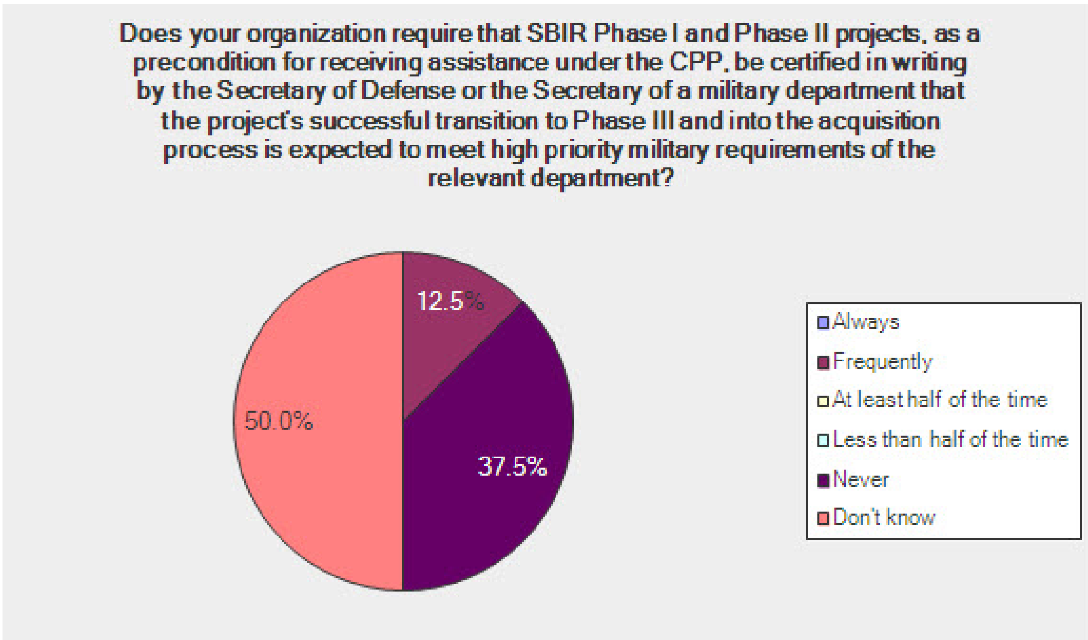

Figure 11. Response to Commercial Pilot Program (CPP) Certification of Projects by Department Secretary

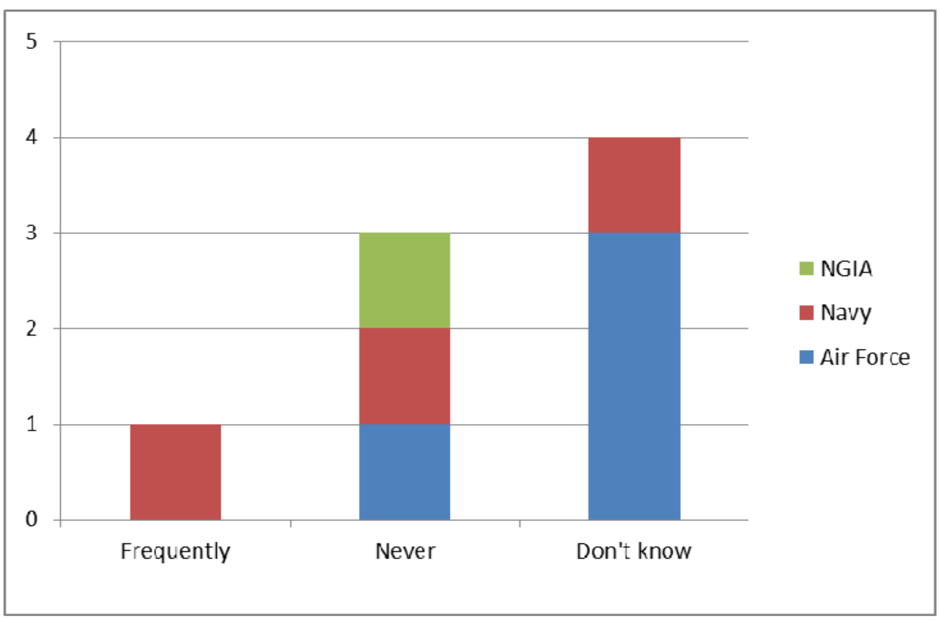

Figure 12. Response by Service to Commercial Pilot Program (CPP) Certification of Projects by Department Secretary

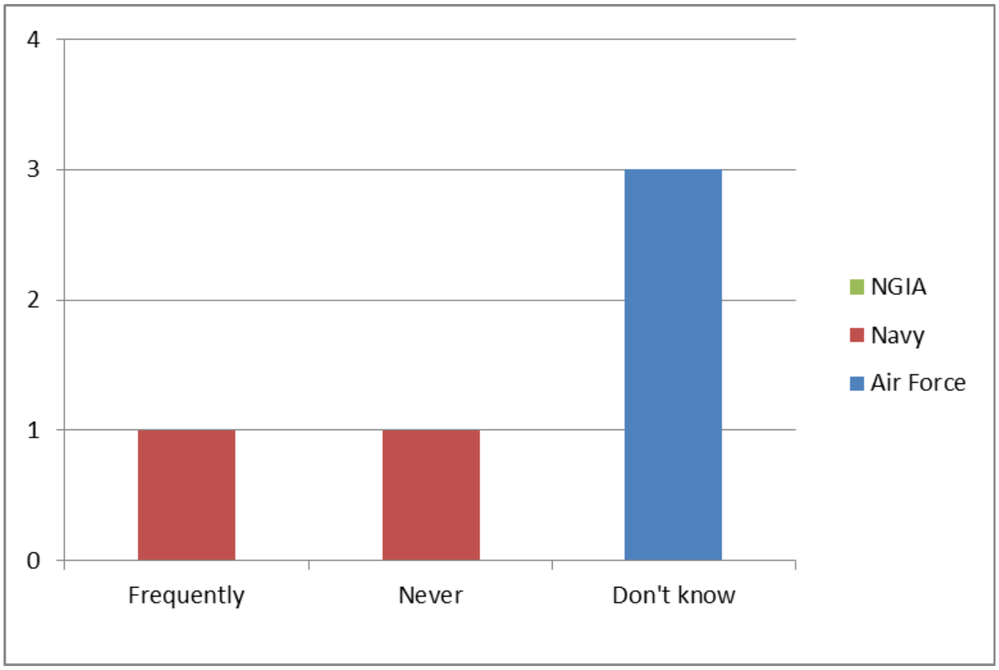

Figure 13. Response by Service to Commercial Pilot Program (CPP) Certification of Projects by Department Secretary (Adjusted for Removal of Non-CPP Responders)

Analysis. A casual look at the responses from the various Services to this question would indicate a large portion of the respondents' organizations either do not know if the organization is keeping this requirement or that they never have keep it (Figure 12).

When one removes the respondents who previously answered "never" or "don't know/not applicable" to the question of CPP creation from the results, one is left with a clearer picture of the situation (Figure 13).

This would indicate that the Air Force organizations, which are the most frequent respondents confirming creation of the CPP, do not know if their military department has implemented the requirement for certification in writing required in Section 252(y)(2).

One also sees the Navy being split on whether this is done in its department, with one respondent answering "frequently" and the other answering "never."

These responses indicate that there is another area for further research needing to be done to determine the type and nature of the responses to this question.

As was previously outlined and which will be further expanded upon later in this paper, the Air Force, Army, and certain Navy organizations utilize contractors such as MILCON Ventures Partners, MacAulay-Brown, Willcor and Dawnbreaker to assist in SBIR- and CPP-related projects at various phases. Some of these firms assist to the extent of helping government personnel to determine whether specific small business firms are able to participate in providing proposals to announced topics at Phase I and whether the Phase I and Phase II firms will be allowed to participate in the CPP projects. In these instances, these contractors do a "vetting" of technology needs and technology SBIR firms. The reason for the department secretary's certification as required in Section 252 was to make certain that projects seeking to progress though the CPP process into commercialization phases met the "high priority military requirements" of each department.[9] Whether contractors should be involved in making this determination is at the very least questionable since delegation of this function to contactors increases the potential for misalignment between military requirements and CPP assistance funds and makes the CPP less predictable for small business. As the results to this question show, this requirement is not being met. Further research into the role of contractors in the determination of project approvals needs to be addressed.

Commercial Pilot Program (CPP)—Input by Program Managers or Program Executive Officers

With a response of 75%, a majority of the respondents answered with an affirmative to the question as to whether their organization had formal processes or procedures for requiring program managers or program executive officers to provide input concerning SBIR topic generation and on accelerated integration of SBIR projects into the acquisition programs (see Figure 14).

The last quarter was evenly split between the respondents who answered in the negative that their organization did not have the processes or procedures in place and who answered that creation of the processes or procedures was "not applicable" to their organization.

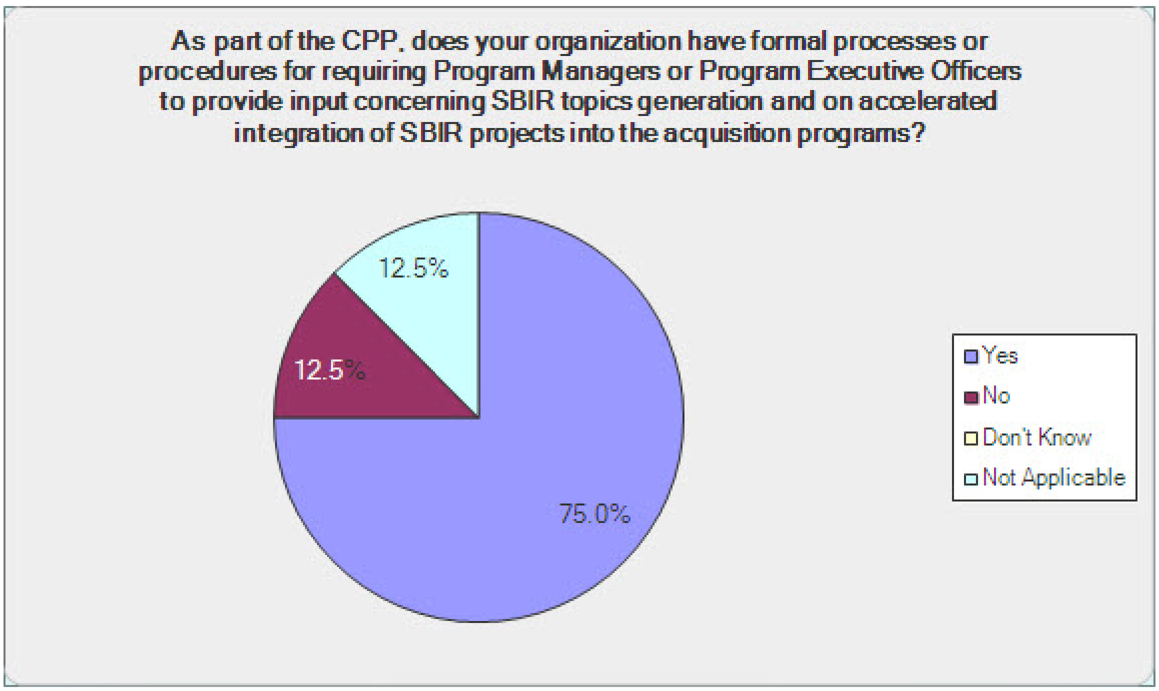

Figure 14. Response to Commercial Pilot Program (CPP) Input by Program Managers or Program Executive Officers

[9] Section 252 (y)(2).

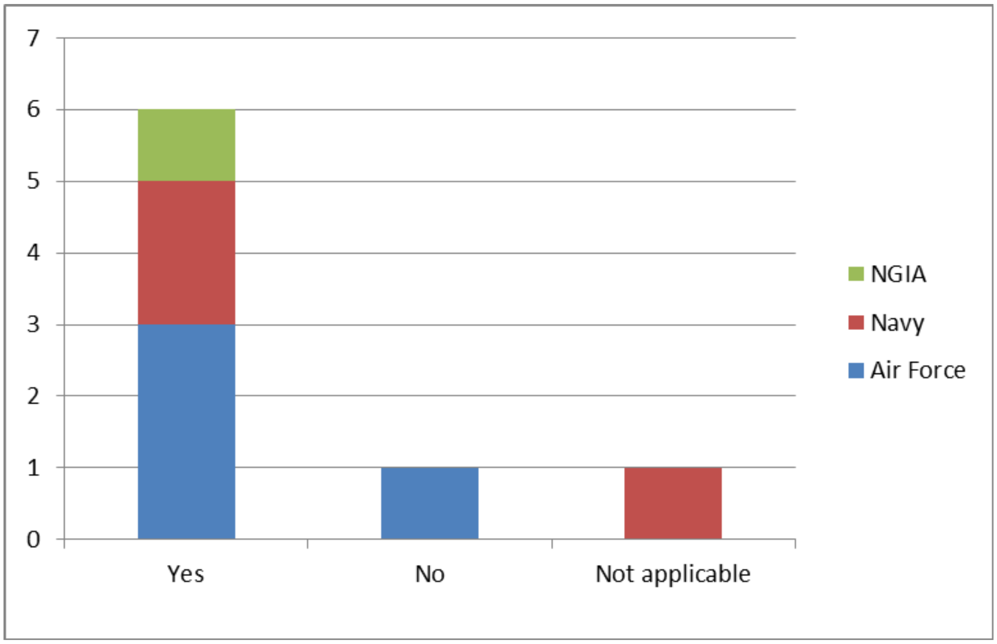

Figure 15. Response by Service to Commercial Pilot Program (CPP) Input by Program Managers or Program Executive Officers

Analysis. The responses by Service to this question (Figure 15) indicate whether their organization is in adherence to the requirements of the statute. However, the NGIA respondent who had previously indicated that their organization had not created the Commercialization Pilot Program still answered affirmatively that they had formal processes or procedures for program manager or program executive officer input as part of the CPP.

Even when taking into account the seemingly erroneous response discussed above, the conclusion here is that the organizations are largely, but not always, involving the PEO and PMs in topic generation within the context of the CPP. This is in contrast to the responses given to the question regarding PEO and PM involvement in topic generation in general reported in the section titled Alignment of SBIR/STTR Topics With DoD Research Plans—Program Manager/PEO Input. In that section, recall that over 50% of the respondents answered that involvement of the PEO and PM was “not applicable.”

The involvement of program executive officers and program managers is critical in the topic generation and identification of projects into commercialization. In a 2009 study entitled *An Assessment of the Small Business Innovation Research Program at the Department of Defense*, the National Academies of Sciences identified that “active championing (of SBIR projects) by Program Executive Officers seems to be a critical ingredient in Phase III success” (p. 182). The study also suggested having senior managers insist that all program managers “integrate SBIR fully into their acquisition programs” (p. 183). These two recommendations represent a cultural change component that Section 252 tried to achieve by requiring PM/PEO input in identifications of areas of effort and by reporting out of the activities of the program managers, program executive officers, and prime contractors in the form of the annual evaluative report on the CPP.

Another issue that involves program managers and program executive officers is that of topic generation. According to the Government Accountability Office (2010) report *Space Acquisitions: Challenges in Commercializing Technologies Developed under the Small*

Business Innovation Research Program, small businesses that were involved with SBIR projects in DoD space related technologies related that there was limited "pull" from the acquisition programs (p. 23). According to the report, three reasons were given for this lack of "pull": DoD topics in which there is no validated requirement, short tenure among DoD officials responsible for progress, and lack of SBIR knowledge among DoD officials (p. 23). Certainly, topic generation by the program managers and program executive officers should include validated requirements and be within the ability of the senior leadership to enforce. Lack of SBIR knowledge is being addressed through more SBIR-related training. Still, the issue of "pull" is again related to changes in organizational culture that apparently remains difficult to accomplish within the DoD.

Contractor Influence on Selection of Projects Within the Commercialization Pilot Program (CPP)

Commercial Pilot Program (CPP)—Contractor Influence

With a response of 83.3%, most respondents answered that their organization did not make decisions to select SBIR Phase I or Phase II projects for CPP assistance based on or influenced by contractors supporting the CPP program for the organization (see Figure 16).

However, 16.7% stated that their organizations' decisions to select SBIR Phase I or Phase II project was in some way influenced by one or more contractors supporting the CPP program for the organization.

With the exception of one respondent from the Air Force, all other Services, including all other Air Force respondents, indicated that contractor influence on decisions to select Phase I or II projects for CPP does not occur (see Figure 17).

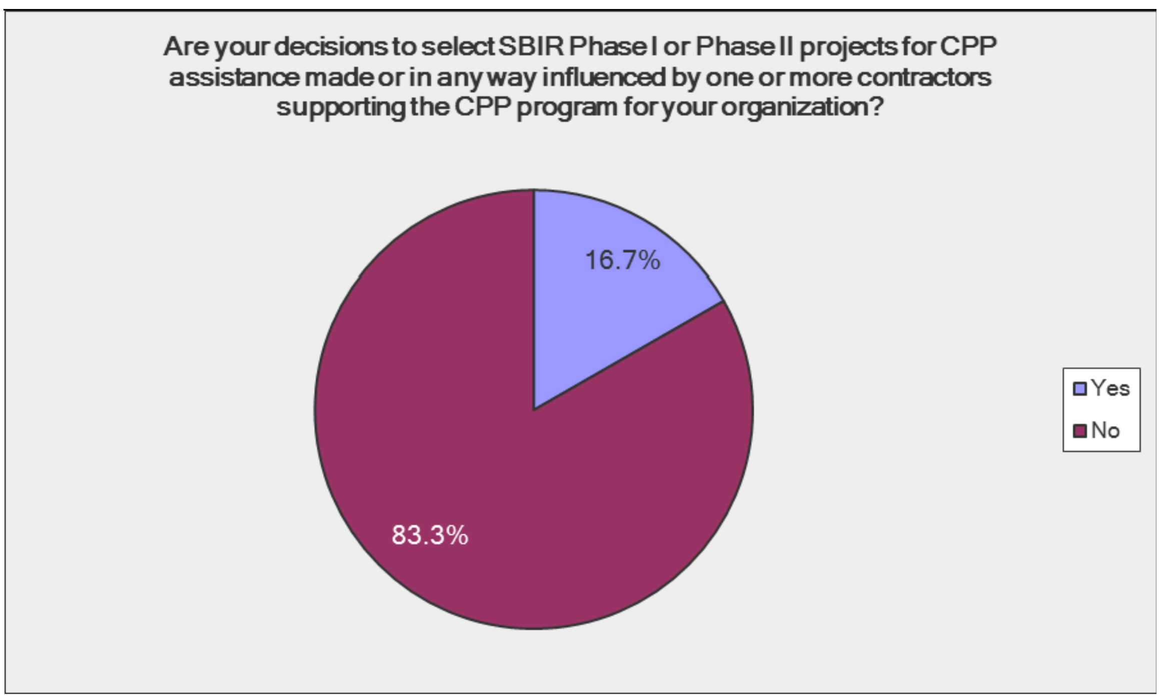

Figure 16. Response to Commercial Pilot Program (CPP) Contractor Influence

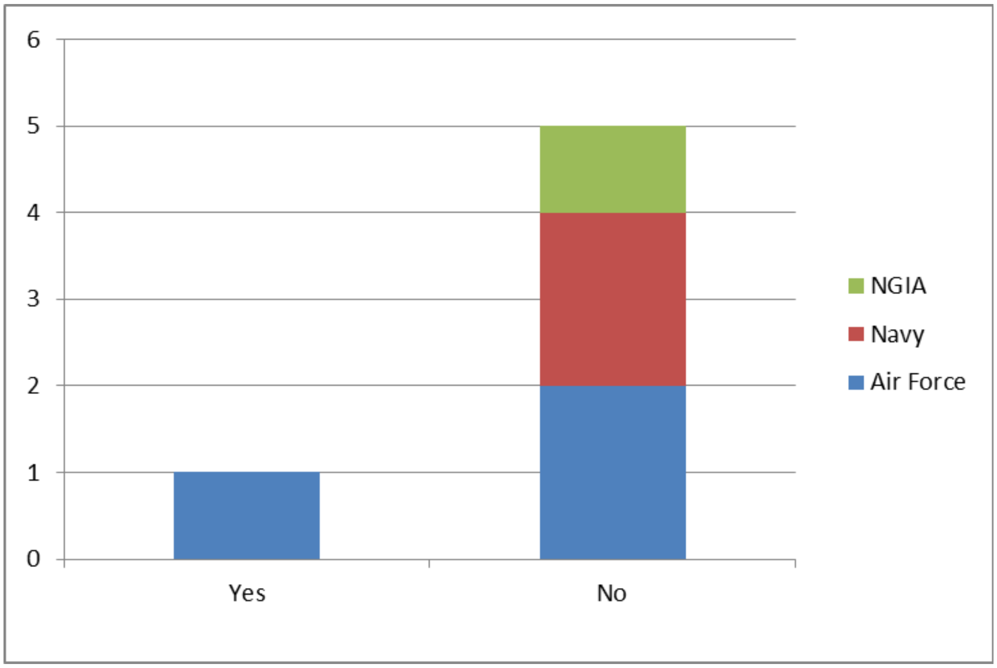

Figure 17. Response by Service to Commercial Pilot Program (CPP) Contractor Influence

Analysis. This finding is in contrast to the publically announced role of contractors in the various CPP programs. With the passage of the SBIR Reauthorization Act of 2000 (Public Law 106-554), which amended Section 9 of the Small Business Act (15 U.S.C. 638), federal agencies were allowed to enter into an agreement with a vendor to provide "technical services." The text of the section is as follows:

> (q) Discretionary technical assistance
>
> (1) In general
>
> Each Federal agency required by this section to conduct an SBIR program may enter into an agreement with a vendor selected under paragraph (2) to provide small business concerns engaged in SBIR projects with technical assistance services, such as access to a network of scientists and engineers engaged in a wide range of technologies, or access to technical and business literature available through on-line data bases, for the purpose of assisting such concerns in—
>
> (A) making better technical decisions concerning such projects;
>
> (B) solving technical problems which arise during the conduct of such projects;
>
> (C) minimizing technical risks associated with such projects; and
>
> (D) developing and commercializing new commercial products and processes resulting from such projects.
>
> (2) Vendor selection

> Each agency may select a vendor to assist small business concerns to meet the goals listed in paragraph (1) for a term not to exceed 3 years. Such selection shall be competitive and shall utilize merit-based criteria.[10]

Using the text of the law as a standard, the role of contractors in the CPP program can be examined. For example, within the Army, MILCOM Venture Partners is a firm that the Army selected to oversee its CPP implementation. The following information was found on their website (www.milcomvp.com) and describes their role in the Army CPP program:

> MILCOM Venture Partners (MILCOM) was selected as the Army's contractor to help manage the CPP, and will: 1) review current SBIR Phase II projects and recommend approximately 25 projects for participation in CPP; 2) provide assistance intended to accelerate technology transition and commercialization to the projects selected for CPP participation; and 3) recommend the amount of additional funding each participating SBIR Phase II project will be allocated from the $15 million CPP fund. In making recommendations for participation in CPP, the following characteristics will be given significant consideration by MILCOM:
>
> 1. The Phase II technology meets a high priority Army requirement;
> 2. The technology can be rapidly transitioned to Army acquisition and/or a commercial product; and,
> 3. Transition to military or commercial products will provide a significant financial return on the investment made in the technology by the SBIR Program, in the form of non-SBIR investment in such technology and product revenue.

The Air Force has contracted with MacAulay-Brown, Inc. (MacB) to provide a lead role, variously described as that of SBIR/STTR program manager[11] or, more recently, as SBIR/STTR project lead (http://www.afsbirsttr.com/Poc/Pocs.aspx). The role of MacAulay-Brown was described in their press release at the time of the contract award:

> The Government-MacB Team will focus on improving the process of identifying and developing topics that address urgent warfighter needs and transition successful results to acquisition programs while strengthening awareness, involvement and advocacy of key S&T customers/stakeholders. (http://www.macb.com/about-us/company-news.php)

The Navy also involves contractors to assist in their CPP program. The contractor firms Dawnbreaker Inc., and Willcor have been contracted to provide program management support, technology transition, and risk management to firms that have SBIR/STTR projects. The firm's involvement in CPP is outlined as follows:

- Willcor is under contract to the Navy to assist companies with the use of Technology Risk Identification & Mitigation Software (TRIMS) for SBIR, a web based tool for risk assessment management, the performance of independent

[10] The full text can be retrieved at http://www.law.cornell.edu/uscode/html/uscode15/usc_sec_15_00000638----000-.html#FN-1.

[11] Air Force presentation given at the 2009 Beyond Phase II Conference (http://www.beyondphaseii.com/2009/presentations/Wednesday/01_CPP_Service_Briefings/c_Services_Briefings-Flake_(Air_Force).pdf).

assessments, and assistance in developing risk mitigation strategies and plans.

- Both Willcor and Dawnbreaker are under contract with the Navy to provide assistance to SBIR firms in planning their transition strategies.
- Both Willcor and Dawnbreaker are under contract to assist firms with identifying issues, preparing manufacturing plans, and conducting Manufacturing and Production Readiness assessments.
- Technology Readiness Assessments are used to assist firms in determining the development status of their technology (TRL) as well as conformance to requirements. Willcor is under contract to the Navy to provide these assessments. (http://www.navysbir.com/Navy_CPP-09.pdf)

Dawnbreaker's role within the Navy's Naval Air Systems Command (NAVAIR) CPP program includes having

> to provide Program and Technology Transition Management Support to the NAVAIR SBIR Program Office to implement a CPP which assists the NAVAIR Program Executive Officers (PEOs) and NAVAIR Acquisition Program Management Offices (PMAs) in identifying SBIR topics that meet the needs of the war-fighter, have the potential for rapid transition and to execute their transition from Phase II to Phase III and insertion into a Program of Record. (http://www.dawnbreaker.com/defense/navair-cpp.php)

Dawnbreaker is also the major contractor in the Navy's Technology Assistance Program (TAP). This program assists Phase II SBIR/STTR awardees with "the services of a business acceleration manager, a market researcher, and others to accelerate the transition of their technology. This is accomplished through the application of a proven process and deliverables, developed collaboratively by the small business and the Navy TAP team" (http://www.dawnbreaker.com/defense/navy-tap.php).

It is clear that there is significant contractor involvement in the CPP programs at the various Services. What is not clear, however, is whether any conflict of interest with Federal Acquisition Regulation provisions and the various programs exist. This is significant because FAR Section 9.5 prohibits a contractor from having consultant conflicts of interest. FAR Section 9.505-1 specifically prohibits a contractor that has "provide(d) systems engineering and technical direction for a system but does not have overall contractual responsibility for its development, its integration, assembly, and checkout, or its production" from having a contract awarded to them for the system or to be a subcontractor or consultant to a supplier of the system or any major components. While the scope of the involvement of the contractors outlined above does not appear to be in conflict with the above quoted section, there may be some unintentional abuses and possibly the role that contractors are actively playing exceeds that of the definition of "technical assistance" as was outlined in 15 U.S.C. 638. The conclusion here is that this is an area in which more research should be conducted.

CPP Incentives and Initiatives

Incentivizing Within Commercial Pilot Program (CPP)

With a response of 66.7%, most respondents answered that their organization did not make develop or deploy acquisition incentives to accelerate the transition of SBIR/STTR technologies into the acquisition process though the Commercial Pilot Program (see Figure 18).

A third, 33.3%, indicated that their organization did develop and deploy acquisition incentives to accelerate the transition of SBIR/STTR technologies into the acquisition process as part of the CPP.

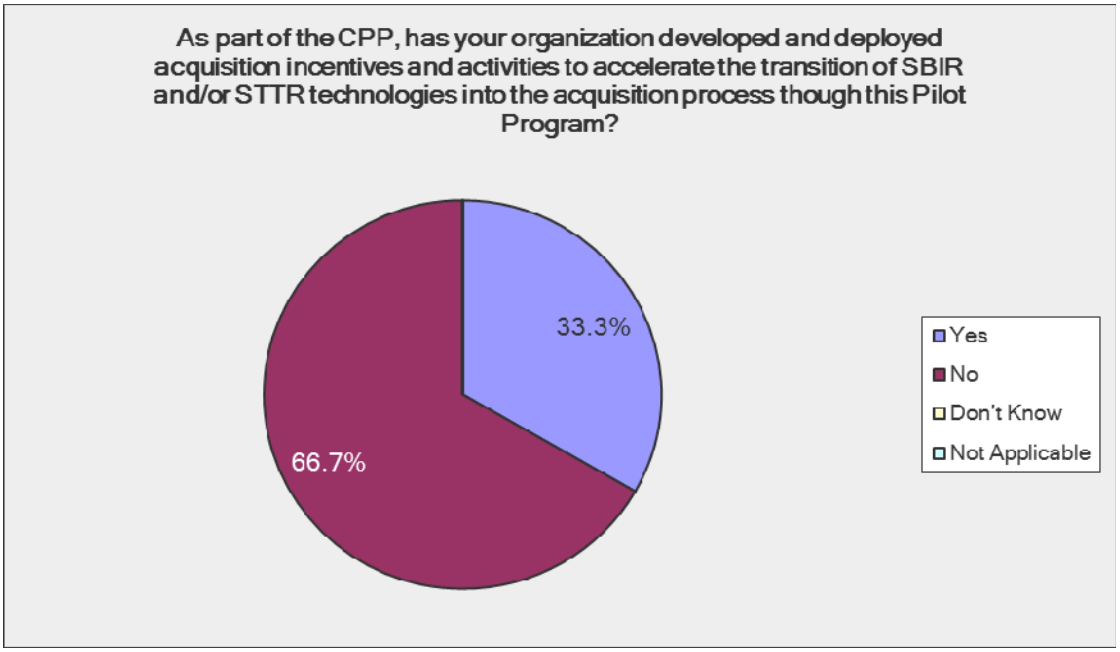

Figure 18. Response to Acquisition Incentivizing Within Commercial Pilot Program (CPP)

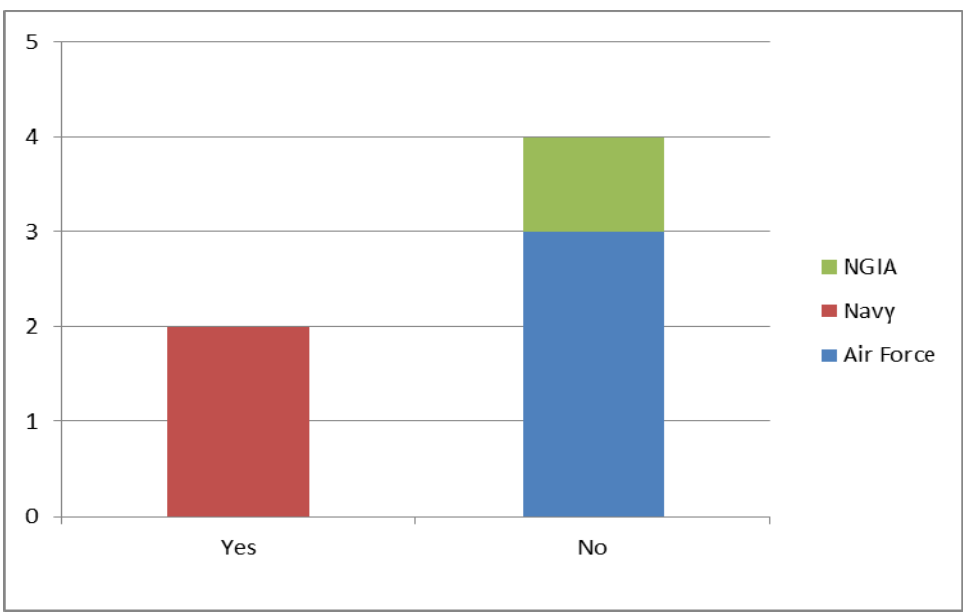

Figure 19. Response by Service to Acquisition Incentivizing Within Commercial Pilot Program (CPP)

Analysis. The two Navy respondents who had confirmed creation of the CPP also were the only respondents who indicated that the Navy used incentives within the Commercialization Pilot Program. The Air Force respondents indicated that the Air Force did not develop any acquisition incentives, even though this is well within the scope of the SBIR/STTR program and must be reported to Congress each year (see Figure 19).

The subject of incentives was a topic of great interest at the SBIR and the Phase III Challenge of Commercialization Symposium held on June 14, 2005. The symposium was convened by the National Academies of Science (2005) and focused on the commercialization of SBIR-funded innovation projects at the DoD and NASA (p. xv). The term "incentives" was used to address methods of change techniques with the various targets being government managers at multiple levels, prime contractors, and small businesses. The ideas suggested took the form of programmatic changes to funding, training, risk reduction (for all three entities, small business, prime contractor and government), alignment with existing projects, and education outreach regarding the SBIR program. The importance of incentives was stressed repeatedly by the participants of this symposium, and within the report of the proceedings this is evidenced by the following two quotes:

> In this era of globalization, optimizing the ability of small businesses to develop and commercialize new products is essential for U.S. competitiveness and national security. Developing better incentives to spur innovative ideas, technologies, and products—and ultimately to bring them to market—is thus a central policy challenge. (NAS, 2005, p. 3)
>
> To capitalize on SBIR's potential, both better information (for small companies and large prime contractors) and supportive incentives are necessary. (NAS, 2005, p. 28)

Section 252 utilizes the term "incentives" specifically in paragraph (y)(5) with regard to the reporting of such in the annual evaluative report of the Secretary of Defense to the Senate committees on Armed Services and Small Business and Entrepreneurship and House committees on Armed Services and Small Business, but the Congressional Guidance Letter gives further instruction with regard to the intent of Congress to have the DoD consider issuing "binding directives, contract clauses, or regulatory amendments through the Defense Federal Acquisition Regulation Supplement (DFARS) to facilitate the requisite incentives" (p. 3).

In the 2006 SBIR CPP Report to Congress, the Department of Defense stated its intention to utilize incentives:

> The Department is exploring a range of incentives to stimulate the transition of SBIR funded technology for promulgation throughout the Department via appropriate mechanisms. Initiatives under consideration include: extension of SBIR Phase III permissive sole-source authority to SBIR subcontracts, reinforcement of SBIR Phase III sourcing authority and data rights, formal consideration of SBIR technology transition planning during acquisition review processes, favorable treatment of proposals which employ SBIR technologies or partnerships, use of incentive or award fees for SBIR-technology sourcing; wider employment of SBIR Phase III contracts toward meeting small business sourcing goals, to include possible multiple small business credits; and encouraging individual performance bonuses for personnel affecting SBIR technology

> transition. The new National Security Personnel System (NSPS) in the process of being rolled-out across the Department is well suited to implement this type of performance-based compensation. It will be up to each participating component and their subcomponents to take advantage of this opportunity to set output-based goals to measure this dimension of performance for relevant program officials while ensuring the integrity of source selection activities. (USD[AT&L/OSBP], 2007, p. 13)

The lack of reported incentive usage would indicate a missed opportunity by the Services. The different approaches to incentives as well as the level of utilization can be found in Table 2.

Incentivizing Within Commercial Pilot Program (CPP)—Types of Incentives Deployed

Since the Navy respondents were the only ones who indicated the usage of incentives, all of the information in Table 2 is related to usage of the incentives within the Navy organizations, but the table also includes all of the types of incentives that could be utilized.

As shown in Table 2, the most utilized incentives were as follows:

- educational and business development assistance to SBIR firms focused on commercialization in federal and dual-use markets, and
- outreach and advocacy with large prime contractors as well as defense acquisition and program management officials.

And while having a high utilization, not used as frequently as the two above was the following:

- contract clauses or regulatory provisions expressly confirming SBIR data rights protections at Phase III at the prime contracting and subcontracting levels. Such clauses are set forth in FAR 52.227-20.

In contrast, the least utilized incentive method was that of contract incentive clauses and bonuses to large prime contractors that integrate SBIR and/or STTR technologies.

An area of additional research might therefore be the use of contract clauses or incentives to increase the transition of projects into Phase III as large prime contractors specially requested in the National Academies of Science SBIR Symposium (2005, p. 27). It is also worth studying whether funding currently spent in outreach and education may be more effective when redirected to these types of incentives.

Table 2. Response to Acquisition Incentivizing Within Commercial Pilot Program (CPP) Types of Incentives Deployed

Which type of incentives and activities did your organization develop and deploy as part of the CPP? (Select all that were utilized and indicate frequency of use)							
Answer Options	**Always**	**Frequently**	**At least half of the time**	**Less than half of the time**	**Never**	**Response Count**	**Utilization**
a. Educational and business development	1	1	0	0	0	2	Most

assistance to SBIR firms focused on commercialization in Federal and dual-use markets							utilized
b. Outreach and advocacy with large prime contractors as well as defense acquisition and program management officials.	1	1	0	0	0	2	Most utilized
c. Contract incentive clauses and bonuses to large prime contractors that integrate SBIR and/or STTR technologies	0	0	0	1	0	1	Least utilized
d. Mentor-protégé arrangements for the benefit of SBIR and/or STTR firms	0	0	1	1	0	2	Some utilization
e. Dedication of specific acquisition dollars for integration of SBIR and/or STTR technologies into major defense systems	0	0	1	1	0	2	Some utilization
f. Contract clauses or regulatory provisions expressly confirming SBIR data rights protections at Phase III at the prime contracting and subcontracting levels	1	0	1	0	0	2	Most utilized
g. Performance incentives to acquisition and program management personnel for developing and execution rapid commercialization of SBIR technologies through government contracts and subcontracts	0	1	0	1	0	2	Some utilization

Conclusions and Recommendations

The overall conclusion of this paper is that while the Department of Defense began implementation of the DoD SBIR CPP program and other Section 252 SBIR/STTR reforms, progress is uneven. Specifically, military departments (MILDEPs) and DoD agencies participating in SBIR and STTR programs have not uniformly conformed to the mandatory Section 252 reforms. When the Departments of Defense, Army, Navy, and Air Force implemented the optional Commercialization Pilot Program, they commonly used the CPP funds to hire business development and venture capital contractors as transition assistance advisers. Although transition assistance advising is recognized by the Congressional Guidance Letter as a valuable form of assistance, the DoD and MILDEPs seemed to disregard several other CPP elements that were expressly spelled in the statute. For instance, the departments have largely not fulfilled the condition of secretarial certification of high military priority before technologies can qualify for CPP assistance, and have declined to implement the CPP incentive authorities to the maximum extent practicable. Unquestionably, the CPP informs the DoD acquisition community about valuable SBIR technologies and helps SBIR firms engage in planning for SBIR technology insertion within the DoD. However, as currently implemented, the CPP is not likely to significantly streamline the Phase III transition process, to change the culture of major acquisition program offices with regards to SBIR, to reduce technology insertion risk, or to incentivize leading prime contractors to utilize SBIR firms in major defense systems. Legislative reforms are needed to rebalance and strengthen the CPP and other Section 252 reforms.

Answers to Research Questions

Alignment with DoD Research Plans

The conclusion we reach to the question as to whether the military Services have aligned their SBIR/STTR topics with DoD research plans, which would include PM/PEO inputs to couple acquisition focus with research needs and have these certified by the respective military secretaries, is that this has not occurred at all. This is the case even though the Section 252 legislation and Under Secretary of Defense SBIR policy requires that this occur. We are left with trying to determine an explanation for why this could have been the case. Taking a positive perspective on this subject, we suggest that either there is a level of ignorance of the statue and policy, which can be remedied by education and management actions, or that the respondents just did not know the answer to the survey questions. On the other hand, this may also suggest that there is resistance in the DoD organization to taking a new approach to topic creation. This, in turn, indicates a challenge to an organization's culture, which will be more difficult to change, but not impossible, when combined again with education and a strong influence from upper levels of management. In any case, the responses to this question would indicate that opportunities for further research exist in trying to determine why the respondents answered in the way they did and to effect change leading to alignment.

Commercialization Pilot Program

The conclusion we reach as to whether the Commercialization Pilot Program was created and was conducted within the requirements of Section 252 is a qualified yes. The Services reported, and documentary evidence exists for the Army (which did not participate in the survey), that there has been a CPP created in each of the major military Services and that there is largely input by program managers/program executive officers in the selection of SBIR/STTR projects to be included in the CPP. The overall implementation of the Commercialization Pilot Program was positive, but suffered from the seeming ignorance of the secretarial certification reporting requirements of the legislation, the potential inappropriate use of contractors resulting in their performance of roles that are governmental functions, and the low utilization of incentives. These findings were the negative aspects of the answer. Those Services that did implement the CPP seemed to pick and choose which requirements within the legislation they would implement.

As mentioned previously, our research has shown that there had been contractors performing some of the functions that were delegated to the department secretary, including the certification process to determine which projects are to be given assistance. Contractor participation in the certification process and the approach to use contractors as "gatekeepers" within SBIR Phase I and II projects shows that contractor influence in those military Service's SBIR/STTR CPP programs is organic—perhaps not by design, but nevertheless is present throughout. This may create issues in the CPP decision-making process, leading to misalignment of CPP resources. We suggest that additional research be performed to look at this issue and to make certain governmental functions are being performed by the proper government authorities, as well as to erect barriers to potential areas of conflict of interest.

Our research also showed the lack of incentives being utilized within the DoD SBIR/STTR CPP. As was noted in the Department of Defense report to Congress on the Commercialization Pilot Program Report for Fiscal Year 2006, the DoD stipulated that it would undertake an exploration of the use of incentives to encourage the transition of SBIR technologies throughout the DoD. Four years later our research has determined that incentive use is almost non-existent and that incentive usage should be emphasized or re-emphasized to the Services. This is an area in which more research should be conducted to ascertain the apparent resistance of the Services to incentivizing SBIR participants.

Promotion of Manufacturing Innovation

Our survey did not succeed in collecting responses to how the Services and the DoD in general performed the implementation of Executive Order No. 13329. What we did find by doing literature review shows that the Services have posted plans on how to encourage manufacturing in their respective SBIR/STTR programs at publically available websites. The Executive Order No. 13329 webpage on the DoD SBIR/STTR site lists links to the Army's, Navy's, Air Force's, and DARPA's Executive Order No. 13329 Manufacturing Innovation Plans (http://www.acq.osd.mil/osbp/sbir/execorder/index.htm).

This report does not make any conclusions regarding these efforts and suggests that further research be conducted to ascertain compliance with Section 252 and congressional intent in that regard.

A Final Observation

As we went about compiling our findings for inclusion in this section, it seems then that a possible reason for the seeming disconnect between some of the specific items mentioned in the legislation, such as the creation of the CPP, and the intent of Congress as outlined in the Letter of Congressional Intent, such as the stipulation of certain types of incentives and the actual implementation may be due to the lack of the dissemination of the Letter of Congressional Intent to the respective Services' secretaries. On May, 16, 2006, the letter was written to the Honorable Kenneth J. Kreig, then the Under Secretary of Defense for Acquisition, Technology, and Logistics, and requested a meeting by June 16 to discuss how the DoD was planning on implementing Section 252 and requested a written status be presented at that meeting. There is no evidence that suggests that the meeting occurred or that the written status was provided. Mr. Kreig announced his resignation on June 6, 2007, effective July 20 of the same year. What level of circulation the letter received initially and subsequently is unknown, and while speculative, we suggest that this may be one possible reason, but not the only possible one, as to why the "disconnect" may have occurred. Additional research may be able to determine whether this suggestion is correct, or as an alternative, the complete intention of Congress in regard to the desired outcomes and means to attain those outcomes could be spelled out specifically in new legislation.

Recommendations for CPP Reforms

Based on the examination of Section 252 legislative text, SBIR-related proceedings of the National Academies Symposium, congressional guidance on Section 252, best practices available across the federal government and internationally, and the DoD-wide survey of SBIR and STTR managers, the following recommendations are made for action by the Secretary of Defense and of the military departments and, where appropriate, by Congress.

1. Create a Streamlined "One-Stop Shop" Process for Assisting SBIR/STTR Firms With Technology Transition, Including Development, Testing & Evaluation, and Procurement

It is clear from research reported in this paper that one of the main obstacles to successful technology transition in the Department of Defense is confusion and lack of information on available assistance programs within government managers and small businesses/industry alike. This confusion and lack of information forces small firms to spend much time navigating the DoD bureaucracy for technology funding sources and introduces uncertainty that discourages acquisition program managers and program executive offices from planning for insertion of technologies developed by small firms. A streamlined "one-stop shop" process for SBIR/STTR firms set up within each military department and/or within the Office of the Secretary of Defense could reduce bureaucratic barriers for small firms and interested PMs/PEOs. If an SBIR/STTR technology looks promising but would require planned and/or targeted assistance with development, testing, or evaluation, the "one stop shop" could help tailor the appropriate funding mechanisms and assist with technology roadmapping, leading to procurement by the Department of Defense under contracts or by major prime contractors under subcontracts. The "one-stop shop" could reduce or altogether eliminate the need for private advisory and assistance contractors, including venture capitalists, to act as gatekeepers for Phase III procurements and as intermediaries between defense acquisition programs and SBIR firms.

2. Raise MILDEP Acquisition Community Sponsorship of SBIR/STTR Topics From at Least 50% to at Least 75%, Seek Prime Contracts' Recommendations of Topics for MILDEP Acquisition Community Sponsorship, and Publicly Designate the Existence of Sponsorship in the Solicitation

As our study confirms, the key technology transition best practice in the United Kingdom and the United States is market "pull" for the technology at issue that occurs when the technology addresses identified need of a defense acquisition program. For this reason, the UK CDE does not fund SBRI topical competitions unless the topics are requested by the Defense Equipment & Supply organization (even when SBRI topics end up receiving additional technology development funding and not acquisition program funding at the conclusion of SBRI contract performance). Likewise, NASA has attempted to fundamentally reform its SBIR/STTR programs by ensuring that all its SBIR/STTR topics meet identifiable acquisition needs. In contrast, the DoD has never gone above its 50% topic sponsorship policy. Although there is a need for some SBIR/STTR topics that will further the long-term research interests of the DoD (e.g., DARPA topics and topics addressing the needs of MILDEP R&D communities), it is clear that the majority of SBIR/STTR topics must have DoD acquisition program sponsorship. Raising the DoD sponsorship policy from 50% of SBIR/STTR topics to at least 75% of topics, seeking SBIR/STTR topic recommendations from major prime contractors for military departments' acquisition community sponsorship, and requiring a public designator of topic sponsors in the R&D or acquisition communities as part of SBIR/STTR solicitations should address any disconnect between the SBIR/STTR solicitations and the needs of defense acquisition programs. It should also provide clearer notice to small firms concerning the possibility of any future procurement prospects for their technologies.

3. Confirm the Overall Authority of MILDEP Offices of Small Business Programs, Small Business Specialists, and Small Business Technical Advisers Over SBIR/STTR Transition Assistance and Incentives

The study shows that a major part of the DoD SBIR Commercialization Pilot Program, as implemented by the military departments, involved contracting for consultants, including venture capitalists, to serve as "transition agents" and evaluators of SBIR firms seeking Phase III contracts or enhancements to Phase II contracts. These private advisory contractors essentially act as source selection "gatekeepers" for Phase III procurements (for example, by pre-selecting candidates presented to Army acquisition program managers for Army CPP funding and procurement assistance, thereby making initial eligibility and responsibility determinations) or as intermediaries between defense acquisition programs and SBIR firms (for example, within the Air Force and the Navy).

However, the current CPP approach duplicates existing responsibilities of OSD agency and MILDEP directors of Offices of Small Business Programs and their small business specialist and small business technical advisers embedded in buying commands and activities. The OSBP directors and their small business acquisition workforce oversees, and advocates for increase in, small business prime contracting and subcontracting participation under the existing legal and regulatory framework, such as 15 U.S.C. § 644(k), FAR 19.201, DFARS 219.201, and DFARS PGI 219.201. The current CPP approach also ignores the recommendations of the National Academies of Sciences to support SBIR Phase III efforts by using existing incentives for subcontracting with small firms. The Phase III Commercialization Symposium highlighted the experience of the Navy Program Executive Office for Submarines (PEO Subs) in utilizing existing subcontracting incentives.

Therefore, it is recommended that overall authority for CPP activities be conferred in the MILDEP and OSD agencies' Offices of Small Business Programs and that small business specialists and technical advisers be funded and encouraged to conduct outreach to program managers/program executive offices and prime contractors, engage in SBIR technology roadmap development, facilitate inclusion of SBIR/STTR technology transition goals into prime contractors' subcontracting plans, and facilitate testing and evaluation funding assistance to small firms as well as subcontracting incentives for large prime contractors.

4. Realign CPP to Facilitate "Pull" of Technologies Into Defense Acquisition Through Secretarial Instructions That Clearly Define Criteria for High Military Priority of SBIR Projects as well as CPP Eligibility and Responsibility SBIR Firms in Each DoD Agency and MILDEP

The essence of the CPP structure is to realign the DoD SBIR technology acquisition process from a "push" by SBIR firms trying to convince the DoD to purchase their products and services to a "pull" of SBIR technologies by DoD acquisition programs (both at the government and the prime contractor level). This realignment is necessary to reverse the attitude inside the DoD that SBIR set-asides are a "tax" against mission-focused DoD acquisition and RDT&E funds. The study indicates that CPP eligibility criteria are not well defined by the DoD and the MILDEPS. They appear to be left to the discretion of the CPP contractors, including private venture capitalists. Thus, the focus of evaluation shifts to whether an SBIR firm has already developed on its own a profitable government acquisition market, not whether the technology is a priority for the Department of Defense or a military department and one or more of its acquisition program executive officers or program managers.

Moreover, the current poorly defined CPP eligibility criteria appear to violate the Small Business Act ban on excluding small firms from contracts without Certificates of Competency. Under the Small Business Act, government contracting officers are not allowed to deny small businesses the awards of any contracts for perceived lack of any "elements of responsibility, including, but not limited to capability, competency, capacity, credit, integrity, perseverance, and tenacity...without referring the matter for final disposition" and a Certificate of Competency to the Small Business Administration.[12] Phase III contracts to SBIR firms are not excluded from this requirement for a CPP determination.

Secretarial instructions should clearly provide for (1) Secretarial certifications of high military priority for SBIR technologies before such technologies are selected for CPP; and (2) a process for evaluation of SBIR firms' business, financial, and manufacturing capabilities that may provide for assessment by business development contractors as well as appeal to the SBA for a Certificate of Competency.

5. Publish Results of Quadrennial Review Concerning SBIR/STTR Topic Alignment With DoD R&D Plans and Program Manager/Program Executive Officer Inputs

The study suggests that few SBIR/STTR agencies have conducted the periodic Quadrennial SBIR/STTR topics review. This review has the potential to improve the usefulness of SBIR/STTR set-asides and encourage greater Phase III awards by aligning SBIR/STTR focus areas with DoD R&D Plans (Defense Technology Area Plan, Basic Research Plan, and Joint Warfighting Science and Technology Plan) as well as acquisition programs' inputs and the DoD Quadrennial Defense Review.

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[12] 15 U.S.C. 637(b)(7)(A) (2011).

OSD and MILDEPs should conduct such review and publish its results.

6. Expand CPP to the STTR Program to Enable Access to MILDEP Testing and Evaluation Facilities, Including Naval Warfare Centers and DoD Academic Institutions, Such as the Naval Postgraduate School

To the extent that SBIR and STTR technologies suffer from the risk of insufficient testing, one major incentive would involve greater access of SBIR and STTR firms to military testing facilities and funding for testing and evaluations at these facilities. Such facilities would include the elements of the Naval Warfare Centers Enterprise such as the Naval Surface Warfare Center and the Naval Undersea Warfare Center, as well as military postsecondary academic institutions such as the Naval Postgraduate School, the Air Force Institute of Technology, and the military Service academies.

Specifically, the Small Business Act should be amended to (1) provide for eligibility of the military postsecondary academic institutions to participate in the STTR program on the same terms as Federally Funded Research and Development Centers (FFRDCs); and (2) confirm the ability of SBIR and STTR CPP firms to use CPP assistance for testing and evaluation activities at military testing and evaluation facilities and military postsecondary academic institutions.

7. Expressly Describe Authorized Acquisition Incentives and Other Types of Incentives in CPP Legislation

It seems clear from the study that the DoD and MILDEP SBIR and STTR managers do not fully comprehend the full range of incentives that are authorized under the CPP program. This appears to be due to lack of awareness of the Congressional Guidance Letter and the proceedings of the SBIR Phase III Symposium at the National Academies. As a result, the DoD and MILDEPs have focused on hiring business advisory and assistance contractors to conduct business evaluations, outreach, and advocacy of small firms. Education and business development incentives are only one category of incentives among seven possible types of incentives listed in the Congressional Guidance Letter.

Congress should expressly list all such incentives in amended CPP legislation.

8. Establish Clear Policies Concerning Technical Assistance Vendors' Investment in SBIR/STTR Firms, Organizational Conflicts of Interest, and Performance by Such Vendors of Inherently Governmental Functions

The current CPP model appears to provide insufficient assurances against organizational conflicts of interest (OCIs) and performance of inherently government functions (IGF) by government contractors. Specifically, there is a potential for venture capital contractors to recommend for Phase III those SBIR firms that are open to future venture capital investments by the recommenders. There is also a potential for business advisory and assistance contractors to recommend only firms that utilize their business development assistance services authorized under 15 U.S.C. 638(q), Discretionary Technical Assistance, which allows SBIR and STTR agencies to contract with vendors for advisory services for individual SBIR and STTR awardees where the awardees will use part of their SBIR and STTR awards to pay for such advisory services. Under FAR 9.505, contracting officers must structure acquisitions with the goal of "preventing the existence of conflicting roles that might bias a contractor's judgment...[and] unfair competitive advantage." Under FAR 9.504, the contracting officer issuing a solicitation (or any solicitation-type CPP invitation for future Phase III or Phase II Enhancement awards) must recommend a plan to the head of contracting activity for resolving any significant potential conflicts of interest. Moreover, under the FAR, Congress, the OSD, and the MILDEPs should absolutely and unequivocally prohibit contractors that are or may be involved in advising or investments to SBIR or STTR firms from participating as advisors on CPP evaluation (including any Phase II enhancements or Phase III awards).

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Disclaimer

All views expressed herein are the author's own, do not necessarily reflect the views of the U.S. Government or any agency thereof, and should not be construed as an attempt to advance or hinder the promulgation of any regulation or conclusion of any trade agreement by the executive branch, or the passage of any legislation before the Congress.

A version of this paper is also being submitted in satisfaction of thesis requirements for an LLM in Government Contracts Law, George Washington University.

Panel 24 – The Other "Big A": Coming to Grips with Affordability

Thursday, May 12, 2011	
3:30 p.m. – 5:00 p.m.	**Chair: Reuben Pitts III,** President, Lyceum Consulting, LLC **Discussant: Brigadier General Michael E. Williamson, US Army,** Joint Program Executive Officer for the Joint Tactical Radio System ***Military Cost-Benefit Analysis: Introducing Affordability in Vendor Selection Decisions*** Francois Melese, Anke Richter, and Jay Simon, NPS ***On a Quantitative Definition of Affordability*** Charles LaCivita and Kent Wall, NPS

Reuben S. Pitts III—President, Lyceum Consulting. Mr. Pitts joined the Naval Weapons Lab in Dahlgren, VA, in June 1968 after graduating from Mississippi State University with a BSME. His early career was spent in ordnance design and weapons systems. He subsequently served on the planning team to reintroduce the Navy to Wallops Island, VA, currently a multiple ship combat, over-the-water weapons testing lab for Surface Ship Combat Systems, Fighter Aircraft, and live missile firings. His outstanding service as the deployed Science Advisor to Commander, U.S. Sixth Fleet was recognized with the Navy's Superior Civilian Service (NSCS) Award and the Navy Science Assistance Program Science Advisor of the Year Award.

Mr. Pitts was selected to lead the technical analysis team in support of the formal JAG investigation of the downing of Iran Air Flight 655 by USS *Vincennes*, and participated in subsequent briefings to CENTCOM, the Chairman of the Joint Chiefs, and the Secretary of Defense. As Head, Surface Ship Program Office and Aegis Program Manager, Mr. Pitts was awarded a second NSCS, the James Colvard Award, and the John Adolphus Dahlgren Award (Dahlgren's highest honor) for his achievements in the fields of science, engineering, and management. Anticipating the future course of combatant surface ships, Mr. Pitts co-founded the NSWCDD Advanced Computing Technology effort, which eventually became the Aegis/DARPA-sponsored High Performance Distributed Computing Program; the world's most advanced distributed real-time computing technology effort. That effort was the foundation for the Navy's current Open Architecture Initiative.

In 2003 Mr. Pitts accepted responsibility as Technical Director for PEO Integrated Warfare Systems (IWS), the overall technical authority for the PEO. In September of that year, he was reassigned as the Major Program Manager for Integrated Combat Systems in the PEO. In this position, he was the Program Manager for the Combat Systems and Training Systems for all U.S. Navy Surface Combatants, including Aircraft Carriers, Cruisers, Destroyers, Frigates, Amphibious Ships, and auxiliaries. In July, 2006, Mr. Pitts returned to NSWCDD to form and head the Warfare Systems Department. While in this position, he maintained his personal technical involvement as the certification official for Surface Navy Combat Systems. He also served as Chair of the Combat System Configuration Control Board and Chair of the Mission Readiness Review for Operation Burnt Frost, the killing of inoperative satellite USA 193.

Mr. Pitts has been a guest speaker/lecturer/symposium panelist at many NAVSEA-level and DoD symposiums, conferences and at the Naval Postgraduate School, the Defense Systems Management College, and the National Defense University. For 19 years Mr. Pitts was the sole certification authority of all Aegis Combat System computer programs for fleet use. He retired from the U.S. Civil Service in September 2008, with over 40 years of service to the Navy.

Brigadier General Michael E. Williamson, US Army—Joint Program Executive Officer for the Joint Tactical Radio System.

General Williamson was born in Tucson, Arizona. He was commissioned at the University of Maine as a Second Lieutenant in the Air Defense Artillery in 1983. His assignments include service as the Automation Officer for the 32nd AADCOM in Darmstadt Germany. He then served as a Chaparral Platoon Leader, Vulcan Platoon Leader, Maintenance Officer and Executive Officer in C Battery, 108th Brigade, Hahn Air Force Base, Germany. After attending the Air Defense Artillery Advance Course, he served as the Chief, Forward Area Air Defense Weapons, Development Branch at Fort Bliss, Texas. He then commanded B Battery, 3/1 ADA (Hawk) in the 11th Brigade at Fort Bliss and also in the 31st ADA Brigade at Fort Hood, Texas. After completing command, he served as the Assistant S-3 in the 31st ADA Brigade.

His acquisition experience began as Sr. Military Software Analyst at NATO's military headquarters in Mons, Belgium. He then served as the Associate Director, Battle Command Battle Lab at Fort Leavenworth, Kansas. After attending Command and General Staff College, he served as the Chief of Information Technology, Acquisition Career Management, within the Office of the Assistant Secretary of the Army for Acquisition Logistics and Technology. He was then selected as a Congressional Fellow and served as a legislative assistant to a Member of Congress. After completing the fellowship, General Williamson served as the Product Manager for the Global Command and Control System-Army, and then as the Acquisition Military Assistant to the Secretary of the Army. He served as Commander of Software Engineering Center-Belvoir (SEC-B), He was then assigned as the Project Manager, Future Combat System (Brigade Combat Team) Network Systems' Integration within Program Manager, Future Combat System (Brigade Combat Team). He then served as the Director of Systems Integration, within the Office of the Assistant Secretary of the Army for Acquisition Logistics and Technology. Prior to his current assignment, General Williamson served as the Deputy Program Manager, Program Executive Office, Integration.

General Williamson's awards and decorations include the Legion of Merit with two Oak Leaf Clusters; the Meritorious Service Medal with 2 Oak Leaf Clusters; the Joint Service Commendation medal, the Army Commendation Medal with two Oak Leaf Clusters, the Joint Service Achievement Medal, the Army Achievement Medal with two Oak Leaf Clusters, the Army Superior Unit Award, the National Defense Service Medal with Bronze Star, the Global War on Terrorism Service Ribbon, the Army Service Ribbon, the Overseas Ribbon and the Army Staff Identification Badge.

General Williamson's education includes a Bachelor of Science from Husson College in Business Administration, a Masters of Science in Systems Management from the Naval Postgraduate School and a PhD in Business Administration from Madison University. He also has graduate certificates in Public Policy from the JFK School of Government, Harvard University and the Government Affairs Institute at Georgetown University. He is a graduate of the Army Command and General Staff College, a graduate of the Advanced Management Program at the Harvard Business School and was a Senior Service College Fellow at the University of Texas at Austin. He is Level III certified in Program Management and Communications and Computers.

Military Cost-Benefit Analysis: Introducing Affordability in Vendor Selection Decisions

Francois Melese—Professor, Economics, and Deputy Executive Director of the Defense Resources Management Institute (DRMI), NPS. Professor Melese has published over 50 articles and book chapters on a variety of topics and, together with NPS colleagues, was among the first to apply transaction cost economics to generate new insights into military cost estimating. He is a member of Sigma Xi, the Western Economic Association, and the American Economic Association. Dr. Melese joined the DRMI faculty in 1987. [fmelese@nps.edu]

Anke Richter—Associate Professor, NPS. Dr. Richter received a BA in Mathematics and French from Dartmouth College (1991) and a PhD in Operations Research from Stanford University (1996). Her graduate work was supported by a grant from the Office of Naval Research. Dr. Richter was previously a Director of Health Outcomes at RTI-Health Solutions, RTI International. Her research interests include resource allocation for epidemic control, disease modeling and economic impact assessment, and bio terrorism. She has published in numerous journals. Dr. Richter is a member of the Institute for Operations Research and the Management Sciences (INFORMS) and the International Society for Pharmacoeconomics and Outcomes Research (ISPOR). She has published in several peer-reviewed journals, including the *Journal of the American Medical Association*, *Journal of Clinical Epidemiology*, *PharmacoEconomics*, *Medical Decision Making*, *Clinical Therapeutics*, and *Managed Care Interfaces*. Although English is Dr. Richter's first language, she is also fluent in German and French. She joined the NPS faculty in August 2003. [arichter@nps.edu]

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Abstract

This study extends previous research by the authors that focuses on the growing global challenge of affordability. Ballooning public debt burdens are forcing countries around the world to rethink their approaches to procurement decisions. This paper offers a new approach to government vendor selection decisions in major public procurements. A key challenge is for government purchasing agents to select vendors that deliver the best combination of desired non-price attributes at realistic funding levels. The mechanism proposed in this paper is a three-stage, multiattribute, sealed-bid procurement auction. It extends traditional price-only auctions to one in which competition takes place exclusively over attribute bundles. The model reveals benefits in public procurements by defining an alternative in terms of its value to the buyer over a range of possible expenditures, rather than as a single point in budget-value space. This approach leads to some interesting results. In particular, it suggests that in a fiscally constrained environment, the traditional approach of eliminating dominated alternatives could lead to sub-optimal decisions. The final extension of the model explicitly examines the buyer's decision problem under budget uncertainty. The result is in a new metric proposed to evaluate vendors: an expected utility measure of performance.

Introduction

This study focuses on the growing global challenge of affordability. Ballooning public debt is forcing countries around the world to rethink their procurement strategies. Recent congressional testimony urges the DoD to "achieve a balanced mix of weapon systems that are affordable" (Written testimony of M. Sullivan , 2009). In the absence of profits to guide public procurement decisions, the challenge is to select vendors that deliver the best possible combination of desired non-price attributes at realistic funding levels. The public procurement mechanism proposed in this paper is a multiattribute sealed-bid procurement auction with multiple budgets.

The U.S. Federal Acquisition Regulation (2005) provided guidance in Subpart 14.5 on a two-step procurement process for government agencies:

> Step one consists of the request for, submission, evaluation, and (if necessary) discussion of a technical proposal. No pricing is involved. Step two involves the submission of sealed price bids by those who submitted acceptable technical proposals in step one. Invitations for bids shall be issued only to those offerors submitting acceptable technical proposals in step one. An objective is to permit the development of a sufficiently descriptive and not unduly restrictive statement of the Government's requirements especially useful for complex items.

Blondal (2006) discusses a similar two-stage[1] bidding process, in which the procuring agency issues a general request and then later issues a detailed request based on the responses.

Much of the multiattribute auction literature, including Che (1993), Beil and Wein (2003), and Parkes and Kalagnanam (2005), either implicitly or explicitly includes price alongside non-price attributes in the buyer's value/utility function.[2] While this standard approach is appropriate in many private-sector contexts, it generates complications in public procurements such as major defense acquisitions. Unlike the private sector, where the incentive to maximize profits provides a clear objective, the best government decision-makers can do is to maximize value to the public subject to funding (budget) constraints.

In an application that maximizes value subject to a budget constraint, Michael and Becker (1973) make the case that costs be excluded from measures of value. The authors' focus is on performance and affordability. Vendors compete for a government contract based on their relative costs of producing different components of quality and their unique (sunk) technology investments that define their ability to offer different tradeoffs among these components. A similar approach is known as "cost as an independent variable" (CAIV). Larsen (2007) offers the following explanation of CAIV:

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[1] Blondal defined *stage* differently than we do in this paper. We use the term to refer to a decision or set of decisions that depends only on exogenously given parameters and previous decisions. For example, Blondal considers a government agency's offer and the vendor responses to be a single stage, whereas we treat these as two distinct stages. Using our interpretation, Blondal's model is, in fact, a five-stage process.

[2] Value functions are often referred to in defense procurement as *measures of effectiveness* (MOEs). The term MOE is used in a few different ways. It may describe an attribute itself, a single-attribute value function, or a multiattribute value function, which might incorporate the whole objective's hierarchy, or only a portion of it. For a detailed discussion of MOEs, see Sproles (2000). Regardless, this paper emphasizes using an MOE that includes exclusively non-price attributes.

> All acquisition programs/issues consist of three fundamental elements: cost, performance and schedule. Under CAIV, performance and schedule are considered a function of cost. Cost and affordability should be a driving force, not an output after potential solutions are established. (p. 15)

Loerch, Koury, and Maxwell (1999) discuss a *Value Added Analysis* approach for applying multiattribute preferences to optimize the United States Army's force structure under a budget constraint, in accordance with the CAIV concept. The scope of our model differs from theirs, in that we focus on a single acquisition program. This allows us to incorporate vendors' decision-making into the model, along with issues of asymmetric information. In our model, as in theirs, prices and costs do not appear in the buyer's value function. Instead, the buyer provides information about possible budget levels, allowing prices to appear in affordability constraints in the spirit of CAIV.

Budget constraints may not be known when the vendor selection decision is made. Buede and Bresnick (1999) describe the acquisition process as having four major phases and point out that vendor selection occurs in the first phase, while the budget may change throughout the entire process. Two pioneers in defense economics, Hitch and McKean (1967), advocate determining the maximum effectiveness for a given budget and then examining how each alternative fares under several different budget scenarios. Quade (1989) also advocates evaluating vendor proposals based on a range of possible budgets. This leads to the generation of what we call an "expansion path" for each vendor, which shows how the vendor's proposals change as the budget increases or decreases and thus provides a more complete view of the vendor's ability to provide performance. Our model allows the buyer to offer a set of possible budget levels and solicit vendor proposals for each one, leading to the generation of expansion paths.

Expansion paths reveal valuable information to government procurement agents. Suffering from asymmetric information, buyers have very limited knowledge of the vendors' costs of producing a particular attribute, as well as the technologies (production functions) that combine those attributes into products under consideration. Parkes and Kalagnanam (2005) describe the vendors' private information: "Seller costs can be expected to depend on [the] local manufacturing base and sellers can be expected to be well informed about the cost of (upstream) raw materials" (p. 437). The general motivation for constructing the expansion paths is expressed succinctly by Keeney (2004): "If you do not have the right problem, objectives, alternatives, list of uncertainties, and measures to indicate the degree to which the objectives are achieved, almost any analysis will be worthless" (p. 200). It is imperative in public procurement for alternatives to be adequately described and for any budget uncertainty to be explicitly acknowledged. We emphasize that this can be carried out using a *value-focused thinking* approach, as discussed by Keeney (1992) and by Parnell (2007) in the context of national defense. That is, it is important for the buyer's evaluation process to be carried out independent of the particular alternatives offered.

In the Model section, we introduce our proposal for a three-stage procurement model. This multiattribute sealed-bid procurement auction emphasizes the use of a value function with exclusively non-price attributes and the specification of a set of possible budget levels. We formulate the decision problems faced by the buyer and the vendors, and discuss various insights derived from the model. We also provide two historical examples of government procurement decisions that likely could have benefited from a more complete formulation of alternatives and specification of uncertainties.

After vendor bids have been solicited for a spectrum of possible budget levels, the Budget Uncertainty section expands the formulation of the buyer's problem to explicitly include the buyer's beliefs of the probability associated with various budget levels. We follow a decision under uncertainty approach as introduced by Pratt, Raiffa, and Schlaifer (1964). In addition to expressing their beliefs about various budget levels as probabilities, the government buyer specifies a utility function over the value of attribute bundles that incorporates his or her risk attitude, as discussed by Dyer and Sarin (1982) and Matheson and Abbas (2005). The result is a new metric proposed to evaluate vendors: an expected utility measure of performance.

Model

The procurement agency (the buyer) begins by specifying a multiattribute value function over a set of desired attributes $A = \{a_1, \ldots, a_n\}$, as well as a set of (increasing) possible budget levels $B = \{b_1, \ldots, b_k\}$. There are *m* vendors, each of whom will respond in the second stage with a bid. A bid consists of a set of attribute levels that can be produced by a vendor for each of the *k* possible budget levels. Vendor *j*'s bid can be expressed as *k* vectors of the form $A_j = \left(a_{1j}, \ldots, a_{nj}\right)$ for $j = 1, \ldots, m$, where a_{ij} is the level of attribute *i* offered by vendor *j*. Note that unlike bids in most multiattribute auctions, A_j does not include any information about price. Instead, the price is captured in the multiple possible budget constraints. The buyer's ultimate decision (the third stage) is to select a vendor $j \in \{1, \ldots, m\}$. The buyer's preferences over the attributes are represented by a value function $V\left(A_j\right)$. The same value function is used for all possible realized budget levels.

For ease of exposition, we assume $V\left(A_j\right)$ is an additive multiattribute value function similar to that discussed by Keeney and Raiffa (1976) and Kirkwood (1997), although it is later demonstrated the conclusions of the paper do not require $V\left(A_j\right)$ to be additive. The use of additive multiattribute value functions requires the assumption of mutual preferential independence (Dyer & Sarin, 1979; Kirkwood & Sarin, 1980). This implies that alternatives can be compared exclusively on the set of attributes over which they differ, ignoring levels of other attributes.

For any given budget level, the buyer's objective is as follows:

$$\max_j \; V\left(A_j\right) = \sum_{i=1}^{n} w_i v_i\left(a_{ij}\right), \qquad (1)$$

where w_i is the weight the buyer places on attribute *i*: $0 \le w_i \le 1$, and $\sum w_i = 1$, and $v_i\left(a_{ij}\right)$ is the buyer's single-attribute value function for attribute *i*. We assume that $v_i(a_{ij})$ is scaled such that the minimum achievable value is zero and the maximum achievable value is one. Note that since $V\left(A_j\right)$ is a weighted average of terms between zero and one, it also ranges from zero to one. We assume the buyer has an understanding of the range of attribute levels in determining the weights and that the buyer explicitly shares the weights and the single-attribute value functions. It is necessary for the government buyer to completely specify its preferences to the vendors by providing w_i and $v_i(a_{ij})$ for $i = 1, \ldots, n$. The final stage of the model involves applying Equation 1 to the set of vendor bids and the buyer selecting the vendor that yields the highest value.

Given the buyer-determined set of desired attributes *A*, along with the weights and single-attribute value functions, and the set of possible budget levels *B*, each vendor produces an attribute bundle to submit to the buyer for each of the *k* possible budget constraints. Since vendors have private information about their own production capabilities, costs, and profit requirements, each vendor forms his or her own private beliefs about the likelihood of a bid being accepted.[3] We assume that all vendors believe the probability of a bid being accepted is increasing in $V\left(A_j\right)$ for all possible budget levels.

The problem faced by a representative vendor *j* for an arbitrary budget level *b* can be expressed as follows:

$$\max_{a_{ij}} \; V\left(A_j\right)=\sum_{i=1}^{n} w_{ij} v_i\left(a_{ij}\right),\; i=1,\ldots,n$$

$$\text{subject to } \; C_j\left(v_i\left(a_{1j}\right),\ldots,v_n\left(a_{nj}\right)\right)\le b\,, \qquad (2)$$

where C_j is the total cost paid by firm *j* (with the desired profit margin included) to produce a set of single-attribute values. The cost incurred to generate the corresponding attribute bundle cannot exceed *b*. We assume that C_j is increasing in v_i for all *i* and that C_j is strictly convex. This condition is not overly restrictive, since it simply implies decreasing returns from vendor investments to improve any individual attribute value. Because the objective function in Equation 2 is linear, given the assumed properties of a representative vendor's cost function, a unique solution (vendor proposal) will exist.

For purposes of illustration, and ease of exposition, the remainder of this study focuses on two vendors and two (non-price) attributes. The two vendors can have different technologies with which to combine the two attributes and may face different costs to improve individual attributes. The Lagrangian function to solve the vendor's problem is given by the following:

$$L_j = w_1 v_1\left(a_{1j}\right)+w_2 v_2\left(a_{2j}\right)-\lambda_j\left(b-C_j\left(v_1\left(a_{1j}\right),v_2\left(a_{2j}\right)\right)\right) \text{ for } j = 1,2. \qquad (3)$$

Since an improvement in either attribute increases the value of a particular attribute bundle to the buyer, or $\partial V / \partial v_i > 0$, each vendor will use the total available budget *b* to produce its attribute bundle proposal. In this case, first order necessary conditions for an optimum are given by the following:

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[3] For simplicity, we assume that each vendor determines its required profit margin for each possible budget level proposed by the buyer and that these fixed profit margins are incorporated into the attribute bundles offered. We focus on the vendor's decision of how to allocate fixed amounts of funding across the set of attributes to maximize the value provided to the buyer. Although our results do not require any more details of vendor behavior , we believe this would be an interesting avenue for future research. This exploration could be based on a vendor's search for an optimum bidding strategy in a Dutch auction (see McAfee & McMillan, 1987, or Milgrom, 1989), which requires a complete formulation of the bidder's beliefs, values, and risk attitude.

$$\frac{\partial L_j}{\partial v_1} = w_1 + \lambda_j \frac{dC_j}{dv_1} = 0 \quad (4a)$$

$$\frac{\partial L_j}{\partial v_2} = w_2 + \lambda_j \frac{dC_j}{dv_2} = 0 \quad (4b)$$

$$\frac{\partial L_j}{\partial \lambda_j} = b - C_j\left(v_1\left(a_{1j}\right), v_2\left(a_{2j}\right)\right) = 0\,, \quad (4c)$$

where Equation4c simply asserts that the total budget is being used. Solving Equations 4a and 4b yields

$$\frac{w_1}{dC_j/dv_1} = \frac{w_2}{dC_j/dv_2}\,. \quad (5)$$

This implies that the optimum strategy for each vendor is to choose a bid that uses the entire budget and for which the two attributes have equal ratios between the weight placed on the attribute by the buyer and the vendor's marginal cost of increasing the value provided by that attribute.[4] With two competing vendors, there will be two bids that can be represented by attribute bundles: $\left(a_{11}, a_{21}\right)$ and $\left(a_{12}, a_{22}\right)$.

Of course, cost functions are likely to vary across vendors, meaning that the marginal costs in Equation 5 are likely to vary across vendors as well, resulting in a potentially diverse set of bids. Multiattribute auctions allow vendors to differentiate themselves in the auction process and to bid on their competitive advantages (Wise and Morrison, 2000).

With the buyer's preferences and the vendor's bidding strategy in place, we now demonstrate how a buyer can explore important differences between vendors. Each vendor goes through the process described above for the *k* different budget estimates, each time producing a bid that satisfies Equation 5 for each of the *k* possible budgets. This set of bids from a vendor constitutes an expansion path. It tells the buyer precisely how a vendor's bid will change as the budget constraint is relaxed (or tightened). For purposes of illustration, throughout the remainder of the paper, we use a set of six possible budget levels to simulate alternative possible funding constraints: ($5M, $10M, $15M, $20M, $25M, $30M) or simply (5, 10, 15, 20, 25, 30).

Consider the following functional form for the cost functions:

$$C_j\left(v_1\left(a_{1j}\right), v_2\left(a_{2j}\right)\right) = \alpha_{1j} e^{\beta_{1j} v_1\left(a_{1j}\right)} + \alpha_{2j} e^{\beta_{2j} v_2\left(a_{2j}\right)}\,,\ \alpha_{1j}, \alpha_{2j}, \beta_{1j}, \beta_{2j} > 0 \text{ for } j = 1, 2\,. \quad (6)$$

This particular functional form is separable, in that it consists of the sum of cost functions on the individual attributes. Each individual attribute cost function is increasing and convex, where the exponent β_{ij} in Equation 6 determines the convexity of each

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[4] Note that Equation 5 has a unique solution for each vendor when the entire budget is being used. Because the cost function is strictly convex, as we move along the budget constraint curve, the marginal cost of improving one attribute's value is increasing, and the marginal cost of improving the other attribute's value is decreasing.

function. Although the results of the study do not depend on this particular functional form, this offers a relatively simple way to illustrate our expansion path approach to government vendor selection decisions.

Figure 1 offers an example of an expansion path. The buyer in this example places a weight of 0.7 on Attribute 1 and 0.3 on Attribute 2. The vendor represented in Figure 1, whom we will refer to as Vendor 1, faces lower marginal costs to improve Attribute 1 than to improve Attribute 2 at low levels. Specifically,

$$\alpha_{11} = 2.2, \alpha_{21} = 2.7, \beta_{11} = 2.0, \beta_{21} = 1.7 . \qquad (7)$$

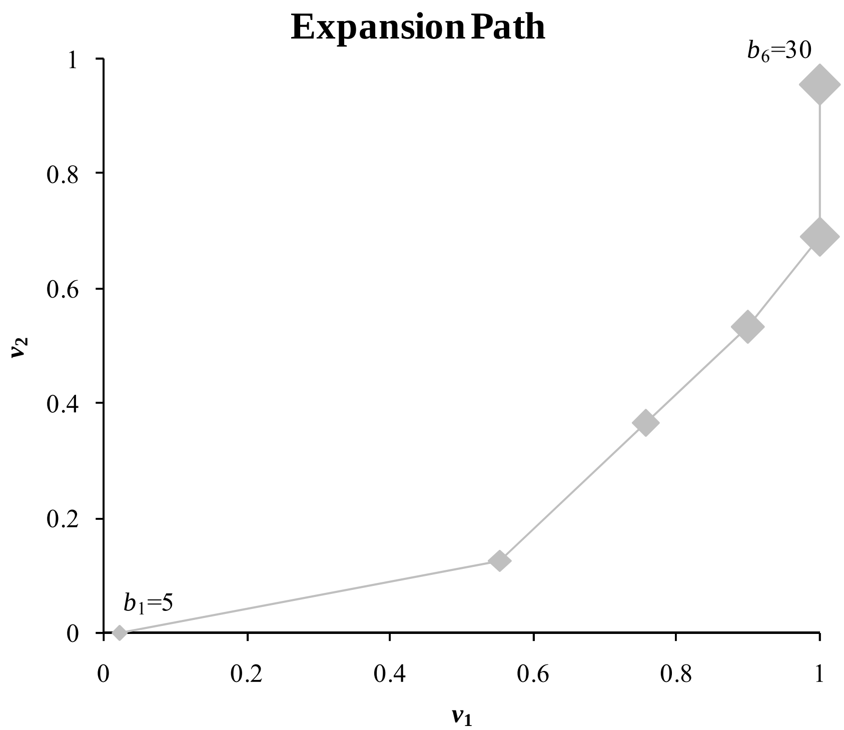

Figure 1. Expansion Path

Note. This graph shows the expansion path for a vendor as the budget increases from 5 to 30. The markers of increasing size show the vendor's attribute bundle proposals as the budget increases in increments of 5.

Expansion paths will differ among vendors if the parameters of their cost functions (α_{ij}, β_{ij}) differ. Consider a second vendor (Vendor 2), whose individual-attribute cost functions are more convex. Specifically,

$$\alpha_{12} = 1.5, \alpha_{22} = 1.5, \beta_{12} = 2.7, \beta_{22} = 2.7 . \qquad (8)$$

Vendor 2 is symmetric in the sense that he or she does not specialize in providing a particular attribute. Any asymmetry in Vendor 2's expansion path is due to the buyer having asymmetric preferences over the two attributes.

Applying the parameters in Equations 7 and 8 results in the expansion paths shown in Figure 2. The two piecewise linear expansion paths, one for each vendor, are based on the six possible budget levels.[5] They illustrate optimum combinations of attribute values that can be produced by each vendor and offered to the buyer at the different funding levels.

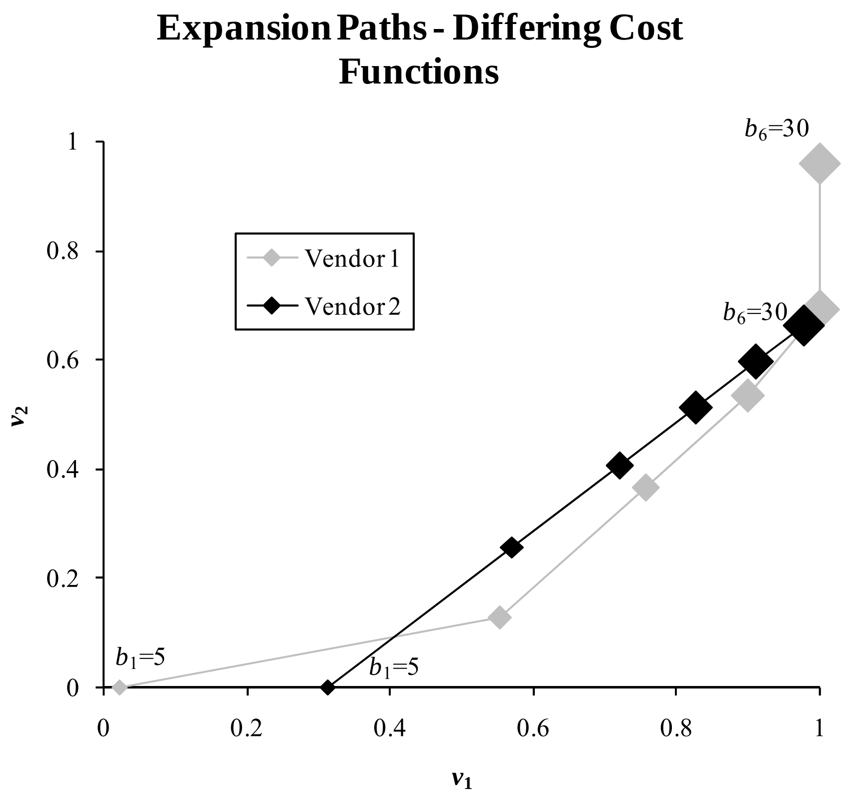

Figure 2. Expansion Paths—Differing Cost Functions

Note. This graph shows the expansion paths for two vendors with differing cost functions as the budget increases from 5 to 30. The markers of increasing size show each vendor's attribute bundle proposals as the budget increases in increments of 5.

Figure 2 reveals an interesting dynamic, which relates to one of the key insights of this study. Under optimistic assumptions about future budgets, it is clear that Vendor 1 will be preferred and selected as the winner. At relatively high budgets, Vendor 1 dominates Vendor 2. However, the reverse is true under a more pessimistic budget. Under severe budget constraints (e.g., $5 million), it is clear that Vendor 2 will be preferred and selected as the winner. If a government buyer believes a significant budget cut is possible then selecting a dominant alternative under the optimistic budget scenario (Vendor 1) may be misleading. The dominated alternative (Vendor 2) should not be prematurely eliminated since it may, in fact, end up being the preferred vendor.

[5] Fitting a curve to the points might also be a reasonable approach. We use a piecewise linear form because we specifically would like every attribute bundle in the vendor's bid to fall on the expansion path because we believe this makes the method more transparent. We would advise the analyst and the buyer to use their discretion on which approach to take, based on the particular context of the auction.

To illustrate this new expansion path approach more clearly, we compute $V(A_j)$ for each of the twelve attribute pairs shown in Figure 2. The two vendors' bids can then be plotted as curves in "budget-value" (or cost-effectiveness) space, as shown in Figure 3.

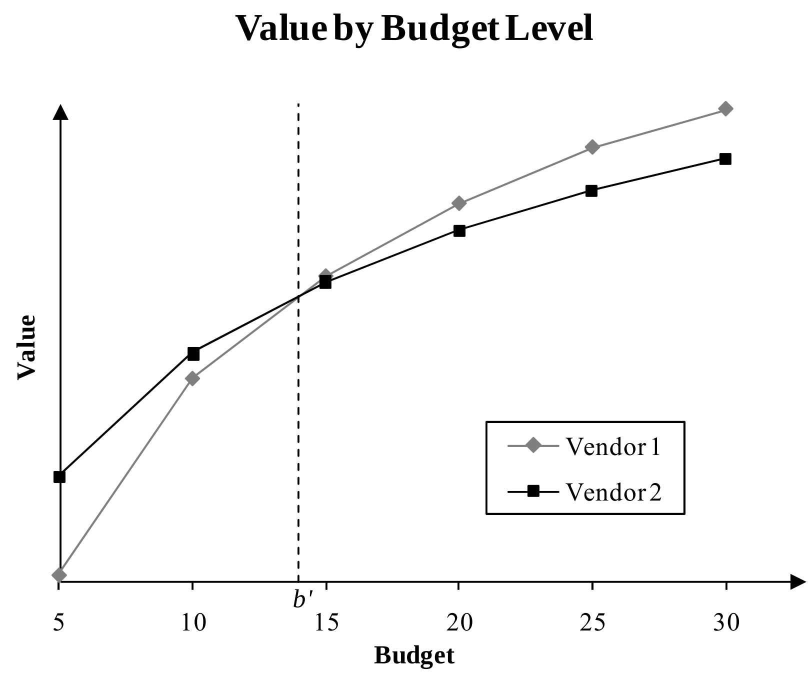

Figure 3. Value by Budget Level
Note. This graph shows the value provided by each vendor's bid for various budget levels.

Related to the expansion paths, the bids illustrated in Figure 3 are piecewise linear curves. We can think of each one as a function expressing the value to the buyer of the attribute bundles each vendor will provide over the range of possible budget levels. We will write this function for vendor *j* as $\Omega_j(b)$, defined for all possible budget levels *b*.

The dynamic revealed in Figure 2 is illustrated more clearly in Figure 3. It is apparent from Figure 3 that Vendor 2 dominates the competition for any positive budget below the switch-point, $b < b'$, while Vendor 1 dominates for any budget above the switch-point, $b > b'$. As Quade (1989) also discusses, this observation suggests rethinking the simpler definition of dominance, which refers to points (not functions) in cost-effectiveness space.

Viewing alternatives as functions in budget-value space reveals that the point-based definition can be misleading. A static comparison that begins by assuming a relatively high fixed budget would eliminate Vendor 2 from further consideration. For example, consider offers from Vendor 1 and Vendor 2 based on optimistic budgets above *b'*. A technique that focuses on points and not functions would eliminate Vendor 2; yet, Figure 3 indicates that eliminating Vendor 2 prematurely could lead to a less desirable outcome if subsequent budget cuts resulted in an actual budget somewhere in the range of $0 < b < b'$. This observation suggests the need for a new approach to government vendor selection decisions.

This switch-point phenomenon occurs as a result of differences in the two vendors' expansion paths. There is nothing unique about the particular functions chosen in our example. The same results can be obtained in many different ways, including with non-additive forms of the buyer's value function. In fact, non-linear interactions between attributes are likely to magnify this effect.[6]

While the approach in this paper involves assessing the expansion paths by soliciting vendors' attribute bundle offers for multiple budgets, it may be possible for a government buyer to obtain similar information by soliciting price bids for multiple sets of performance requirements (i.e., specified attribute levels). This would have the advantage of not requiring the buyer to reveal a value function, but also the corresponding disadvantage of not allowing each vendor the flexibility to achieve the desired values with the least costly combinations of attribute levels. Using either approach, the buyer benefits by being able to incorporate affordability into the decision in a meaningful way when the budget is not known with certainty. In particular, the buyer gains the ability to view each alternative as a function in cost-effectiveness space, rather than as a single point.

Selecting a vendor based on points in cost-effectiveness space can lead to worse outcomes than expected, since there may be uncertainties present that are implicitly ignored. One example is the $8.8 billion U.S. Navy and Marine Corps Intranet (NMCI) contract, which was awarded to Electronic Data System (EDS) in 2000. Wilson (2006) explains that EDS was the lowest bidder and that problems arose due to the scope of EDS' task being much larger than expected by either party. Whether another vendor might have performed better than EDS given the expanded scope is unknown. (See Jordan, 2007, for more information on NMCI.)

A second example is the U.S. Air Force's acquisition of the Boeing (then McDonnell Douglas) C-17 Globemaster III. This aircraft, commonly referred to as the C-17, is used as an airlifter for troops and cargo. McDonnell Douglas' C-17 proposal was selected in 1981, effectively ending the bidding process. However, a dollar amount was not specified until 1986, when the Air Force awarded McDonnell Douglas a $3.39 billion contract. Even after 1986, the C-17 program was subjected to a great deal of change. Kennedy (1999) explains the following:

> In addition, how much airlift was required for war plans was largely undefined. Securing necessary funding for the C-17 was simply an ordeal. That the program's funding fell victim to the budget axes wielded by Congress, DoD, and Air Force undermined the ultimate goal—timely operational delivery of the C-17.

As in the NMCI example, it would have been very difficult to foresee the eventual outcome for the C-17 based simply on a cost-effectiveness point when the decision was made.

The sensitivity of vendor selection decisions to different funding scenarios is a fundamental result that arises in a wide variety of government procurement contexts and places a premium on affordability. In a constrained fiscal environment, we strongly recommend the adoption of an expansion path approach to guide government vendor selection decisions.

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[6] For example, consider a multiplicative value function and suppose that one vendor has to incur a large cost to increase the value from 0 to 0.1 for one particular attribute. This vendor will offer bids of little value for low budgets but, depending on cost functions, may offer very attractive bids for higher budgets.

Budget Uncertainty

A natural extension of the model is to consider a procurement auction in which the buyer assigns a probability distribution over the set of possible budgets. If the buyer believes that the realized budget will be *b* with probability *p*(*b*) or, in the continuous case, that *b* has a probability density function *f*(*b*) then the government vendor selection problem can be examined using a decision under uncertainty approach.

This adds a valuable new layer to the problem: We must now include the buyer's risk attitude, because he or she will be evaluating gambles over multiple possible values. We express risk attitudes through a utility function *U*, which takes the overall multiattribute value measure as its argument (see Dyer & Sarin, 1982, or Matheson & Abbas, 2005, for details). This approach allows us to separate the buyer's attitude toward risk and their strength of preferences over the attributes.

Given a value function *V* and maximum and minimum achievable values, *U* can be assessed using simple binary gambles. For example, the buyer could specify an attribute bundle a^0 that provides the minimum value (zero) and an attribute bundle *a** that provides the maximum value (one) and then consider a hypothetical gamble in which he or she receives *a** with probability *p* and a^0 with probability 1-*p*. For any other attribute bundle *a'*, *U*(*V*(*a'*)) would simply be the value of *p* for which the buyer is indifferent between receiving the uncertain gamble and a certain value, *a'*.

The government buyer's new problem is to select a vendor *j* to maximize

$$\sum_b p(b)U\left(\Omega_j(b)\right), \tag{9}$$

or, in the continuous case, to maximize

$$\int f(b)U\left(\Omega_j(b)\right)db. \tag{10}$$

That is, the government buyer maximizes the expected utility provided by the vendor, incorporating both the strength of its preferences over the vendor's attribute bundle proposals, expressed by Ω_j, and its risk attitude, expressed by *U*.

Consider both the buyer and vendors' information used to generate Figure 2. Recall that the buyer places weights of 0.7 and 0.3 on Attributes 1 and 2, respectively, while individual vendor production and cost characteristics are given by the parameters in Equations 7 and 8). Now suppose the buyer has the exponential utility function[7]

$$U(V)=\frac{1-e^{-2V}}{1-e^{-2}}. \tag{11}$$

where, as previously specified, *V* varies between zero and one over the possible attribute bundles. The function and parameters given by Equation 11 represent a decision-maker who is risk averse. Note that since the minimum value of *V* is zero and the maximum is one, *U*(*V*) also varies between zero and one. Figure 4 illustrates the values and corresponding

[7] We chose the exponential function because it has constant absolute risk aversion, measured by a risk tolerance parameter (in this case, 0.5), making its assessment reasonably straightforward and understandable. It is commonly used in decisions under uncertainty, but the analysis could certainly be carried out using a different class of utility function if desired.

utilities to the buyer of each vendor's attribute bundle proposals under the six possible budget scenarios, superimposed on the utility function defined by Equation 11.

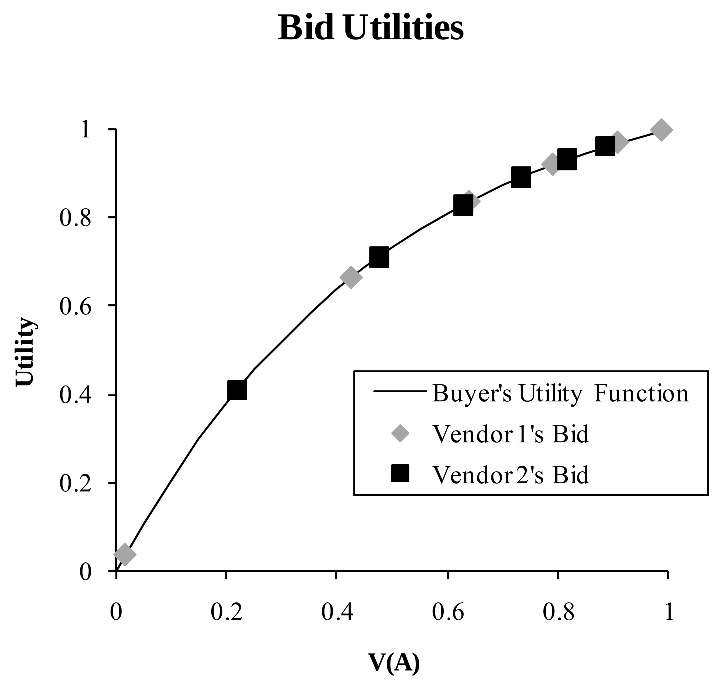

Figure 4. Bid Utilities

Note. This graph shows the buyer's utility function and the value and corresponding utility offered by each vendor for the six budget scenarios in the decision under uncertainty example.

Consider a scenario in which the buyer believes that b_1, …, b_6 will occur with probabilities 0.1, 0.15, 0.35, 0.25, 0.1, and 0.05, respectively. Given these probabilities for the six budget levels and this particular buyer's preferences, the expected utility if Vendor 1 is selected is 0.771, as opposed to 0.800 if Vendor 2 is selected. While this aggregate result suggests that our buyer should select Vendor 2, disaggregating the vendor selection problem offers additional insights.

The bundle of attributes provided by Vendor 1 would be more desirable for budget levels 15, 20, 25, and 30, one of which is likely to occur with a probability of 0.75. However, in the case of a very low budget, Vendor 1's attribute bundle would be far less desirable. Yet, the expected values of the two bids are nearly identical. Such insights would be nearly impossible to obtain when presented with only a single bid from each vendor for the most likely budget, b = 15. More revealing and robust analysis is only feasible if the buyer solicits bids from the vendors over multiple possible budget levels.

Constructing a gamble over possible overall values is extremely difficult if a vendor's bid consists of only one attribute bundle for a single budget, rather than a set of attribute bundles for multiple budgets. A decision under uncertainty approach requires decision-makers to place a value on all possible outcomes. The procurement auction framework advocated in this paper ensures that these outcomes are fully specified.

Conclusion

This paper offers a new approach to government vendor selection decisions in major public procurements. The paper describes a simple three-stage, multiattribute procurement process for government vendor selection decisions. It allows the buyer to incorporate the government's preferences over multiple attributes, and it allows each vendor to offer its best possible bid based on the budget estimate for the program and on each vendor's cost structure. The model operationalizes a version of the popular concept of cost as an independent variable (CAIV). The results of this study reveal the importance in the public sector of including costs as part of a budget constraint, rather than incorporating costs directly in the buyer's value and utility function.

The model developed in this paper allows vendors to submit bids for a range of possible budget levels. This leads to the generation of an expansion path for each vendor, which illustrates how each vendor's bid improves as budgets increase. Most importantly, it is demonstrated that a vendor whose bid is dominated at one particular budget level can easily end up being the winner at another budget level. This makes it vital for procurement agencies to rethink traditional public sector bid solicitations. Instead of viewing each vendor as a single point in cost-effectiveness space, it is important for governments to view each vendor as a curve in budget-value space. In economies where affordability is a priority and where budgets are likely to change over time, the approach proposed in this paper can result in better choices for voters and taxpayers since it ensures vendors are not prematurely eliminated from consideration.

Finally, since precise funding levels may not be known with certainty when vendor selection decisions are made, we explicitly model vendor selection as a decision under uncertainty. In this case, the buyer assigns a probability distribution over all possible budgets (funding levels) while a utility function captures the buyer's attitude toward risk. This methodology enables buyers to generate expected utilities from vendor proposals, providing a valuable new approach and metric for government vendor selection decisions.

The approach in this paper can be thought of as a strategic choice of auction mechanism for a buyer when a range of budget authorities for the program can be estimated and products are differentiated and complex. The approach combines the competitive advantages of auctions with the flexibility of decisions based on multiple attributes of a product, all while incorporating considerations of affordability when the budget level is not known with certainty.

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On a Quantitative Definition of Affordability

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Abstract

This paper introduces a definition of affordability based on the microeconomic theory of the consumer. We replace utility maximization with effectiveness maximization and discuss our conceptualization in terms of a cost-effectiveness framework. We convert our original ideas into a more useful degree (amount) of affordability (i.e., we ask not "Is it affordable?" but "How affordable is it?"). This allows us to attach meaning to, and interest in, the concept of an affordability index—or the measurement of the degree of affordability.

Introduction

There is currently intense debate over whether various government programs (e.g., health care, defense, and the environment) are affordable. There are also questions about the long-term affordability of Social Security and Medicare. Given that affordability is at the forefront of many of these programs, it is imperative that we can define and quantify it. Affordability is a concept that everyone seems to understand, but that everyone also has trouble precisely defining and even more trouble quantifying. Webster's defines affordability as "the ability to manage or to bear the cost of without serious loss or detriment." But this begs the question; what is "serious loss or detriment?" This ambiguity is prevalent in the affordability literature. For example, Kroshl and Pandolfini (2000) note that

> No single formula precisely defines an affordable system. As a micro-concept, an affordable system is procured when needed within a budget, operated at a desired performance level, and maintained and supported within an allocated life-cycle budget. As a macro-concept, affordable systems are constrained by top-

> line budgets, require timing for competing uses of resources, and must contend with the dimension of inflexibility in near-term budgets, although long-term considerations may make many programs justifiable.

Redman and Straton (2001) define affordability as

> that characteristic of a product or service that enables consumers to: (1) *procure* it when they need it; (2) *use it to meet their performance* requirements at a level of quality that they demand; (3) *use it whenever they need it* over the expected life span of the product or service; and (4) *procure it for a reasonable cost* that falls within their budget for all needed products or services.

With regard to defense programs, the relatively recent emphasis on affordability[1] is in marked contrast to the Department of Defense's behavior during the Cold War. Then, the emphasis was on effectiveness, and cost, if considered at all, was just another variable. The end of the Cold War brought a defense drawdown and accompanying budget cuts, causing an increased emphasis on cost in resource allocation decisions. This emphasis was formalized in a July 19, 1995, memo titled "Policy on Cost-Performance Trade-Off" signed by the then Under Secretary of the U.S. Department of Defense for Acquisition and Technology. The memo introduced the cost-as-an-independent-variable (CAIV) initiative. CAIV mandated that decisions be made considering both total life-cycle costs (TLCC) and effectiveness as the decision variables. While CAIV made TLCC visible, it allowed for trade-offs between effectiveness and TLCC. Thus, if decision-makers put enough weight on effectiveness, they could still approve systems that were not necessarily affordable, leading the DoD to revise the concept of affordability. The DoD defines affordability as "the degree to which the life-cycle cost of an acquisition program is in consonance with the long-range investment and force structure plans of the Department of Defense or individual DoD Components."

It is interesting that the U.S. Department of Defense has difficulty in identifying what is or is not affordable. In our private lives, we all know implicitly what affordability means. For example, in deciding whether to buy a new car, I have many options, including keeping my old car rather than buying a new one. To make my decision, I must decide how much I am willing to spend on a car as well as decide what attributes I desire in a car. One of the options I could consider might be a luxury car. In evaluating the affordability of a luxury car, I would determine whether it fit into my budget. At this point, things get a little complicated. What does fit in my budget mean? It might mean that I have already determined the maximum amount I am willing to spend on a car. In that case, the luxury car either costs no more than my pre-determined amount or it doesn't (i.e., is affordable or isn't). On the other hand, I might have in mind an amount I am willing to spend on a car, but I might also be willing to make trade-offs with other items in my budget if the alternative exceeds my pre-determined amount. For example, I might be willing to forego eating in restaurants, going to the movies, etc., in order to buy the luxury car. In that case, I would want the utility of a combination of goods that includes the luxury car to offer at least as much utility as any combination of goods that does not include the luxury car. Therefore, the luxury car is affordable if, after making trade-offs, it fits in my budget and produces at least as much total utility as I would have without it. This leads to a workable definition of affordability: A system is affordable if, after making any desired tradeoffs, it fits in the budget and offers at least as much utility as the current mix of systems.

[1] For another view of affordability and an excellent review of the affordability literature, see Melese (2010).

Our goal in this paper is to develop an operational definition of affordability that lends itself to quantification. We first lay out a model of choice that is the foundation of modern economic reasoning. We next apply this formulation to a defense budget decision. Finally, we construct a quantifiable, operational affordability measure.

The Model

Assume that the government defense agency currently produces or purchases a good q_1 at a unit cost of c_1 that provides social utility (i.e., contributes to the defense of the country). Suppose a new good, q_2, at a unit cost of c_2, is available, where q_2 can be independent of, a substitute for, or a complement to q_1. Assume also that the agency currently has a budget of B, which it uses to purchase or produce a quantity q_1^* of the good q_1. Assuming a social utility function $U = f(q_1, q_2)$, the agency faces three possible situations. The first is that q_2 is not affordable, in which case the agency will not produce or purchase it. In the second situation, q_2 is affordable, and social utility is maximized by partially substituting q_2 for q_1. In this case, both q_1 and q_2 will be produced or purchased. In the third case, q_2 dominates q_1 and social utility is maximized by discontinuing q_1 and producing or purchasing only q_2. We examine each case in more detail below.

Case 1: q_2 Is Not Affordable

If $c_2 > B$, q_2 is clearly not affordable unless funds are available to increase B. If the situation is as shown in Figure 1, however, the affordability of q_2 is not clear. In Figure 1, q_1^* is the quantity of q_1 given a budget level of B and a price of c_1 with q_2 not included (i.e., it is the status quo). Including q_2 results in the budget line and social indifference curves shown. $U = f(q_1^*, 0)$ is the indifference curve representing the combinations of q_1 and q_2 that produce as much utility as q_1^*. Note that there are combinations of q_1 and q_2 that satisfy the budget constraint. Many of the definitions of affordability noted above define affordability by whether it fits within the budget constraint. Under these definitions, q_2 is affordable. By our definition of affordability, however, q_2 is not affordable because, whereas q_2 fits within the budget constraint, adding q_2 does not achieve a utility level at least as high as q_1^*. There is no combination of q_1 and q_2 that both satisfies the budget constraint and produces as much utility as q_1^*. With a budget level of B, adding q_2 results in lower utility; therefore, q_2 does not meet our definition of affordability, and q_2 is not produced. This explains a lot of seemingly paradoxical behavior. For example, in the debate over health care some note that there are families and individuals who seem to have enough income to purchase health insurance yet do not. The reason is that their expected level of utility with health insurance in their mix of consumption goods is lower that the mix without it given their income.

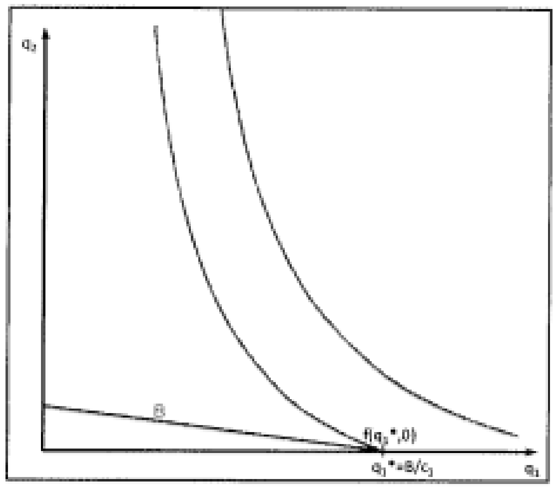

Figure 1. Case 1

Case 2: q_2 Is Affordable, Leading to the Production or Purchase of Both q_1 and q_2

This case is shown in Figure 2. As before, $U = f(q_1^*, 0)$ is the indifference curve showing the combinations of q_1 and q_2 that produce as much utility as q_1^*. In this case, however, there are combinations of q_1 and q_2 within the budget constraint that produce as much or more social utility as does q_1^*. Point A is the combination of q_1 and q_2 that produces maximum utility for a budget level of B; however, any combination of q_1 and q_2 in the area between the indifference curve $U = f(q_1^*, 0)$ and the budget line B (shaded area) produces more utility and costs as much or less than q_1^*. Thus, q_2 is affordable.

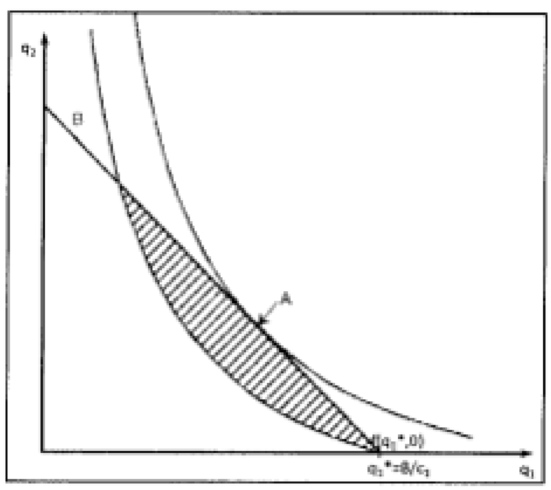

Figure 2. Case 2

Case 3: q_2 Dominates q_1

Given the contours of the indifference curves and the slope of the budget line in Figure 3, q_2^* satisfies the budget constraint while providing more utility than q_1^* or any combination of q_1 and q_2 that satisfies the budget constraint. Indeed, any quantity of q_2 between q_2' and q_2^* costs less and provides more utility than does q_1^*. In this case, only q_2 is produced.

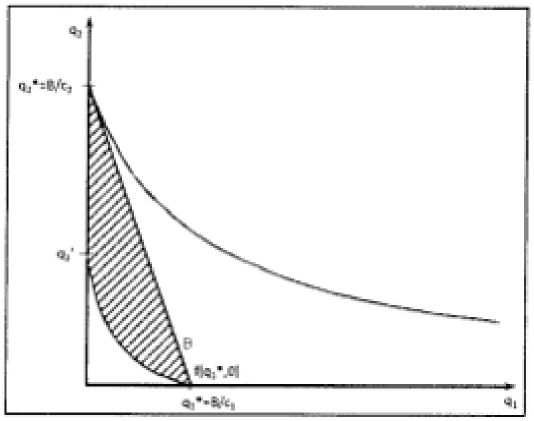

Figure 3. Case 3

In all three cases, the combinations of q_1 and q_2 that cost as much or less than the status quo lie in the triangle formed by the budget line and the q_1 and q_2 axes, that is, by the origin q_1^* and q_2^*. The combinations of q_1 and q_2 that meet our definition of affordability are contained in the area between the budget line and the indifference curve (the shaded area in Figures 2 and 3). This leads directly to a quantifiable measure of affordability: It is the ratio of the set of combinations of q_1 and q_2 that produce at least as much utility as q_1^* to the set of all combinations of q_1 and q_2 that cost as much or less than q_1^*. This ratio defines an affordability index a such that $0 \le a < 1$.

Extensions

More Than One Good in the Status Quo Budget

In this case, q_1 represents a vector of goods. Let q_i, $i = 1,...,n$ be the existing goods, with q_1^* representing the optimal mix of the current goods. Introducing q_2 into the mix leads to the same three cases described above except that the tradeoffs are now among multiple goods.

Affordability Over Time

Many affordability decisions involve long-lived assets and therefore affordability must be assessed over multiple time periods. Affordability over time is much more complicated than affordability over a single time period. In this situation, every time period must be assessed for the existence of the three cases above. By our definition of affordability, if in any one-time period the first case holds, q_2 is not affordable. However, if it is possible to alter the budget in a particular period where q_2 is not affordable so that it becomes affordable without making it unaffordable in another period, then it meets our criteria for affordability.

Illustrative Example

Let the measure of effectiveness for each alternative system be described by an exponential function with two nonnegative parameters a_i and c_i:

$$v_i(q_i) = 1 - e^{-g_i(q_i)} \tag{1}$$

where

$$g_i(q_i) = a_i q_i^{b_i}.$$

The parameter a_i determines the rate at which v_i increases with $q_i^{b_i}$. The parameter b_i affects the shape of v_i in that $b_i > 1.0$ produces S-shaped curves while $b_i \le 1$ produces concave growth curves. This function is general enough to exhibit both increasing and decreasing marginal effectiveness.

Let the joint effectiveness of the two systems be described by

$$v(q_1, q_2) = 1 - e^{-f(q_1, q_2)}$$

where

$$f(q_1, q_2) = g_1(q_1) + g_2(q_2) + d \cdot g_1(q_1) \cdot g_2(q_2). \tag{2}$$

The parameter d represents synergistic affects between q_1 and q_2. If $d > 0$ then q_1 and q_2 reinforce one another and produce a higher measure of effectiveness for the same (q_1, q_2) than when $d = 0$. This joint function exhibits two important traits. First, it exhibits eventually decreasing marginal effectiveness along any direction in the $(q_1, q_2)-$plane. Second, $v(q_i, q_j) \to v_i(q_i)$ as $q_j \to 0$ so that the joint measure of effectiveness reduces to the appropriate individual measure of effectiveness when one alternative is removed. These effectiveness measures are defined for all non-negative (q_1, q_2) but we will restrict our consideration to only integer values of q_1 and q_2.

Suppose the current system is such that $a_1 = 0.17$ and $b_1 = 0.6$ while the new, more effective, system is such that $a_2 = 0.21$ and $b_2 = 0.8$. Also assume $d = 0.3$. This produces a joint measure of effectiveness with the effectiveness contours presented in Figure 4.

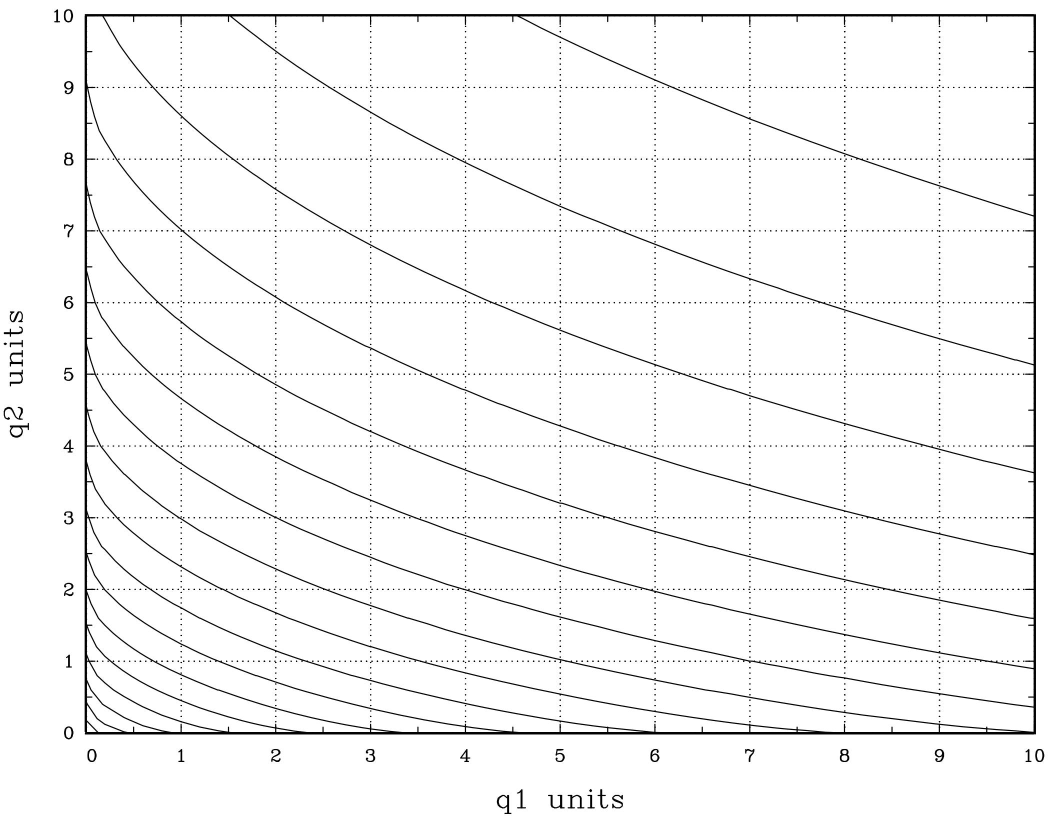

Figure 4. Contour Plot for $v(q_1, q_2)$ of Equation 2

Suppose the budget is $B = 10$ and assume that the current system inventory is $q_1 = 10$ so $v_1(10) = 0.492$. Is the new alternative affordable? To answer this we need to specify c_2. Suppose there are four cases to consider: $c_2 = 1, 2, 5$ and 10. Each produces a budget constraint line between $(q_1, q_2) = (10, 0)$ and $(q_1, q_2) = (0, q_2^{\max})$, where $q_2^{\max} = 10, 5, 4, 2$ or 1, respectively.

The new system is affordable if there are (q_1, q_2) combinations for which

$$v(q_1, q_2) \geq v(10, 0) = v_1(10) = 0.492 \tag{3}$$

and

$$c_1 q_1 + c_2 q_2 \leq 10. \tag{4}$$

Figure 5 presents the situation graphically. The region for which $v(q_1, q_2) \geq 0.492$ is depicted by the set of closely spaced contours (at intervals of 0.004). All combinations of (q_1, q_2) for which $v(q_1, q_2) < 0.492$ occupy the region with no contours. The four regions for which (q_1, q_2) satisfy Equation 4 are identified by their respective lines. The situation shows that q_2 is not affordable when $c_2 = 10$. There are no integer solutions other than $(q_1, q_2) = (10, 0)$, that satisfy Equation 3 and Equation 4. If $c_2 = 5$, we find q_2 is affordable at $(q_1, q_2) = (5,1)$. If $c_2 = 2$, we find 14 integer solutions, other than $(q_1, q_2) = (10,0)$, that are affordable. Finally, if $c_2 = 1$, there are 44 combinations, other than $(q_1, q_2) = (10,0)$, that are affordable. The answer to the question of whether the new system is affordable clearly depends on c_2. If $c_2 = 10$, then "no." But if $c_2 < 10$, then "yes."

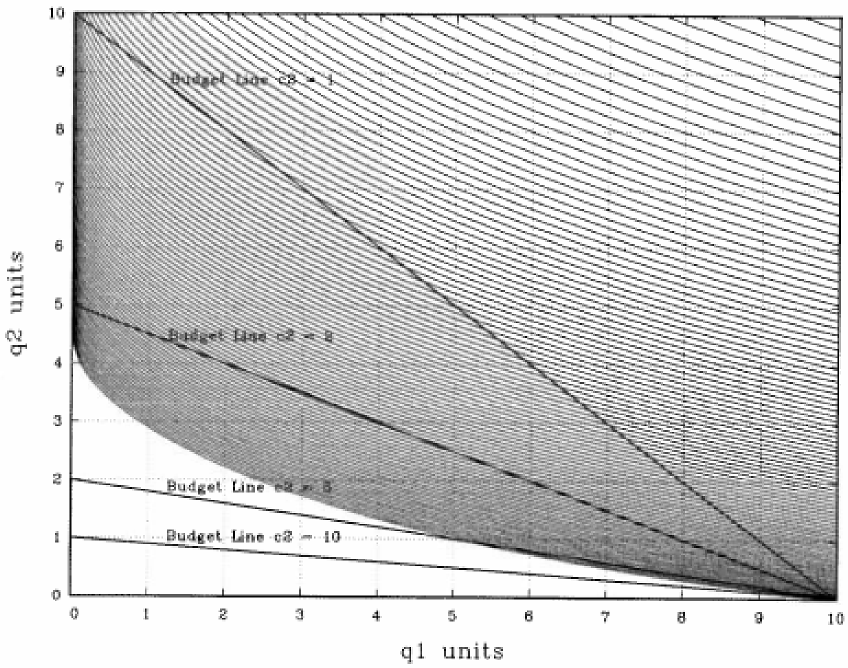

Figure 5. The Affordability of q_2 when c_2 = 10, 5, 2, and 1.0

If a system is deemed affordable, then the next question we ask is: How affordable is it? The answer is given by the affordability measure we developed in Section 2. The affordability measure is given by the area defined by Equation 3 and Equation 4 relative to the area defined in Equation 4 alone. The calculation of this area is an exercise in freshman calculus, but a useful approximation obtained by simple computation. All we need do is cover the area $\Omega = \{(q_1, q_2) \mid 0 \le q_1 \le 10; 0 \le q_2 \le 10\}$ with a grid of equally spaced points and count how many grid points lay within each area. If $N =$ the number of grid points satisfying Equation 3 and Equation 4, and $M =$ the number of grid points that lay on or below the respective budget line, then $A = N / M$ is an estimate of the measure of affordability. The finer the grid, the better the approximation. Table 1 illustrates this effect. $A^{(x)}$ denotes the value of A obtained using a grid of width x. The third column is the result of using an integer-based grid while the fourth and fifth columns present estimates for A using an increasingly finer grid.

Table 1. Affordability Measure

c_2	q_2	$A^{(1)}$	$A^{(0.1)}$	$A^{(0.01)}$
1.00	10	0.733	0.736	0.753
2.00	5	0.400	0.474	0.507
2.50	4	0.259	0.348	0.384
3.33	3	0.100	0.242	0.215
5.00	2	0.063	0.047	0.054
10.00	1	0.000	0.002	0.001

Note that N is an approximation to the area $\mathbf{N} = \{(q_1, q_2) \mid v(q_1, q_2) \geq v(0,10)$ and $B \geq c_1 q_1 + c_2 q_2\}$, while M is an approximation to the area $\mathbf{M} = \{(q_1, q_2) \mid B \geq c_1 q_1 + c_2 q_2\}$. Because $\mathbf{N} \subset \mathbf{M}$, it will always be the case that

$$0 \leq A \leq 1.$$

Affordability depends on more than just the alternative cost, c_2, and it is of value to use the model to study the effect of variations in other factors. For example, what is the change in the situation if the effectiveness of q_2 is further enhanced? Suppose the design of the alternative system can be improved so that $a_2 = 0.31$ and c_2 while all other parameters remain the same. This situation yields the measures of affordability in Table 2. We now find that even at $c_2 = 5.0$ the new system has a modest measure of affordability.

Table 2. Affordability Measure (a_2 = 0.31)

c_2	q_2	$A^{(0.01)}$
1.00	10	0.848
2.00	5	0.696
2.50	4	0.620
3.33	3	0.494
5.00	2	0.260
10.00	1	0.020

Of course, there are many other possibilities to consider. Not only is it of interest to understand the affect of the variation in a single variable, but also the affect of a combination of variables varying simultaneously. In the end we require a complete sensitivity analysis. Instead of pursuing these matters here, we prefer to consider the incorporation of uncertainty. To a certain extent a study of uncertainty and its effects on affordability is quite similar to a sensitivity analysis, but more focused.

Affordability-Effectiveness Analysis

Our paired-comparison development of affordability extends easily to the situation where we have multiple competing alternatives. Let there be a set of K candidate alternatives, each described by their overall effectiveness and discounted life-cycle cost: $\{v_k, c_k; k = 1, K\}$. The relative cost-effectiveness of the members is assessed in the usual way by viewing a scatter diagram plot of the members of this set in cost-effectiveness space (i.e., a plot of v_k versus c_k). We wish to replace this plot with a scatter diagram plot in affordability-effectiveness space; that is, a plot of v_k versus A_k. This is achieved by repeating the paired-comparison analysis process for each of the candidate systems in order to obtain their description in terms of the ordered pairs $\{v_k, A_k; k = 1, K\}$. We illustrate this using the data of the previous section.

Let the original system and the three candidate systems be described as before by Equation 1 and Equation 2 with parameters as given in Table 3.

Table 3. Multiple Candidate System Example

k	a_k	b_k	c_k
0	0.17	0.6	1.0
1	0.21	0.8	2.0
2	0.35	0.7	5.0
3	0.41	0.9	10.0

The evaluation of the three new systems gives $A_1 = 0.495, A_2 = 0.343, A_3 = 0.054$. The respective cost-effectiveness and affordability-effectiveness plots are presented in Figure 6.

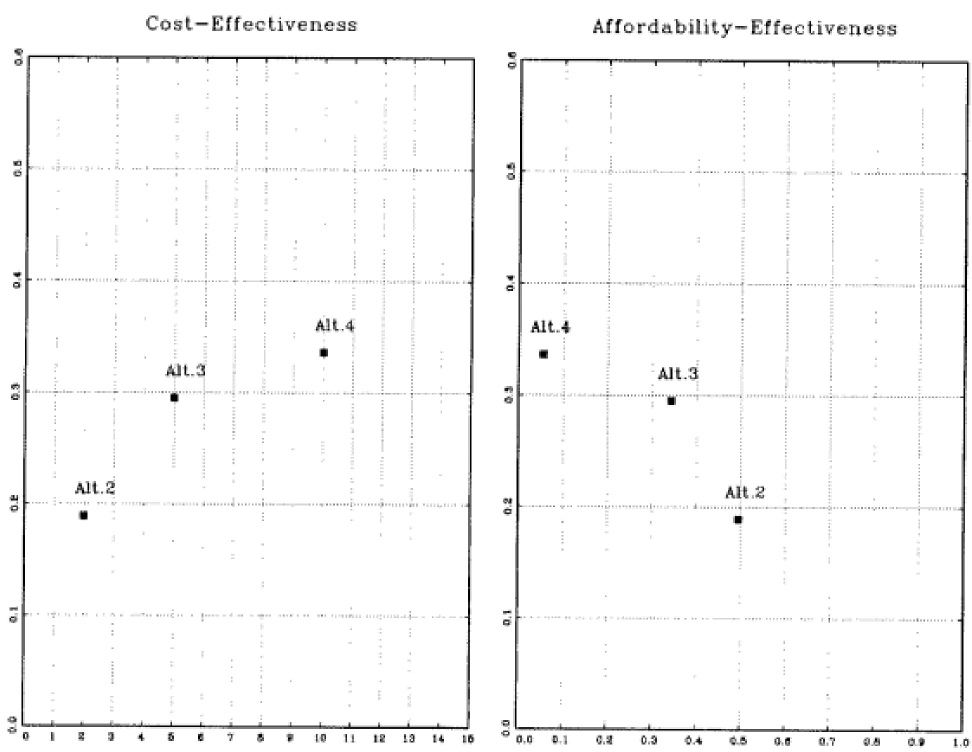

Figure 6. Cost-Effectiveness and Affordability-Effectiveness

Note how each may be viewed as the mirror image of the other. Both exhibit an efficient frontier, although with the opposite orientation with respect to the preferences of the horizontal axis. In the cost-effectiveness plot the preferred direction is upward and to the left while in the affordability-effectiveness plot the preferred direction is upward and to the right.

If the apparent mirror image of the two plots of Figure 6 is a pattern that always appears, then one could argue that the information produced by the affordability analysis offers nothing beyond the information contained in the cost-effectiveness analysis. The efficient set is the same in both plots and the trade-offs are mirror images of one another: Is the increase in effectiveness in choosing Alternative 3 over Alternative 2 worth the increase in cost? As opposed to: Is the increase in effectiveness in choosing Alternative 3 over Alternative 2 worth the loss in affordability? A small change in our example shows this not to be the case. Let the cost of Alternative 2 increase to $c_2 = 3.0$ and let that cost of Alternative 4 decrease to $c_4 = 9.0$. Application of our analysis to this new situation gives the results presented in Figure 7. Now we find a different efficient set in affordability-effectiveness space. In fact, Alternative 2 is now no longer efficient—it is dominated by Alternative 3. This is a significant alteration of the cost-effectiveness situation: the efficient set is now composed of only Alternatives 3 and 4. The decision to be made now concerns only two alternatives.

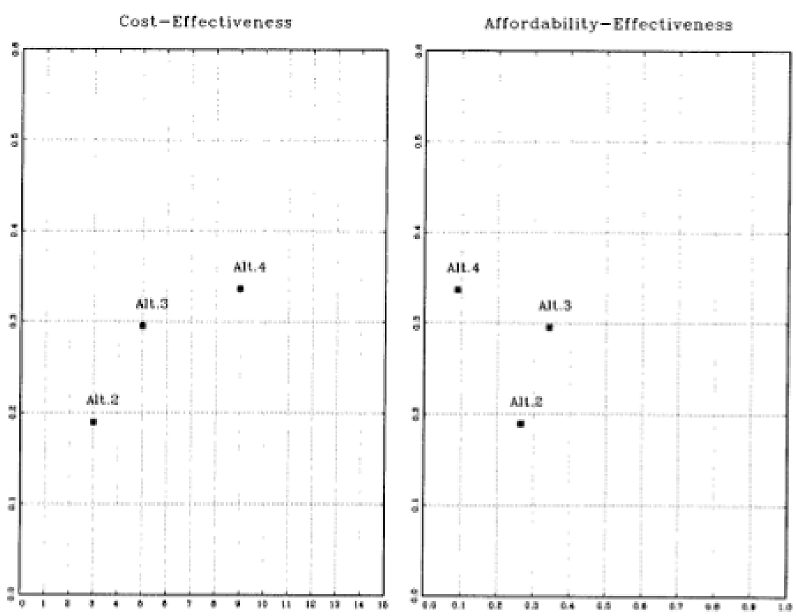

Figure 7. Cost-Effectiveness and Affordability-Effectiveness With c_2 = 3.0 and c_4 = 9.0

Uncertainty and Affordability Risk

Our affordability concept accommodates uncertainty in an obvious way. All we need to do is interpret the occasion when $(q_1, q_2) \in \mathbf{N}$ as an event and the metric $A = N / M$ as a random variable. Now the determination of an alternative's affordability is equivalent to calculating the $P\{\mathbf{N} \neq 0\} = 1 - P\{\mathbf{N} = 0\}$ or determining the $P(A > 0) = 1 - P(A = 0)$. Since affordability is a binary concept—either $(q_1, q_2) \in \mathrm{N}$ or not—an alternative is affordable if there exists only a single point for which $(q_1, q_2) \in$ **N**.

Of more use to the decision-maker is an assessment of the affordability measure. An alternative with a high measure of affordability implies that there are many combinations of (q_1, q_2) that will be preferred to the status quo. In the presence of uncertainty this can mean a higher likelihood for a satisfactory outcome—one in which the chosen (q_1, q_2) actually produces at least as high effectiveness as the status quo. Thus, it is of some interest to the decision-maker to ascertain $P(\alpha_L \leq A \leq \alpha_H)$ for various (α_L, α_H). This is equivalent to assessing the quantiles of A and this requires the distribution function of A. The assessment of affordability risk now takes explicit form.

- AFFORDABILITY RISK (Type 1). The likelihood that an alternative is unaffordable:

$$P(A = 0).$$

- AFFORDABILITY RISK (Type 2). The probability that the measure of affordability is less than some minimally acceptable level:

$$P(A < \alpha_{\min}).$$

The assessment of both types can be accomplished in many ways, but we find simulation modeling particularly attractive.

Simulation modeling makes good use of all available information concerning the uncertainties of the situation. It incorporates available theoretical results, subjectively assessed information, and assumptions the decision-maker is willing to make to fill in the gaps in required information. In our present context, there often are probability models representing estimations errors, particularly if life-cycle cost estimates rely on statistical techniques as regression in building cost estimating relations (CER). Moreover, the analyst often has knowledge of the measurement errors and imprecision in the evaluation of effectiveness.

An Illustration of Affordability Risk Assessment

We now illustrate the simulation modeling approach using our previous, deterministic example. The main issue of concern is computation of the probability distribution of A. This is all the information we need to assess any statistic relating to A, especially those we use to represent our two measures of risk. Simulation modeling provides only an approximation of the statistic of interest, but the accuracy of this approximation is limited only by the amount of time and computation we allocate to the task.

All parameters relating to the existing system are assumed known with certainty: $q_1 = 10, a_1 = 0.17, b_1 = 0.6, c_1 = 1$. The nominal values for the new system are as before: $a_2 = 0.21, b_2 = 0.8$ and $d = 0.3$. Cost is considered uncertain within the range: $1 \leq c_2 \leq 10$. Although the decision-maker is willing to believe the certainty attached to the parameters of the existing system, all parameters of the new system are viewed as only nominal.

We present six runs illustrating risk assessment scenarios under a variety of input specifications. Each illustrates the type of information the decision-maker may use: (1)

assumptions based on little or no prior information, (2) subjective assessment of related information, or (3) available hard data provided by the analyst (e.g., life-cycle cost estimation error and effectiveness estimation errors). The first three scenarios depict a situation where the decision-maker is willing to accept the effectiveness estimate for the new system (q_2) but not its cost estimate nor the value of the future budget. Run 1 assumes the decision-maker is willing to state a value for the minimum, most likely, and maximum value for c_2 and B. This type of prior information can be expressed as a triangular probability distribution or a Beta distribution parameterized to accept specification in three-parameter form (instead of the traditional two-parameter form). This type of Beta is referred to as a Program Evaluation and Review Technique (PERT) distribution. In Run 2 the decision-maker is willing to specify only a minimum and maximum for c_2 while believing that any value between these limits is equally likely. This information is represented by a uniform probability distribution. Run 3 extends this less informative prior to the budget as well. The last three runs illustrate the situation when the decision-maker no longer accepts the effectiveness estimate for the new system but is willing to employ the parameters as the most likely values in PERT distributions. Runs 4 and 5 illustrate pessimistic views of the new system effectiveness estimate. Run 6 illustrates the amount of improvement required in a_2, relative to Runs 4 and 5, to reduce the risks to acceptable levels (assuming a decision-maker who can tolerate a level as high as 0.05 or 5%). Each run employs 5,000 Monte Carlo trials with Roman hypercube sampling.

Table 4. Simulation Scenarios

RUN	a_2	b_2	c_2	d	B
1	0.21	0.80	PERT(2.0, 2.2, 5)	.3	PERT(9, 10, 10.05)
2	0.21	0.80	Uniform(2, 5)	.3	PERT(9, 10, 10.05)
3	0.21	0.80	Uniform(2, 5)	.3	Uniform(9, 10.05)
4	PERT(.17, .21, .22)	PERT(.65, .80, .85)	Uniform(2, 5)	.3	Uniform(9, 10.05)
5	PERT(.17, .21, .22)	PERT(.65, .80, .85)	Uniform(2, 5)	.3	Uniform(8, 10.05)
6	PERT(.20, .35, .40)	PERT(.65, .80, .85)	Uniform(2, 5)	.3	Uniform(8, 10.05)

The results are presented in Table 4 using four statistics. Columns 2 and 3 are the limits of the 95% confidence interval for A. These define the limits of the interval on the real line within which we will experience the actual (realized) value of A. The fourth column gives the estimate of Type 1 Risk (i.e., the likelihood the new system will be unaffordable). The last column presents the estimate of Type 2 Risk (i.e., the likelihood that actual A will be less than what is minimally acceptable—be specified as 0.1). The relative frequency distributions of A are presented in Figures 8–13.

Table 5. Affordability Statistics

RUN	$\alpha_{(.025)}$	$\alpha_{(.975)}$	$P(A=0)$	$P(A \leq 0.1)$
1	0.125	0.475	0.000	0.010
2	0.026	0.475	0.000	0.298
3	0.000	0.467	0.023	0.343
4	0.000	0.452	0.030	0.355
5	0.000	0.425	0.211	0.502
6	0.061	0.693	0.003	0.041

Comparing the results of Runs 1–2 demonstrates an important insight for decision-makers: the amount of probabilistic information provided affects the assessed risk. Both the PERT and uniform distribution have the same range of values but the PERT distribution provides more information: the most likely value, as well as the upper and lower bounds. As a consequence, the PERT distribution decreases the likelihood of values at, or near, the extremes of the distribution while placing more likelihood on values nearer the most likely value. This manifests itself in less assessed risk: a more narrow 95% confidence interval for A and a very small value for $P(A \leq 0.1)$. Using the uniform distribution for c_2 represents a reduction in information and leads to more assessed risk: a wider confidence interval for A shifted towards zero and higher $P(A \leq 0.1)$. Run 3 represents a further reduction in information and increase in assessed risk: the 95% confidence interval for A now includes zero with $P(A=0)=0.029$ and $P(A \leq 0.1)=0.404$.

Runs 4–5 illustrate the situation where the decision-maker does not have complete confidence in the estimate of effectiveness for the new system. Actual a_2 may be as much as 19% below the nominal while only 5% above the nominal, but its most likely value at the nominal estimate. Likewise, b_2 may be as much as 19% below nominal or 6% above with a most likely value at the nominal estimate. Run 4 is to be compared with Run 3 to see the effect on risk when uncertainty in effectiveness is added to the analysis. Run 5 is to be compared with Run 4 to see the effect of an even more pessimistic budget environment.

Run 6 addresses risk from a different perspective. The question here is the amount of increased effectiveness that must be offered by the new system to lower the risk to an acceptable level. We illustrate using only a_2 to keep a narrow scope. We find the new system reduces risk significantly if $0.20 \leq a_2 \leq 0.40$ with most likely value 0.35. This produces $P(A=0) \leq .01$ whereas $P(A \leq 0.1) \approx 0.05$, presenting a considerably less risky situation than Runs 4 and 5. This result is only suggestive—a more detailed analysis also involving b_2 would be required to more completely answer the question.

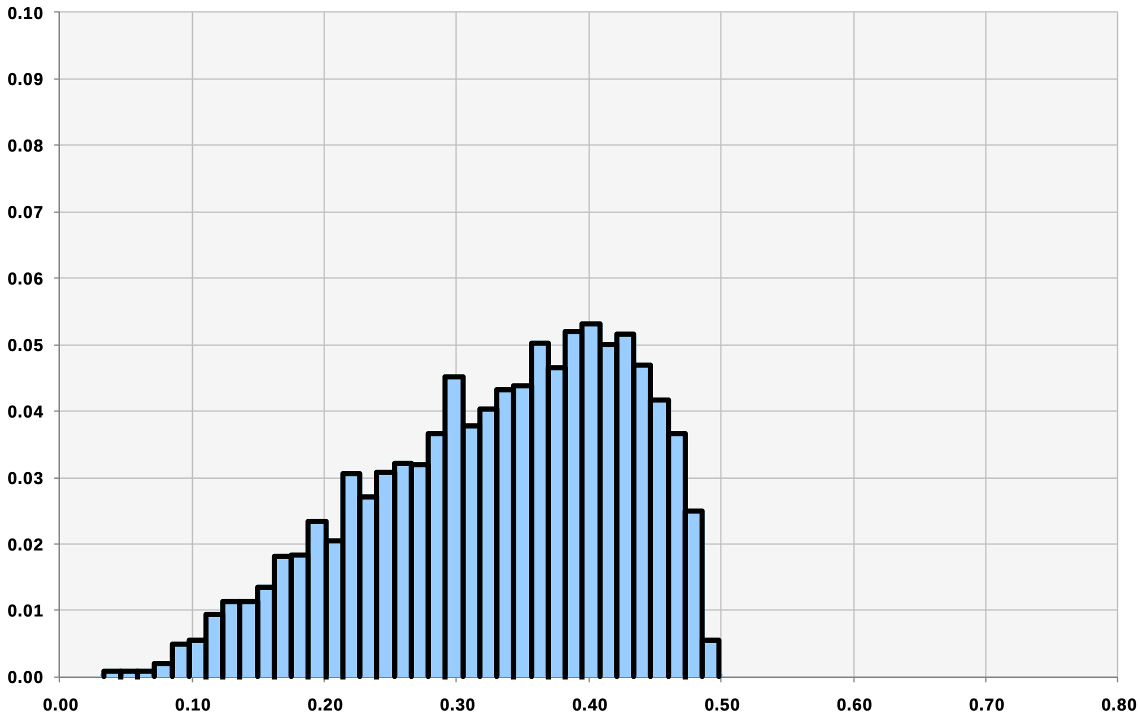

Figure 8. Run 1 Affordability Measure

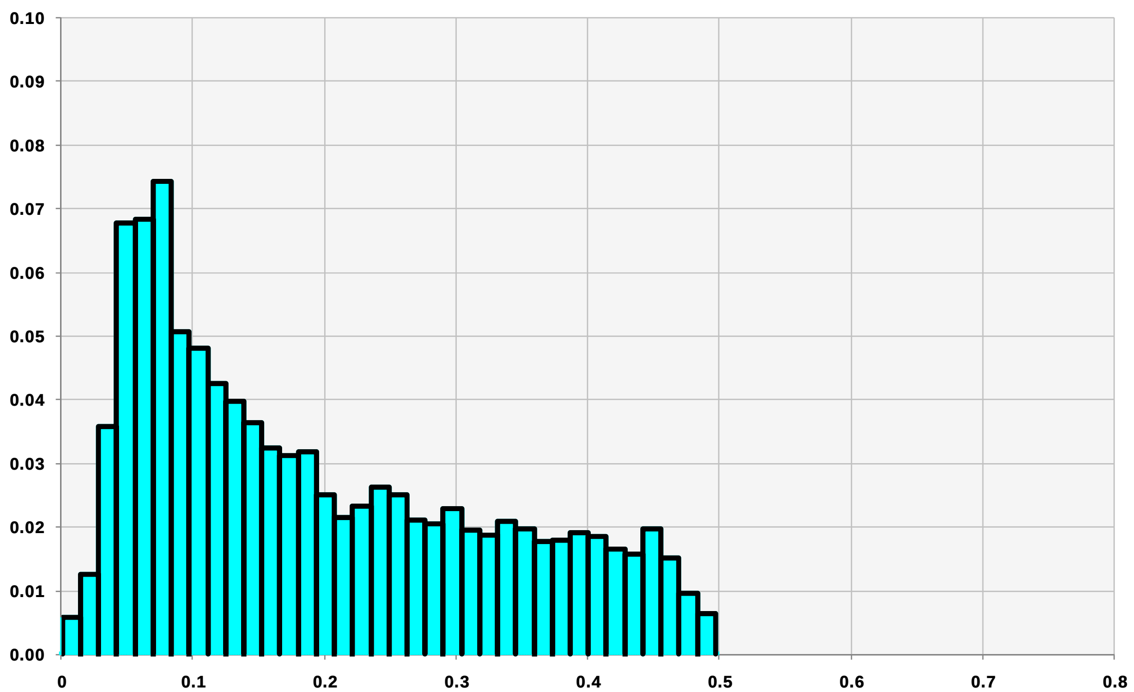

Figure 9. Run 2 Affordability Measure

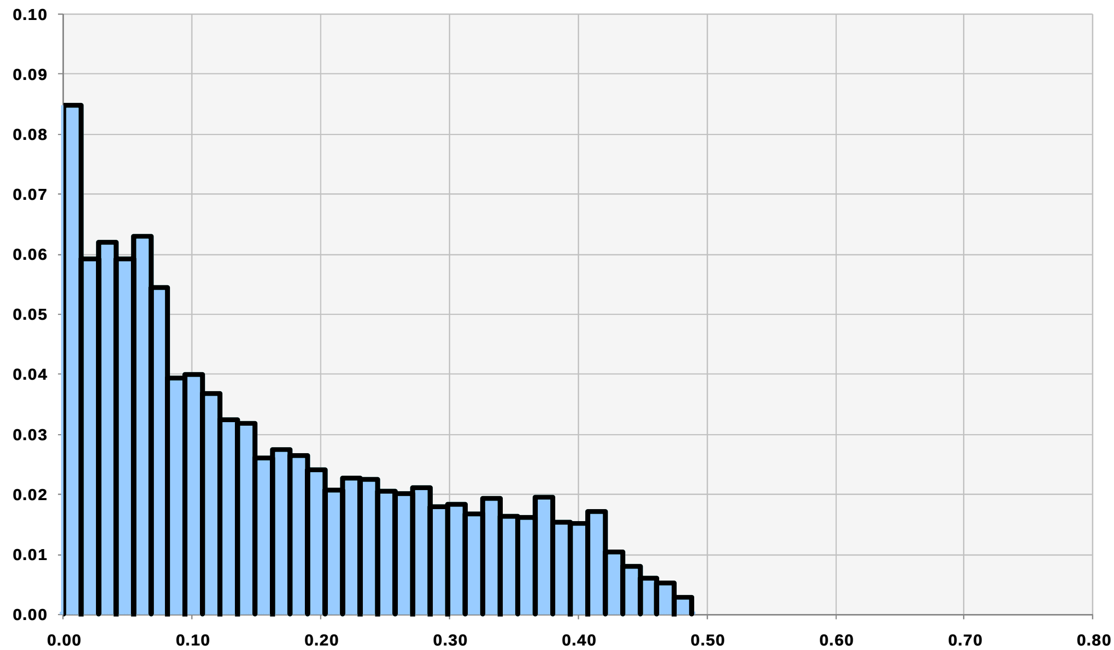

Figure 10. Run 3 Affordability Measure

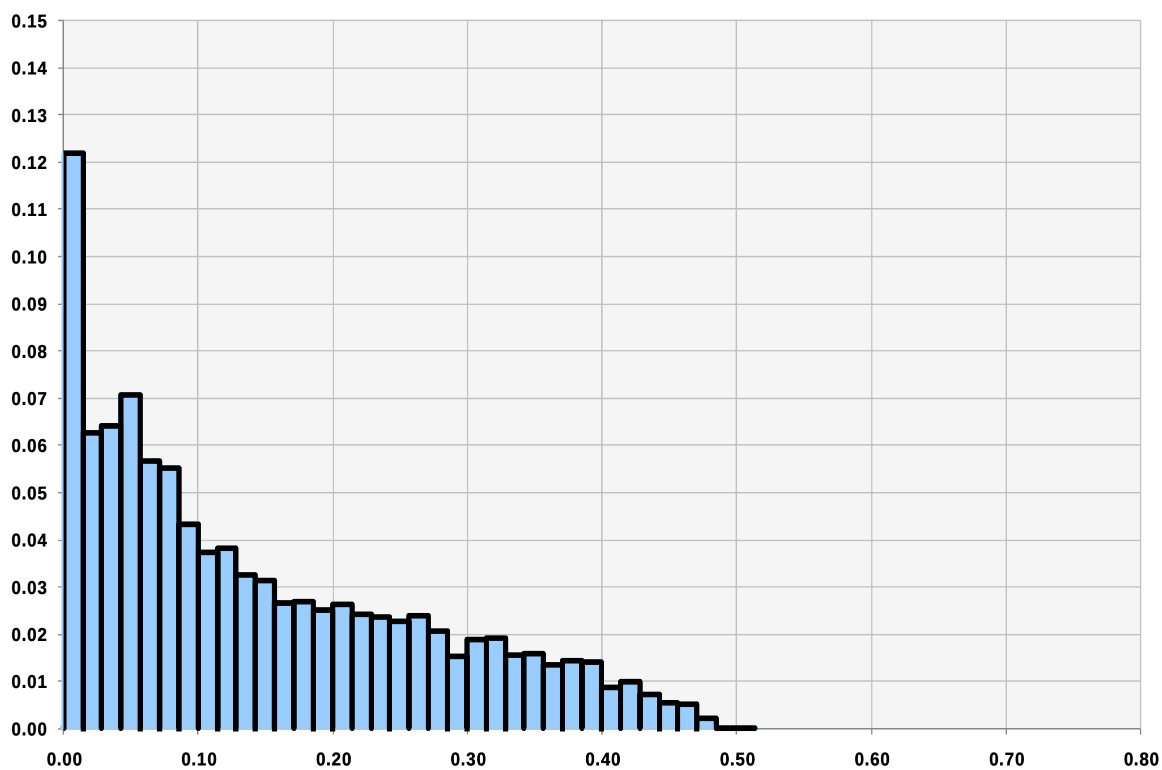

Figure 11. Run 4 Affordability Measure

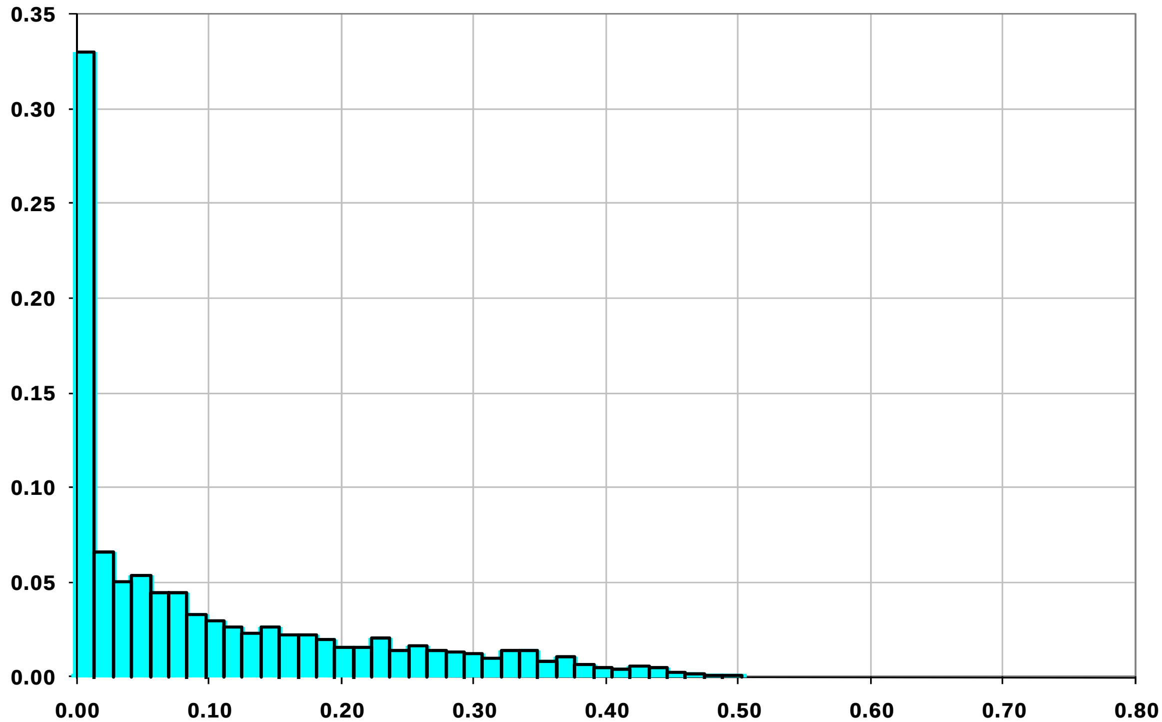

Figure 12. Run 5 Affordability Measure

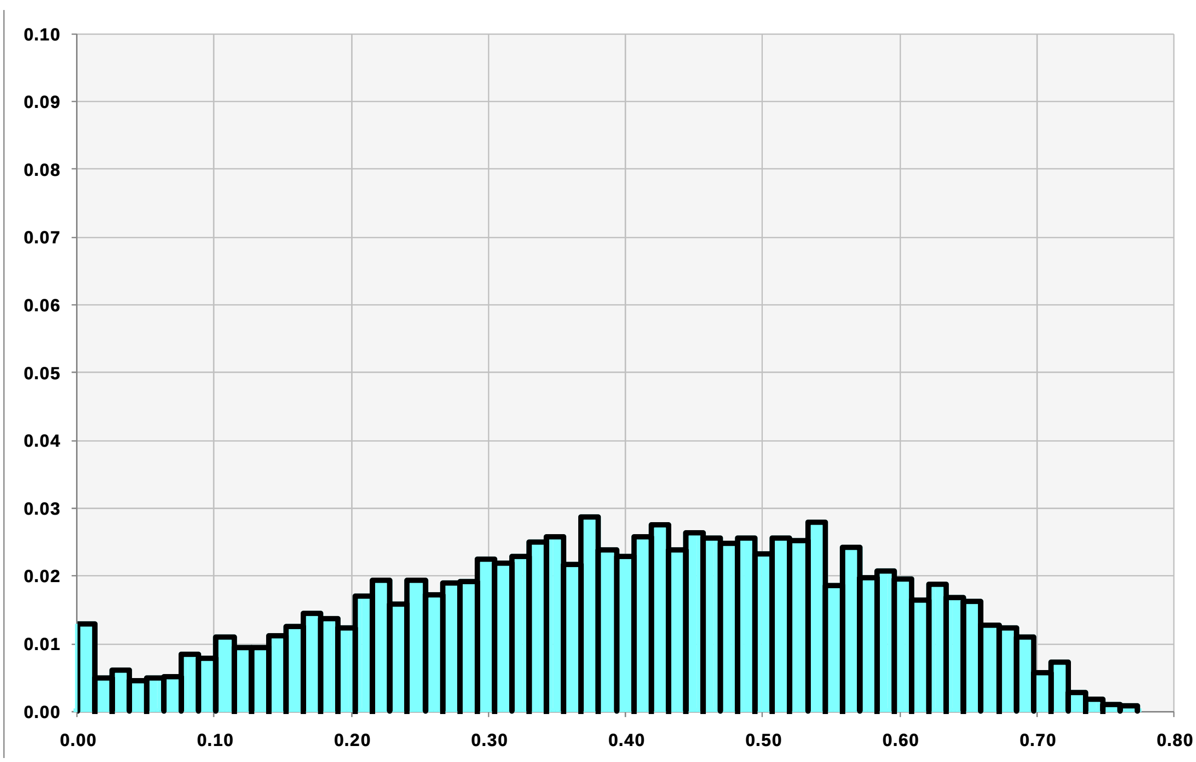

Figure 13. Run 6 Affordability Measure

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Panel 25 – Logistics Enablers for Enhanced Acquisition Outcomes

Thursday, May 12, 2011	
3:30 p.m. – 5:00 p.m.	**Chair: Lorna B. Estep,** Deputy Director of Logistics, Air Force Material Command ***Maximizing Effectiveness Using a Flexible Inventory*** Manbir Sodhi, University of Rhode Island, and James Ferguson, Marie Bussiere, and Betty Jester, USN ***Identifying and Managing Manufacturing and Sustainment Supply Chain Risks*** Nancy Moore, Elvira Loredo, and Amy Cox, RAND Corporation ***Comparing Acquisition Strategies: Maintenance-Free Operating Period vs. Traditional Logistics Support*** Nickolas H. Guertin, Open Architecture, PEO IWS, and Paul Bruhns, ManTech International Corporation

Lorna B. Estep—Deputy Director of Logistics, Directorate of Logistics and Sustainment, Headquarters Air Force Materiel Command, Wright-Patterson Air Force Base, OH. Ms. Estep is a member of the Senior Executive Service. She is responsible for the Materiel Support Division of the Supply Management Activity Group, a stock fund with annual sales of $7 billion. She directs a wide range of logistics services in support of Air Force managed spare parts, to include transformation programs, requirements determination, budgeting, acquisition, provisioning, cataloging, distribution and data management policy. She also provides supply chain management policy, guidance and direction in support of headquarters, air logistics centers, and U.S. Air Force worldwide customers.

Estep started her career as a Navy logistics management intern. She has directed the Joint Center for Flexible Computer Integrated Manufacturing, was the first program manager for Rapid Acquisition of Manufactured Parts, and has served as Technical Director of Information Technology Initiatives at the Naval Supply Systems Command. In these positions, she has developed logistics programs for the Department of Defense, implemented one of the first integrated and agile data-driven manufacturing systems, and directed the development of complex technical data systems for the Navy.

Maximizing Effectiveness Using a Flexible Inventory

Manbir Sodhi—Professor of Systems and Industrial Engineering, Department of Mechanical, Industrial, and Systems Engineering, University of Rhode Island. Professor Sodhi obtained his graduate degrees from the University of Arizona and has taught courses in Systems Design, Systems Simulation, Deterministic and Stochastic Optimization, etc. In addition to consulting for several companies, he has also worked as a visiting scientist at the Naval Undersea Warfare Center (NUWC) Division, Newport, and at the NATO Undersea Research Center in La Spezia, Italy. His recent work has appeared in professional journals that include the *Journal of Scheduling*, *International Journal of Production Research*, and *IIE Transactions*. He is currently exploring decision models supporting supply chain planning in defense operations and is developing tools and concepts of operations for the use of unmanned undersea vehicles (UUVs) for a variety of search operations. [sodhi@egr.uri.edu]

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Marie Bussiere—Head, Undersea Weapons Acquisition and Life Cycle Engineering Division, Torpedo Systems Department, Naval Undersea Warfare Center (NUWC) Division, Newport. Ms. Bussiere is responsible for Torpedo Test Equipment; Propulsion and Mechanical Systems; Production, Logistics, and Quality Assurance; and Fleet Engineering Support. She is a graduate of the University of Rhode Island, where she earned a Bachelor of Science degree in Electrical Engineering. She also earned a Master of Business Administration from Salve Regina University and received a diploma from the Naval War College for coursework in the areas of Strategy and Policy, National Security Decision Making, and Joint Maritime Operations. [marie.bussiere@navy.mil]

Betty Jester—Technical Program Manager, Torpedo Production, Naval Undersea Warfare Center (NUWC) Division, Newport. For the past six years, Ms. Jester has served as the Branch Head for Quality Production and Logistics, where her primary responsibilities include resource, financial, and personnel management. Ms. Jester has extensive experience in torpedo systems, having worked on torpedo programs since graduating from the University of Rhode Island with a Bachelor of Science degree in Electronic Computer Engineering. She also earned a Master of Business Administration from Salve Regina University. She derives her technical expertise from working on all aspects of torpedo life cycle development, from requirements definition through development and test, production and support, and maintenance for both lightweight and heavyweight torpedoes. [betty.jester@navy.mil]

Abstract

Although uncertainty in production and inventory systems is not desirable, predictions for demand are inherently uncertain. When the set of products is complex, that is, composed of multiple subassemblies, and there are shared subassemblies amongst different product types, the option for storing partially completed assemblies may also help in meeting demand uncertainties. Furthermore, as new technology is developed and new models are added to the inventory, older models can sometimes be upgraded to add the new functionality and increase the overall effectiveness of the inventory in meeting demand. Thus, when faced with uncertain demand for one or more products over a geographically distributed domain, the set of recourses for a manufacturer/planner include excess production (inventory storage), rapid re-location of inventory, production surges, when to upgrade technology or procure new models, what level of assembly to store the products, and where to store these, as well as in what quantities and ratios of

product types. Factors affecting these decisions are manpower availability, budgets, ease of upgrade, cost of new procurements, and probabilities of demand realization. This paper explores related decision models in the context of the torpedo enterprise. Solutions of mathematical models are illustrated and features of some of the models leading to specific solution algorithms highlighted. Simulations to assess the utility of the solutions obtained by analytical methods are also presented.

Introduction

Managing complex products that have long lifetimes is not an easy task. However, most defense and many industrial organizations deal with such products on a daily basis. Whereas non-durable goods (i.e., goods with lifetimes of less than three years) can be sold in large volumes with very little post-sales support, durable goods such as commercial grade printing and photo-copying systems, enterprise wide computing systems, weapons, and weapon systems are designed to accommodate evolutionary updates of the design of key components, or technology refreshes and insertions that either fix existing bugs and/or introduce new features by upgrades to modules. The complicating factor here is that the upgrades/insertions have to be done to a large inventory of in-service products while meeting promised deliveries. In the context of some defense organizations such as the torpedo enterprise, there are mandates on reserve quantities for different types of weapons, scheduled rotations between training and warshot inventory, mandatory maintenance schedules, etc. Furthermore, issues such as obsolescence and part failures must also be taken into consideration, and contracts for acquiring new and replacement parts must also be matched with the budgets and promised deliveries to the fleet.

Following Keynes (2006), it is generally accepted that the main motives for holding money are transaction, precautionary and speculative. As explained in Arrow, Karlin, and Scarf (1958), precautionary motives protect against uncertainty; speculative objectives are fueled by anticipation of future gains, and transaction encapsulates the reluctance to change currencies/investments because of the fixed or variable fees incurred in flipping from one type of investment to another. Reasons for holding an inventory of goods are generally the same as those for holding currency. It can be argued that the exception is when goods are held in reserve to meet uncertain demands, with the objective of exceeding some level of customer satisfaction. The accounting of costs and benefits in defense organizations is somewhat different, and this paper seeks to develop the argument that the goal of holding inventory in this sector is to respond sufficiently to future threats. In an environment of rapidly changing threats (Hilsenrath, 2011), the utility of an inventory of weapons is not just in its ability to meet current needs, but also in its ability to meet future requirements with minimal transformation effort.

Costs Involved in Defense Logistics

The costs considered when modeling inventory decisions in commercial enterprises are typically holding, ordering, shortage, and backorder costs. Holding costs include the cost of money (opportunity loss because of the money tied up in inventory or the cost of capital borrowed to purchase inventory). Shortage costs include the cost of lost sales, which lead to lower profits. Backorder costs are the costs incurred when orders not delivered in a timely manner and must be rushed to the customer using more expensive logistics channels. Other costs considered when analyzing inventory decisions are lateral transfer cost (Lee, 1987), multiple channel supply costs, etc., .; additional issues include buyer/vendor coordination, including price discounts (Goyal & Gupta, 1989). In terms of maximizing inventory effectiveness in the commercial world, companies maximize profit, and demand serves as the primary constraint. In other words, profit is king, and demand is the main constraint to maximizing profit. As we will see (and would be expected), this is not the case when supporting weapon systems.

The nature of costs in the defense sector is considerably different. Defense logistics agencies are issued annual budgets for maintaining supply chains with the goal of stocking adequate levels of weapons and supplies to meet contingency demands. Stated slightly differently, the Fleet requirements drive inventory need, and the main constraint is the allowable budget; other constraints include Intermediate Maintenance Activities (IMA) capacity in terms of personnel and test equipment. To use the language from the previous paragraph, demand is king, and the budget (a type of profit) is the primary constraint when maximizing demand fulfillment. This brings out the point that in the Department of Defense (DoD), cash flow is controlled by a higher authority and cannot be increased based on "selling" more inventory. The budget is set (at some point in time), and support of the weapon system must be optimized based on that amount. This type of inventory effectiveness optimization does not lend itself to commercial enterprise, because in the retail world, profits will change based on company performance.

Logistics Costs in the Torpedo Enterprise

Another level of complexity is added to the Torpedo Enterprise's inventory system, in that its inventory is stored at three IMAs, each with differing cost models. The IMA in Pearl Harbor, HI, is contractor run and was awarded based on a competitive services contract. The IMA in Yorktown, VA, is run by the U.S. Navy; the labor at this IMA is "free," as it is supplied by sailors. The third IMA is located at NUWC, Division Keyport and is staffed with Government Civil Service labor. These differing structures (commercial, military, and federal) sometimes cause issues in regards to standardization of processes and organizational cohesiveness. Further, the torpedo enterprise, because it supports a weapon for war, is also governed by legal statutes related to safety, hazardous material, Radio Frequency Identification (RFID), and Unique Identifier (UID), to name a few; these are all cost drivers.

There are also inventory considerations below the torpedo All Up Round (AUR) level. Torpedo unique parts are inventoried by the Naval Inventory Control Point (NAVICP), and items common between torpedoes and other DoD systems are inventoried by the Defense Logistics Agency (DLA). Demands for these parts are tracked through the use of in-house databases. Problems with inventory re-order are sent to the Naval Undersea Warfare Center (NUWC) for technical recommendations (e.g., suitable replacements when obsolescence is encountered).

The torpedo enterprise inventory for purposes of this paper is the warshot and exercise inventory maintained at the AUR configuration in bunkers at or near the IMAs. These torpedo inventories are stored for both the Atlantic Fleet and the Pacific Fleet, and the torpedoes are available for the Fleet to requisition. The quantity goal for the torpedo enterprise inventory is Non-Nuclear Ordnance Requirements (NNOR), with a wartime surge capability referred to as WAR RESERVE. At one time, the planning to support the Atlantic Fleet and Pacific Fleet requirements was handled separately, but several years ago, the enterprise moved to centralized inventory planning and handling (i.e., one Planning Cell). The Planning Cell meets with the Fleet representatives quarterly, at a minimum, to discuss warshot and exercise requirements; exercise torpedoes are units capable of being fired and recovered for the Fleet to maintain proficiency. These warshot and exercise requirements are translated to IMA capacity, and torpedo build requirements are determined to workload the IMAs. So, the flexibility of the inventory at the AUR level is the IMA's capacity to build exercise and warshot torpedoes, and to turn one into the other, and vice versa. Fleet/ship requirements can also be met through a mix of torpedo configurations (i.e., MK48 Mod 6 versus MK48 Mod 7) that are tailored to the target operating theatre. Additionally, there is flexibility of inventory at the AUR torpedo level through the upgrade of operational software via download capability. Versions of operational software can be downloaded at IMAs during weapon maintenance and preparation, or even on board ships. Operational software brings flexibility to AUR torpedoes with improved and varying performance.

Since our enterprise is not in production of AUR torpedoes at this time and has not been for many years, Foreign Military Sales can both limit and enhance the Torpedo Enterprise's flexibility. To sell AUR torpedoes to other nations at this time has a negative impact on the US's inventory quantity, but provides valuable resources to reconstitute production capability or performance enhancements in both hardware and software, which are helpful in the long run of the program (i.e., financing torpedo upgrades in the future).

Use of older torpedo configuration hardware that has been "moth balled" (e.g., MK48 Mod 4) brings with it the flexibility of "quantity versus quality." Older torpedo hardware which has been slated for demilitarization can be revitalized to add quantity to the inventory with calculated performance degradation. Unrelated to the purpose of this paper, performance versus quantity models exist to evaluate overall torpedo enterprise inventory effectiveness.

Modeling Inventory Effectiveness

In the discussion that follows, details of some preliminary models investigating the impact of flexibility on inventory operations are presented. The first approach utilizes an established two-level service model with conversion options between different part types to estimate the benefit that may be garnered by pooling inventory. The second approach presents a mathematical programming approach for determining optimal inventory decisions, with transfers and conversions between different part types and common subassemblies. A brief literature review is first presented.

A two class inventory system for modeling consumable items in a defense setting has been presented in Deshpande, Cohen, and Donohue (2003). The authors construct a model approximating the management of consumables by the DLA and propose a threshold for determining backorders for different classes of items. This model is useful when considering the allocation of pooled inventory items, but requires the setting of priorities for different classes externally. Clearly, this is difficult to do. However, this paper explains many of the issues particular to inventory management in defense settings.

Multi-echelon models for inventory management of spares in the defense industry have been considered by Simon (1971) and Yanmei, Jiangsheng, Sujian,and Weimin (2008), among others. However, most multi-echelon models consider single item types and the location of inventory pools at different levels to meet demand changes at different end points by cross-shipping when necessary. A fundamental analysis of the two-level case for repairable items is in Simon (1971), Muckstadt (1973), and Graves (1985). Although substitution of items, examined in Karaesmen and Van Ryzin (2004), can result in significant savings, it has not generally been considered in these multi-echelon models. Begnaud, Benjaafar, and Miller (2009) do consider multi-echelon inventory planning with flexible substitution opportunities, but the decision for interchanging items with an associated transaction cost is not developed.

There is a vast body of literature related to mathematical programming models for lot sizing. Starting with Wagner and Whitin (1958), Crowston and Wagner (1973), etc., the solution approaches for such problems have involved either dynamic programming approaches, specialized algorithms, or integer programming formulations and solutions (Belvaux & Wolsey, 2000; Wolsey, 2002). As noted in Wolsey (2002), many real-world lot sizing problems can now be adequately solved using commercial-off-the-shelf mathematical programming software. Wolsey (2002) further classifies lot sizing problems using three fields: [x, y, z]. The first field, x, indicates the problem version, and its choices are LS (lot sizing), WW (Wagner Whitin), DLSI (Discrete Lot Sizing with Initial Stock), and DLS (Discrete Lot Sizing without initial stock). The second field describes the production capabilities: C for capacitated, CC for constant production, and U for uncapacitated. When multiple items share production capacities, the additional qualifier BB is prepended to DLSI. The third field describes extensions/variants and includes B (Backlogging), SC (startup costs), ST (startup times), LB (minimum production levels), SL (sales constraints), and SS (safety stock considerations). The first two fields of problem considered here could then be described as DLSI-CC. Since the nomenclature proposed does not capture transformations, we suggest an extension to the nomenclature—T for transformation whereby items can be transformed from one product type to another. Although there are a large number of additional combinations that can be proposed, for now, the nomenclature used to describe the multi-item lot sizing problem with transformations can be BB/DLSI-CC-T.

Based on the discussion above, we propose the thesis that for a defense logistics operation, a fundamental measure of inventory effectiveness is the flexibility to meet a variety of potential needs for future operations. Based on this assumption, two preliminary models are developed to show how the increase in flexibility can indeed result in improvements to service levels. The first approach is based on an established two-level service operation, first explored in Sherbrooke (1968), further developed in Simon (1971), Muckstadt (1973), and others. The second model presented is a multi-product lot sizing model with transformations between different product types.

A Preliminary Investigation of the Impact of Flexibility in 2-Level (Base–Depot) Operations

Following Sherbrooke (1968), a two-level operation for recoverable parts is described as follows: Several distributed maintenance facilities (j = 1,…, N) restore incoming recoverable parts. While most parts can be repaired locally, some fraction of incoming parts has to be sent to the central depot for repair. The base and depot each maintain their own levels of inventory independently, and this inventory of parts is used for immediate replacement of incoming parts that undergo repair. When this inventory is depleted, the turnaround of outgoing parts is delayed until some refurbished units are available. The organization of this system is shown in Figure 1. As indicated in the figure, the parts are assumed to arrive at base j with exponential inter-arrival times, at rates λ_j respectively. The service time at each base is μ_j. The depot is designated by the index 0. The total transfer time between the base and the depot is denoted as τ_j, and the stock levels maintained at the depot and bases are (S_0, S_1,…, S_n).

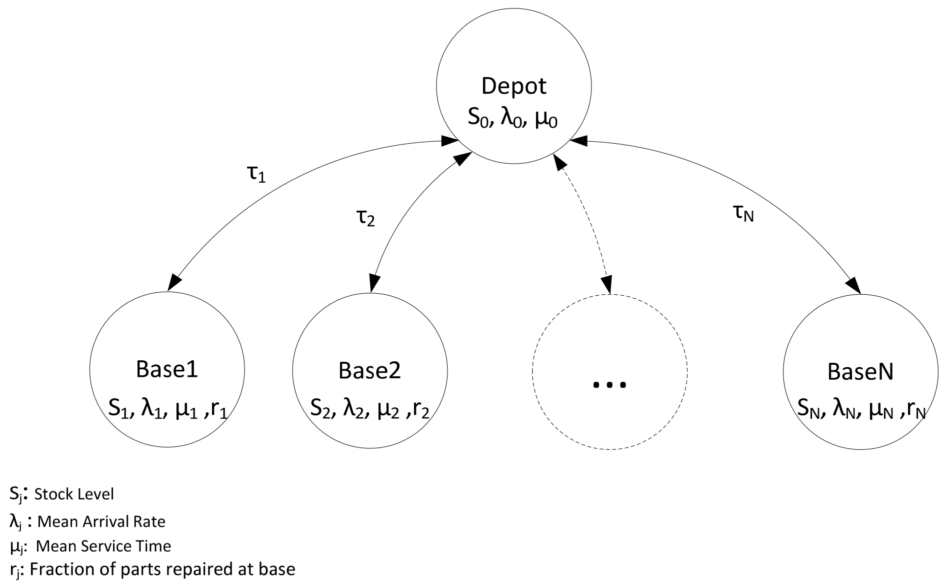

Figure 1. 2-Level Structure for Repairable Items

For such a scenario, given an allocation of spares ($S_0,\ldots,S_N$) among the bases and depot, the average number of parts waiting in the system at the base and the depot (L_0 , L_1, …, L_N) is computed in the following way:

$$L_0 = \sum_{k=s_0}^{\infty} (k - S_0) e^{-\lambda_0 \mu_0} \frac{(\lambda_0 \mu_0)^k}{k!}$$

$$L_j \approx \sum_{k=s_j}^{\infty} (k - S_j) e^{-\lambda_j \beta_j} \frac{(\lambda_j \beta_0)^k}{k!}, \, j = 1,\ldots,N$$

where,

$$\lambda_0 = \sum_{j=1}^{N} (1 - r_j) \lambda_j \text{ , and}$$

$$\beta_j = r_j \mu_j + (\tau_j + \frac{L_0}{\lambda_0})(1 - r_j) \,.$$

A detailed discussion can be found in Tijms (2003).

Now, let us assume that the system handles two part types, k=1, 2. The repair protocol is the same—that is, base *j* repairs incoming parts with probabilities r_{j1} and r_{j2} respectively. The stock levels at the depot and the bases are (S_{01}, S_{02}, S_{11}, S_{02},…, S_{N1}, S_{N2}) respectively. A simulation experiment was conducted in which arrival and service rates were randomly selected (with a service ratio of ½ for the bases and the depot). The transportation time between the base and the depot was set to $2^*\mu_j$. The total inventory level was varied, as shown in Figure 2. This was done for each product type, and an optimal distribution of inventory was determined. The expected number of items in the system for each product type was recorded as $\mathcal{L}_1$ and $\mathcal{L}_2$. Finally, an optimal allocation of inventory for the combined system was determined using an evolutionary algorithm, and the total number of items in the system was noted as $\mathcal{L}_3$. A graph comparing $\mathcal{L}_1 + \mathcal{L}_2$ and $\mathcal{L}_3$ is shown in Figure

2. As expected, the performance of the pooled system is significantly superior to that of the separate systems. For the parameters used here, the number of parts in the system required to maintain an equivalent service level is smaller by a factor of 4 on the average.

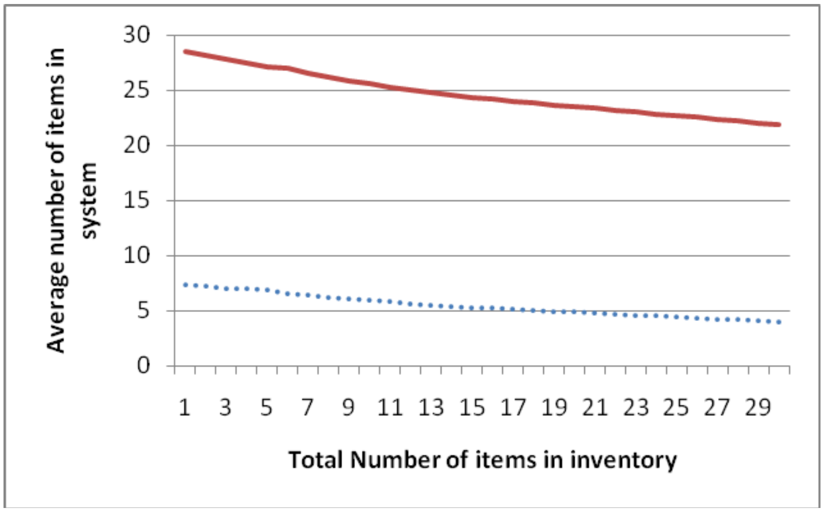

Figure 2. Comparison of Pooled vs. Segregated Inventory Performance

The example presented here emphasizes the advantages of a pooled inventory and transformations between two product types. This analysis is a part of ongoing work focused at developing metrics for effective inventory with transformations in the context of defense organizations.

Basic Lot Sizing Model

The model being expanded in this section that seeks to mimic the Torpedo Enterprise's inventory is a lot sizing problem. The assumptions of this model are unlimited and instantaneous production, unlimited inventory storage, no incoming or outgoing inventory, and deterministic demand. However, these assumptions can easily be altered by adding the proper constraints. The constraining costs in the model are inventory carry-over ($/period/unit), set-up costs ($/set-up), and production costs ($/production unit). The objective of this model is to meet demand for each period, while minimizing cost over the periods being studied, and allowing transformations between products/subassemblies during the planning horizon.

Mathematically this model can be written as follows:

$$P_{it} = production\ of\ product\ i\ in\ time\ t$$

$$I_{it} = inventory\ carry - over\ of\ product\ i\ in\ time\ t$$

$$S_{it} = setup\ of\ production\ for\ product\ i\ in\ period\ t$$

$$\chi_{ij} = cost\ of\ producing\ (i = j)\ products$$

$$\sigma_i = setup\ cost\ of\ product\ i$$

$$\phi_i = cost\ of\ holding\ product\ i$$

$$\delta_{it} = demand\ of\ product\ i\ in\ time\ t$$

$$Min\, Z - \{\Sigma_i \Sigma_j \Sigma_t(\chi_{ij} P_{ijt} | i - j) + \Sigma_i \Sigma_t(\phi_i I_{it}) + \Sigma_i \Sigma_t(\sigma_i S_{it}) | \forall\, i, t\} \quad (1)$$

$$S.\, t.$$

$$P_{it} + I_{i(t-1)} = \delta_{it} + I_{it} \quad (2)$$

$$P_{it} \leq S_{it} * M \quad (3)$$

$$P_{it}, I_{it} \geq 0 \quad (4)$$

$$P_{it}, I_{it} = Integer \quad (5)$$

$$S_{it} = Binary \quad (6)$$

Equation 1 is the objective function which minimizes the production inventory and setup costs of the system. Equation 2 ensures the conservation of material within the model flow. Equation 3 uses Big M logic to set the setup decision for product *i* to 1 if production for product *i* is needed. Equations 4–6 incorporate the necessary non-negativity, integer, and binary constraints, respectively. A flowchart of the base model can be seen in Figure 3.

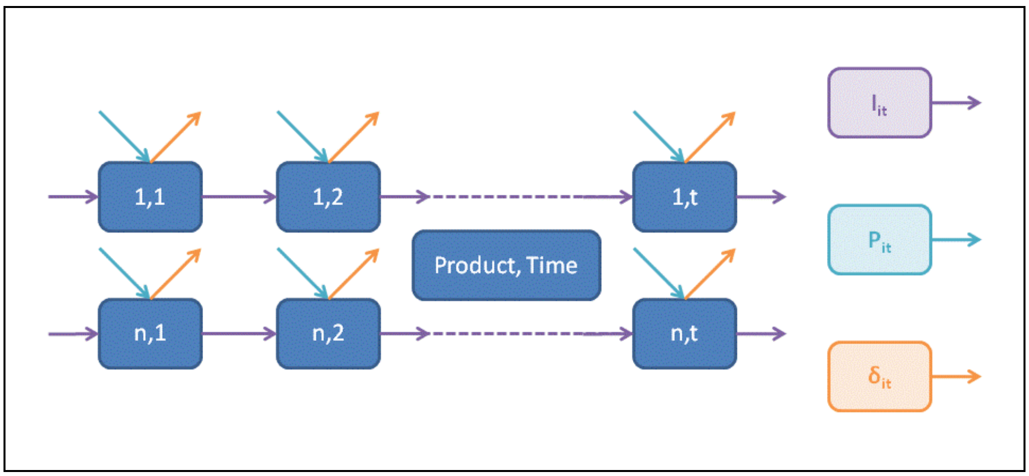

Figure 3. Simple Model for Transformations Among Different Part Types

Transformation Expansion

The first expansion to be integrated into the lot sizing model is that of product transformation. Consider the problem where two distinct products can, at a price, be converted from one to the other. An example is the production of modern automobiles, where the base model can be upgraded to more "deluxe" or "luxury" models. Another similar example that this model was developed for, is the transformation of torpedoes from one model to another. The ability to transform products in an inventory creates a more flexible inventory and provides the opportunity for cost savings depending on the transformation and setup costs of a particular system.

In order to expand the model to include transformations, the following variable is added to the model's environment.

$$T_{ijt} = transformation\ of\ product\ i\ into\ j\ in\ time\ t$$

And the following constant is changed to include transformation costs from one product to another.

$$\chi_{ij} = \text{cost of producing } (i = j) \text{ or transforming } (i \neq j) \text{ products}$$

Furthermore, Equations 1 and 2 are expanded to include the new variable and constant.

$$Min\ Z = \left\{\sum_i \sum_j \sum_t \left(\chi_{ij} P_{ijt} \middle| i = j\right) + \sum_i \sum_t \left(\phi_i I_{it}\right) + \sum_i \sum_t \left(\sigma_i S_{it}\right) + \sum_i \sum_j \sum_t \left(\chi_{ij} T_{ijt} \middle| i \neq j\right) \middle| \forall\, i, t\right\} \quad (7)$$

$$P_{it} + I_{i(t-1)} + \sum_j T_{jit} = \delta_{it} + I_{it} + \sum_j T_{ijt} \quad (8)$$

Note that in Equation 7, the same cost matrix is used for both production and transformation. For Production *i* = *j*, while for transformation, *i* ≠ *j*. For the conservation of material constraint, the left-hand side (incoming) of the constraint adds the summation of the transformations from all products *j* into product *i* for the given period, while the right-hand side (outgoing) adds the summation of the transformations from product *i* into all products *j* for the given period. A flowchart of the transformation expanded model can be seen in Figure 4.

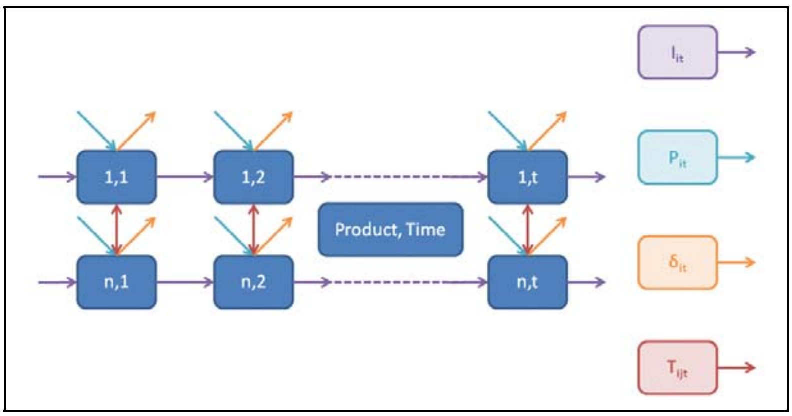

Figure 4. Transformation Expansion

Move Expansion

The next model expansion considers the system where there is more than one location for producing and storing products. Each distinct location can have its own associated production, storage, inventory, and setup costs. It is assumed that movement of products between locations is instantaneous. This assumption can, however, be dropped by manipulating the time (*t*) values associated with the move variables in the conservation of material constraint.

In order to expand the model to include transformations, the following variable is added to the model's environment.

$$M_{itkl} = \text{move of product } i \text{ in time } t \text{ from location } k \text{ to location } l$$

And the following constant is changed to include movement costs from one location to another.

$$\rho_{ikl} = \text{cost of moving product } i \text{ from location } k \text{ to location } l$$

Furthermore, all of the other constraints and variables must have a location subscript added to their definitions.

Equations 7 and 8 are expanded to include the new variable, constant, and location subscript:

$$Min\ Z = \left\{ \begin{matrix} \sum_i \sum_j \sum_t \sum_k \left(\chi_{ijk} T_{ijtk} \middle| i \neq j\right) + \sum_i \sum_j \sum_t \sum_k \left(\chi_{ijk} P_{itk} \middle| i = j\right) + \\ \sum_i \sum_t \sum_k \left(\varphi_{ik} I_{itk}\right) + \sum_i \sum_t \sum_k \sum_l \left(\rho_{ikl} M_{itkl}\right) \end{matrix} \middle| \forall\, i, t, k \right\} \tag{9}$$

$$P_{itk} + I_{i(t-1)k} + \sum_j T_{jitk} + \sum_l M_{itlk} = \delta_{itk} + I_{itk} + \sum_j T_{ijtk} + \sum_l M_{itkl} \tag{10}$$

The expansion of Equation 7 adds the term for the movement cost and movement variable. Also, the subscript for location is added to all of the costs and variable definitions. In Equation 10 (conservation of material constraint), the left-hand side (incoming) of the constraint adds the summation of the movements from all locations *l* to location *k* for the given period, while the right-hand side (outgoing) adds the summation of the movements from location *k* to all location *l* for the given period. A flowchart incorporating the movement expanded model can be seen in Figure 5.

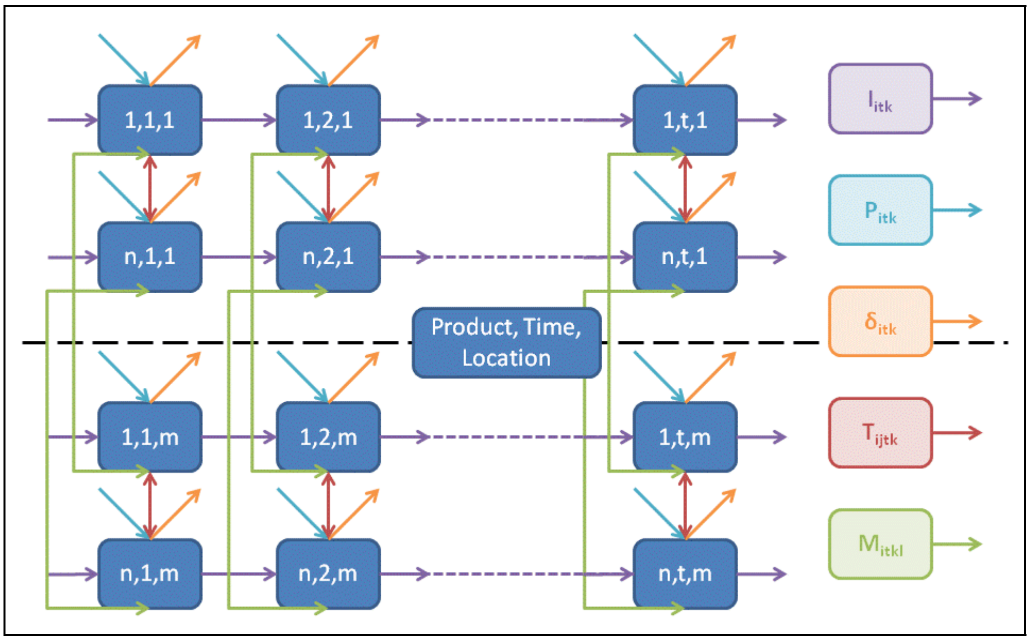

Figure 5. Movement Expansion

Multi-Level Product Expansion

Another possible expansion of this model would be to consider not only the finished products, but also the subassemblies that are used to build them. In order to evaluate such a model, the subassemblies would need their own cost constants for production/purchase, storage, movement, transformation (if applicable), and setup (if applicable). Demand for the subassemblies would be a function of the demand on the finished products. A simple flow chart showing finished products as compositions of subassemblies can be seen in Figure 6.

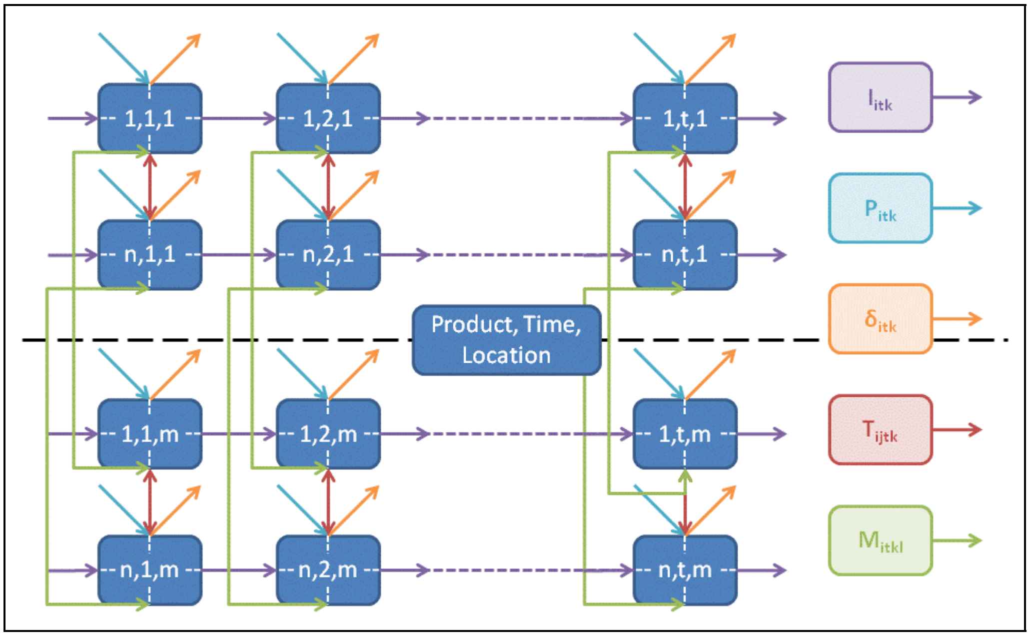

Figure 6. Subassembly Expansion

Expanded Model

The fully expanded model (not including the subassembly expansion) is as follows:

$$P_{itk} = \text{production of product } i \text{ in time } t \text{ at location } k$$

$$I_{itk} = \text{inventory carry} - \text{over of product } i \text{ in time } t \text{ at location } k$$

$$S_{itk} = \text{setup of production for product } i \text{ in period } t \text{ at location } k$$

$$T_{ijtk} = \text{transformation of product } i \text{ into } j \text{ in time } t \text{ at location } k$$

$$M_{itkl} = \text{move of product } i \text{ in time } t \text{ from location } k \text{ to location } l$$

$$\chi_{ijk} = \text{cost of producing } (i = j) \text{ or transforming } (i \neq j) \text{ products at location } k$$

$$\phi_{ik} = \text{cost of holding product } i \text{ at location } k$$

$$\sigma_{ik} = \text{setup cost of product } i \text{ at location } k$$

$$\rho_{ikl} = \text{cost of moving product } i \text{ from location } k \text{ to location } l$$

$$\delta_{itk} = \text{demand of product } i \text{ in time } t \text{ at location } k$$

$$Min\ Z = \left\{ \begin{matrix} \sum_i \sum_j \sum_t \sum_k (\chi_{ijk} T_{ijtk} | i \neq j) + \sum_i \sum_j \sum_t \sum_k (\chi_{ijk} P_{itk} | i = j) + \\ \sum_i \sum_t \sum_k (\phi_{ik} I_{itk}) + \sum_i \sum_t \sum_k \sum_l (\rho_{ikl} M_{itkl}) \end{matrix} \middle| \forall i, t, k \right\} \quad (11)$$

$$P_{itk} + I_{i(t-1)k} + \sum_j T_{jitk} + \sum_l M_{itlk} = \delta_{itk} + I_{itk} + \sum_j T_{ijtk} + \sum_l M_{itkl} \quad (12)$$

$$P_{itk} \leq S_{itk} * M \quad (13)$$

$$P_{itk}, T_{ijtk}, I_{itk}, M_{itkl} \geq 0 \quad (14)$$

$$P_{tzk}, T_{ijtzk}, I_{tzk}, M_{tzkt} = Integer \quad (15)$$

$$S_{tzk} = Binary \quad (16)$$

As mentioned, it is possible to use commercial integer programming solvers, with appropriate reformulations, to attempt solution of this problem; research on this topic is ongoing.

Conclusion

This paper examines inventory costs in the context of defense operations. Based on the argument that inventory costs in defense operations are not the same as those in commercial enterprises, it is proposed that inventory effectiveness, in this context, should be measured in terms of the ability to meet a range of anticipated and sometimes unanticipated threats. This does not necessarily mean that planning can only be for "known knowns" and "known unknowns," but not for "unknown unknowns." Initial models have been developed to examine inventory decisions for complex products, that is, those composed of multiple subassemblies in which there are shared subassemblies among different product types. It is possible that the option for storing partially completed assemblies may also help in meeting demand uncertainties. Thus, when faced with uncertain demand for one or more products over a geographically distributed domain, the set of recourses for a manufacturer/planner include excess production (inventory storage), rapid re-location of inventory, production surges, when to upgrade technology or procure new models, what level of assembly to store the products, and where to store these, as well as in what quantities and ratios of product types. Solutions of mathematical models are illustrated, and simulations to assess the utility of the solutions obtained by analytical methods are also presented.

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Identifying and Managing Manufacturing and Sustainment Supply Chain Risks

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Elvira Loredo—Operations Researcher, RAND Corporation. Ms. Loredo was a member of the Deployed in Iraq/Afghanistan Group, which conducted fieldwork on improvised explosive devices (IEDs) in combat zones. The group helped identify and transfer new data sources; provide daily, on-site analytical support to counter-IED planners at various levels of command; revamp the IED information management system in Afghanistan; and draft special reports for field commanders on critical subjects, such as the performance of counter-IED Task Force Paladin in Afghanistan and the suicide bomber threat. Prior to that, Loredo was on the Analysis of Alternatives (AoA) for KC-135 Recapitalization study team, which produced a detailed AoA for the U.S. Air Force's aging tanker fleet. Loredo received her BS in systems analysis and MS in management science from the University of Miami, and her PhD in industrial engineering from Arizona State University. [loredo@rand.org]

Amy Cox—cox@rand.org

Abstract

In recent years, the Air Force and, particularly, its suppliers, have pursued various means to improve performance, reduce costs, and otherwise adopt best industry practices. While these practices offer many benefits in efficiency and effectiveness, they can also make supply chains more brittle and increase the risks and consequences of supply disruption.

Recognizing the changing nature of its supply chain risks and their effects on its operations, the Air Force asked RAND to identify emerging best practices for supply chain risk management (SCRM), assess current Air Force management of aircraft manufacturing and sustainment risks against these practices, and recommend ways to improve. To do this, RAND researchers reviewed relevant literature and DoD and Air Force guidance and interviewed companies recognized for their SCRM as well as DoD and Air Force personnel involved in SCRM-related functions.

This presentation summarizes what RAND researchers found and outlines ways to improve Air Force SCRM.

Comparing Acquisition Strategies: Maintenance-Free Operating Period vs. Traditional Logistics Support

Nickolas H. Guertin—Director, Naval Open Architecture Enterprise Team (OAET) PEO, Integrated Warfare Systems–IWS-7. Mr. Guertin received a BS in mechanical engineering from the University of Washington and an MBA from Bryant University. He is a registered Professional Engineer and is Defense Acquisition Workforce Improvement Act (DAWIA) certified in Program Management and Systems Planning Research Development and Engineering. Mr. Guertin enlisted in the U.S. Navy as a submarine nuclear power plant electrical operator. After six years on active duty, during which time he served aboard USS *Thomas Jefferson* and USS *Silversides*, he joined the Navy Reserve. Following completion of his undergraduate degree, he accepted a USNR commission as an Engineering Duty Officer, specializing in ship construction and repair. He has subsequently retired from the Navy Reserve, having completed a range of engineering duty ship repair and construction assignments leading up to command of a ship repair team. Mr. Guertin began his civil service career at Puget Sound Naval Shipyard in nuclear propulsion plan testing. He then went on to Naval Undersea Warfare Center Keyport as a heavyweight torpedo depot engineer. Mr. Guertin then shifted to combat systems as the Sonar Participating Manager representative for Trident Command and Control System testing. Mr. Guertin's experience in Open Architected systems includes being on the team that started the Acoustic Rapid Commercial Off The Shelf (COTS) Insertion (A-RCI) program, the Assistant Program Manager for the Total Ship Monitoring System, and duties as the chief engineer for submarine combat control, which incorporated the business and technical processes established under the A-RCI program. Mr. Guertin currently serves in the Program Executive Office for Integrated Warfare Systems as the Deputy Director for Open Architecture, and leads the transformation to change the business, technical, and cultural practices for how the Navy and Marine Corps buys and builds systems as a coordinated enterprise effort. Mr. Guertin is married to Maria Foderaro-Guertin. They have two children and reside in McLean, VA.

Paul Bruhns

Abstract

For more than a decade, the U.S. Navy has been modernizing many of its software intensive National Security Systems (NSS) using an Open Architecture (OA) approach that leverages capable and reliable commercial off-the-shelf (COTS) technologies and modern, agile software development practices. The focus of the Naval Open Architecture strategy has been to field affordable and superior capabilities more rapidly at reduced costs. NSS and information technology (IT) system upgrades are now routinely accomplished using COTS, proving that the U.S. Navy has achieved measureable success in this area. But this progress has not improved the environment of life cycle cost savings and system sustainment. The Integrated Logistics Support (ILS) elements of most acquisition programs are not taking full advantage of industry best practices that are robust and mature for life cycle affordability and sustainment. There is great cost savings potential in this area, as the cost of ownership of a system aboard a ship over its life cycle for repair and maintenance far exceeds the Navy's initial investment in design and production.

This paper gives an overview of Maintenance Free Operating Period (MFOP) pilot implementations that have been deployed twice aboard Navy ships. It will describe a fundamentally new system sustainment approach and acquisition techniques, which show how MFOP is a viable alternative to traditional ILS life cycle methods. Finally, we will argue that system designs using the MFOP approach are generally superior in terms of cost, performance, and resource management.

Introduction

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Why Maintenance Free Operating Periods?

The simple answer is that an OA/MFOP enabled system saves money and provides the warfighter with a product that is better, cheaper, and faster:

1. Better because the MFOP design yields more operational availability to the warfighter.
2. Cheaper because there is less material, infrastructure, and training to provide and manage through the elimination of platform/system level, material support packages.
3. Faster because distance support techniques eliminate delays in supporting fielded products and are available world-wide.

The Maintenance Free Operating Period Defined

The Maintenance Free Operating Period (MFOP) is defined as the specified period of time that a system must be available in support of its required mission, with a specified level of reliability, and with no open cabinet maintenance. Commercially available methods and products support very high probability of system availability, approaching 99% or greater. In general terms, Reliability (of mission time) is stated as follows:

$$R(t) = e^{-t/MTBF},$$

where *t* is the mission time (required MFOP), and *MTBF* is system Mean Time Between Failure under stated conditions.

An MFOP-enabled system is inherently reliable with continuous health monitoring status to provide confidence that the tactical application availability requirement is highly likely to be met. To achieve this, the MFOP system has the following design enablers:

1. Fault Tolerant Design,
2. Data Collection, and
3. Remote Connectivity.

Fault tolerant COTS based designs utilize vendor-supplied Mean Time Between Failure (MTBF) data as a starting point. The system is then constructed based on a reliability block diagram that provides sufficient redundancy to meet the required level of reliability. This accounts for the MTBF levels of the included components. Note that vendor MTBF data is usually provided to users based upon specific conditions, generally a benign laboratory environment.

Open Architecture and the MFOP Evolution

Open Architecture (OA) is a collection of best practices, technical and business, and when combined with a willing corporate culture, can result in a highly effective life cycle strategy in which total cost of ownership is minimized and capabilities to the warfighter are maximized.

The Navy has extended the work of the Modular Open Systems Approach (MOSA) work performed by the DoD's Open Systems Joint Task Force (OSJTF) to more comprehensively achieve the desired goals of open architecture as a part of the Naval Open Architecture (NOA) effort. NOA is defined as the confluence of business and technical practices yielding modular, interoperable systems that adhere to open standards with published interfaces. It is the goal of the Naval Open Architecture effort to "field common, interoperable capabilities more rapidly at reduced costs" (*Updated Naval OA Strategy*, 2008).

The Navy and Marine Corps are incorporating OA into selected new start acquisition or upgrades to existing programs such as Common Afloat Network Enterprise Services (CANES), Submarine Warfare Federated Tactical Systems (SWFTS), Joint Counter-Radio control improvised explosive device Electronic Warfare (JCREW), and others (Fein, 2009).

The following are the core principals of the Open Systems Architecture approach (Guertin & Clements, 2010):

1. Modular designs with loose coupling and high cohesion that allow for independent acquisition of system components;
2. Continuous design disclosure and appropriate use of data rights allowing greater visibility into an unfolding design and flexibility in acquisition of alternatives;
3. Enterprise investment strategies that maximize reuse of system designs and reduce total ownership costs (TOC);
4. Enhanced transparency of system design through open peer reviews;
5. Competition and collaboration through development of alternative solutions and sources;
6. Analysis to determine which components will provide the best return on investment (ROI) to open…i.e., which components will change most often due to technology upgrades or parts obsolescence and have the highest associated cost over the life cycle.

Achievement of these six principles requires an affirmative answer to a fundamental question: Can a qualified third party add, modify, replace, remove, or provide support for a component of a system, based only on openly published and available technical and functional specifications of the component of that system?

OA is ultimately about enabling acquisition choice. When program managers can compete for products and services across a system design, they can establish an environment of continuous competition for the best possible solution at the best possible price.

MFOP Evolution

Since 2005, two MFOP pilots have been conducted on Navy ships:

- **Submarine MFOP Pilot Program.** The AN/BQQ-10 (a.k.a., Acoustic Rapid COTS Insertion, or ARCI) submarine tactical sonar system is the premier example program for an Open Architecture (OA) in the Navy. This program pioneered OA in the Navy/Marine Corps. In 2005, four submarines were augmented with additional embedded servers and additional design elements to ensure a 90-day MFOP period for tactical software availability within the MFOP boundary. The rest of the system was managed using the traditional ILS support system. Five years later, the tools and techniques now able to tackle the full range of technical challenges that confronted the earlier attempts have been greatly improved by the commercial market computing industry.
- **Surface Ship MFOP Demonstration.** This was conducted in 2010 as a comprehensive OA/MFOP demonstration aboard USS *Iwo Jima* (LHD 7). The demonstration exercised the Navy's evolving concepts for risk reduction and cost savings, as well as exploring the full extent of the MFOP concept. This demonstration relied on reuse of two different operational software assets, one from the Navy's Software Hardware Asset Reuse Enterprise (SHARE) repository, and the other through program/domain awareness. These Navy-funded designs were combined with commercially available management capabilities and re-hosted on a highly reliable commercial blade center with embedded spares that was designed for the entire system boundary. In this demonstration, the system MFOP period was doubled to 180 days, and the certified support package provided in the temporary installation (TEMPALT) had zero maintenance support items provided to the ship.

Case Study: The Surface Ship OA/MFOP Demonstration

Requirements and Approach

The object of the Surface Ship OA/MFOP Proof of Concept demonstration was to develop a scalable and extensible demonstration system that would provide a greater than 99% probability for a tactical capability under test. Success would be measured by completing a deployment on a combat ship of 180 days with no open cabinet maintenance, while eliminating the traditional shipboard maintenance support package. All design decisions associated with the implementation methods were targeted for an NSS of scale and complexity, so that these lessons and designs could be used for large-scale programs such as PEO C4I's CANES, PEO SUB's SWFTS, PEO LMW's Littoral Combat Ship Mission Module program, and PEO IWS's AEGIS, among others.

For control purposes, the system required an operational capability from which to measure system availability and design for reliability. The Common Network Interface (CNI) software application, originally contracted by PEO IWS 6 for Amphibious Assault Ships and developed by GD-AIS, was selected. The specific version of CNI used in the demonstration was selected due to its availability in SHARE repository and the willingness of the originating program office to support the demonstration. A suitable hardware platform, that is, one that would be typical of, and extensible to, a shipboard tactical information system, was then configured to ensure CNI would be operationally available for the stated mission time.

OA/MFOP Demonstration System Design

Three particular design features were used in the surface ship demonstration system (see Figure 1):

- **Fault Tolerance.** The hardware platform was made fault tolerant by adding and embedding redundancy based on the hardware vendor's supplied component MTBF data, and adding a method for controlling spare resources (failover).
- **Data Capture and Collection.** All components, including power and cooling devices, were monitored, either through built-in Simple Network Management Protocol (SNMP) message traps, or more sophisticated software agents running in data servers. This data was continuously collected for online assessment and post mission analyses.
- **Remote Connectivity.** The system was connected to SIPRNET. The purpose of this link was to collect reliability performance information for online assessment, and to allow subject-matter experts (SMEs) ashore to restore system operation in the event of a software failure.

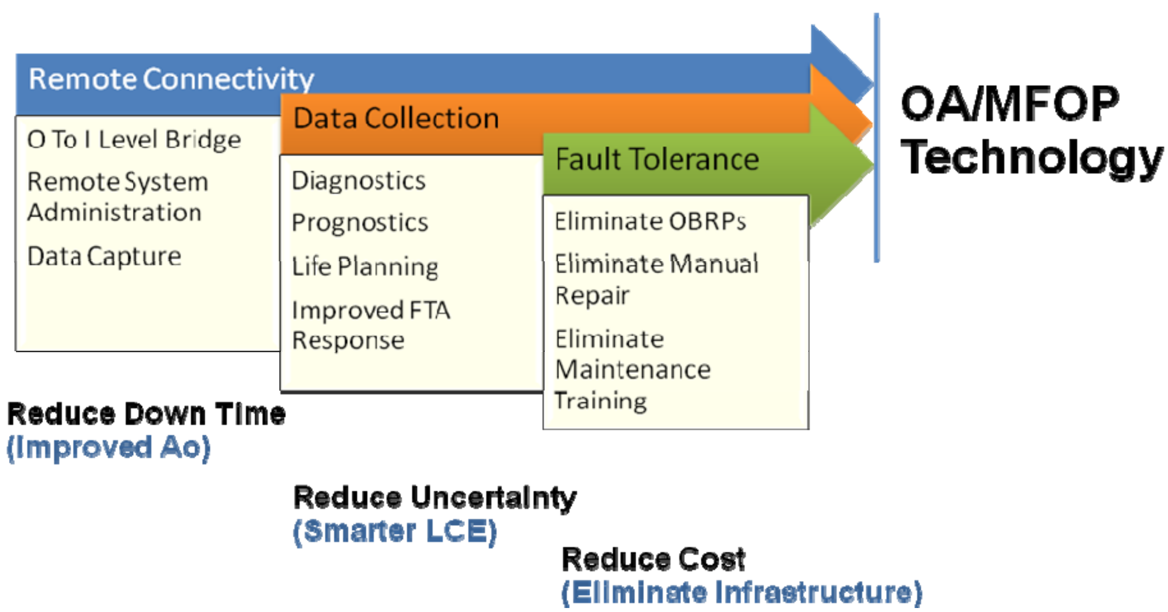

Figure 1. OA/MFOP Enabled System Design Elements

The following paragraphs detail the considerations that went into the design and selection of products for the OA/MFOP system.

Fault Tolerance

The OA/MFOP enabled system tolerates faults by embedding (online) spare resources and employing mechanisms to control them. In the event of a component failure, the system detects the problem and reconfigures around it. The following paragraphs are specific to how this was done in the design of the Surface Ship OA/MFOP Demonstration system.

Embedded Spares

The OA/MFOP proof of concept demonstration system was configured to ensure the CNI operational capability would be available for the entire ship's deployment period of 180 days. This assumed the CNI function was needed continuously, and that the calculated probability of mission success was greater than 99%. Requirements were analyzed and allocated to a potential solution, from which a clear winner emerged. A Blade Center platform was chosen because of the inherent redundancy built into the product design. That is, the number of power, cooling, network communications, processors, and I/O elements were scalable to meet the reliability demands of the operating period.

The specific device chosen was an IBM Blade Center "T-Chassis®" as it provided comprehensive measures for component monitoring (advanced management modules), as well as extended environmental survivability, that is, TELCO hardening Standards NEBS-3/ETSA.[1] To further improve MTBF, the application server magnetic hard drives were relocated to the IBM DS3400, a highly redundant storage area network (SAN) with RAID level 6 applied.

When Reliability Block Diagrams were built to the OA/MFOP demo system configuration and analyzed (using RELIASOFT Inc., Block-Simulator 7), the built in redundancy of the system provided a greater than 99% probability of mission success. This result was expected, but what surprised the development team was that the one-year and four-year probabilities for R(t) were so high (see Figure 2).

Time	With Embedded Spares	Non Redundant
6 Month	> 99%	91%
1 Year	99%	83%
4 Years	89%	48%

Figure 2. R(t) Probability of Mission Success

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[1] NEBS Level 3 Includes Specifications GR1089-Core and GR63.

This was an exciting prospect, as most Navy COTS technology Refresh Cycles occur in four-year increments. Is it possible that all spares could be installed into a system from the beginning?

Dealing With Vendor Supplied MTBF Numbers

The MTBF data provided by the vendor is not detailed enough to perform a precision analysis of failure. We transferred vendor MTBF numbers to a constant failure rate (exponential distribution), where at any time the likelihood of failure was the same. In reality, the probability for component failure is higher when a component is new, and declines to a low probability for the bulk of the hardware lifespan. The probability of component failure during this period is low and relatively stable, but failures do occur. Faults occur on a pseudo-random distribution, often referred to as the "bath-tub curve" (see Figure 3).

It should also be noted that the slope and period of these curves depend on other environmental factors, and are perturbed by temperature, humidity, vibration, and dust. The OA/MFOP demonstration system did not attempt to deal with these effects or de-rate the MTBF results to account for a shipboard environment. We dealt with this uncertainty through environmental monitoring and comparing empirical failure reports to the vendor MTBF data over the course of the system's in service life.

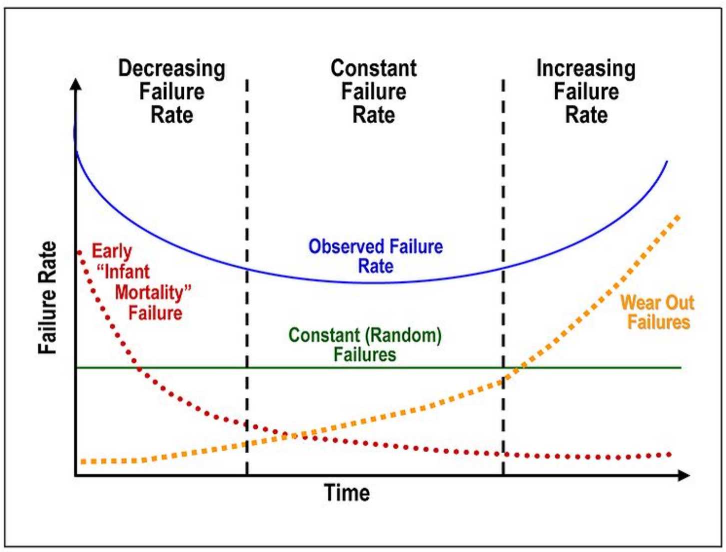

Figure 3. Computer Hardware Failure Rate Profile

Additionally, minimum thresholds for probability of mission success in the face of hardware failures can be established to initiate service technician support for the installed system. Figure 4 depicts cumulative failure density over time. The system design accounted for a number of failures to occur over the life cycle. As long as the failure rate falls below the "acceptability line," there should be sufficient hardware reliability remaining in the system to complete the stated mission time. This mission time could be stated as a deployment period (6 months), or a tech refresh cycle (4 years).

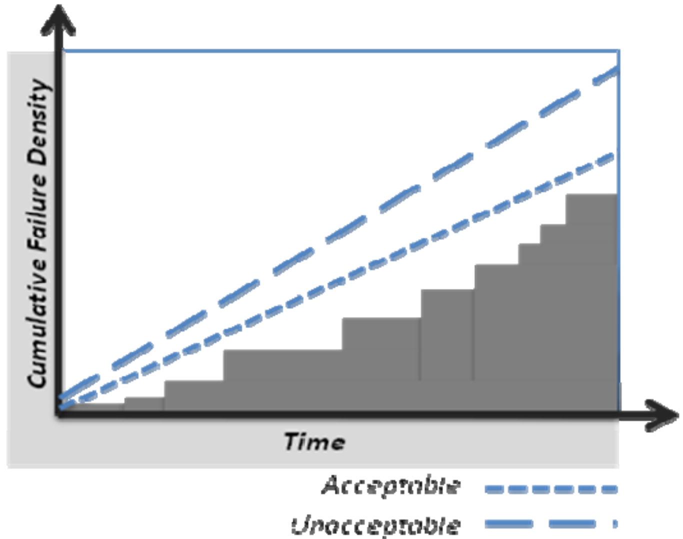

Figure 4. Repair Action Decision Criteria

Failover

Hardware redundancy is not enough. In maximizing full Operational Availability, we need to examine “Uptime” in relation to Total Mission Time. Uptime is not just the longevity of a specific piece of hardware, but the availability of the warfighting capability.

A method of automatically detecting faults and automatically responding to them was established. Processing capacity is redirected to available embedded spares (without operator intervention) in the presence of component failure. This implied that regular polling and tracking of system state information must be provided to a control mechanism that acted to restore operation according to a predefined plan. Automatically detecting faults has been a major focus of system management function effort for NSS projects in the past. Due to the development of robust data center management software capabilities in the commercial market to support innovations such as cloud computing, failover and fault recovery capability can be acquired, vice hand tooled. The OA/MFOP Demonstration development team evaluated software solutions that are commercially available to perform the basic functionality needed to sustain applications to the warfighter, maintenance free. Based on a market survey of product capabilities, the IBM Director Management Software product (Version 5.20) was chosen. This product met the requirements for monitoring and failover, but it also contained a unique feature called “open fabric manager” that managed all worldwide names (WWNs) and logical unit numbers (LUNs) for the included application servers, and could automatically reconnect the application storage volume on the SAN to a spare processor and resume processing. This greatly simplified a traditionally hard problem of reconfiguring around failures. With this method, the applications reside in the same address without any overt additional effort.

Embedded spares and failover management software are the design features that combine to represent the fault tolerant attributes of the demonstration system.

Data Capture and Collection

In the context of OA/MFOP, ongoing performance monitoring provides the feedback loop from which all management responses are applied. At the component level, messages are transmitted via Simple SNMP messages, which are trapped and processed by the system software to assist in failure response. At a higher level, this and other data is collected over time to analyze performance trends for the purposes of making proactive program support decisions. The OA/MFOP demonstration system employed a layered approach to data capture that included time series monitoring of all critical performance and environmental parameters. This layering was a critical design requirement in order to ensure scalability to multiple warfighting platforms and domains. The designers were especially concerned with the disadvantaged network user and the aperiodic communicator. MFOP performance can be achieved with small, but highly targeted system status reports to the shore-side maintainers. The crucial information made available at the appropriate time allows decision makers to perform prognostic maintenance decisions. Given that a failure has occurred, and automatic reconfiguration has been executed according to the pre-scripted recovery plan embedded in the system, a report is generated. The distance support specialist can then examine the know state of the system, the remaining hardware availability, and the likelihood of future component failures (based on life and environmental conditions), and make a decision when action is required. Three decisions are possible: (1) Near-term corrective action is necessary to sustain operational availability of the capability during the deployment period, with flyaway support personnel; (2) No action is required and corrective action can wait until after the deployment is complete; and finally, (3) No action is required until the next full Technology Insertion event. The key difference with an OA/MFOP enabled system, is that these decisions can be made throughout the lifespan of the system, and the decision criteria are fully available throughout the operational command and support infrastructure.

The Specific OA/MFOP Demonstration System Monitoring Scheme

Hardware Monitoring. All replaceable component devices in the OA/MFOP system were monitored. All components within the Blade Center hardware boundary were monitored by the two (redundant) Advanced Management Modules (AMMs). Those external to the blade center were attached to the Ethernet network, and their state data collected through SNMP and Storage Management Initiative–Specification (SMI-S) message traps. These data were then interfaced with the IBM Director Management Software for monitoring and event action response. Finally, the captured data were stored in an Oracle database that could be queried by subject-matter experts, as well as life cycle support planners, project managers, and operational commanders. This data would support those in off board analyses leading to proactive decision-making.

Environmental Monitoring. Knowing the physical environment is a key to determining cause and effect properties of the deployed hardware. Most hardware failures that occur outside the machine’s expected longevity envelope are caused by extreme temperature, humidity, dust, power surges, and vibration. The OA/MFOP demonstration system included an NTI Inc. Enviromux 16™ processor to collect and transmit this data to the management server. The data were time tagged for correlation and trending purposes in support of off-board analyses.

Application Server Monitoring. There are several software agents in the market that provide various levels and degrees of application server monitoring. Generally, they all log application uptime, and provide some level of basic resource monitoring, such as CPU load percentage, Memory percentage, I/O throughput levels, and storage system utilization. The OA/MFOP system selected and used the IBM Director Management Software “Level II Managed Agent©” product for all application servers in the system.

Remote Connectivity

In order to ensure the deployed OA/MFOP system was supported while deployed, the system was connected to SIPRNET where it sent summary and event reports back to the Off Hull terminal, and if necessary, operationally restored using remote system login and administration capabilities.

Reporting

The OA/MFOP system re-used the Remote Off Hull Maintenance Support (ROHMS) software developed by NAVSEA PMS 401 contract for use in the AN/BQQ-10 sonar system to transmit status and other maintenance related reports to a connected shore side terminal. The ROHMS application is constructed on an open source software platform, including the TOMCAT™ web server and the Firefox™ web browser provided by the Mozilla™ Foundation. The ROHMS feature specifically used in the OA/MFOP demonstration was the file transfer functionality. It provided concise reports, most of which used very low network bandwidth, about the size of a typical e-mail record (2-20 KB). Reports were based on queries of specific data elements held in the OA/MFOP deployed system's database. This was not a replication server, as limiting network communication bandwidth was a priority. Under normal conditions, brief reports were sufficient. The OA/MFOP demonstration employed the following reports:

- Summary Status Report: Provided daily, it listed the status of all hardware, environmental levels, Application availability, and resource utilization.
- Event Report: On the occasion that a system event or hardware failure occurred, the ROHMS connector on the ship would transmit an Event Report, listing cause, effect, and restorative action.
- Detailed Report: A third type of report was also employed that provided event detail to be used by SMEs to determine if follow up action or planning was necessary.

Control

Distance support is an alternative maintenance concept that connects SMEs to the ship system over a network (in this case SIPRNET) to assist ship's force in restoring the tactical operation of the system. There are several techniques that can be used to assist in this manner. The two most popular are the following:

- Remote Collaboration: useful for bridging Operational to Intermediate Level maintenance; and
- Remote System Administration: used to login to a system for the purpose of restoring software operation.

The OA/MFOP system employed two Remote System Administration techniques over SIPRNET:

1. Web Browser: A menu driven login using HTTPS with Secure Socket Layer (SSL) encryption. It was used in OA/MFOP, because the system was deployed as autonomous, with no ship's force assistance. This method is very network bandwidth efficient, but in most instances, the utility provided does not necessarily require the services of an off board SME.

2. Virtual Network Connection (VNC): A technique that allows the remote SME to login to a specific server/processor at the System Administrator level. VNC uses frame buffer relay techniques to provide the SME with a remote interface to the target machine. From there, the system can be analyzed, restored, and updated. The OA/MFOP system used the Real VNC ® product to positively control the system during deployment. All distance support objectives were accomplished without any collaboration of ship's force.

OA/MFOP Demonstration System Deployment

TEMPALT Planning and Approval

A Ship Change Document (SCD) was prepared for installation aboard USS *Iwo Jima*. The Ship Main process required that the installation package include drawings, a risk assessment, and a certified Integrated Logistics support package. These were scrutinized and approved through COMNAVSURFLANT. Since the OA/MFOP system did not require open cabinet maintenance throughout the deployment period, the certifying authority waived the following ILS products:

- Maintenance & Repair Documentation,
- 3M System Package,
- On Board Repair Parts,
- Maintenance Assist Modules,
- System Drawings,
- APL/ Supply Support Documentation, and
- Crew Training. (The crew was briefed and given the procedure for an emergency shutdown only.)

Information Assurance Challenges

In order to demonstrate Remote Connectivity capabilities, the OA/MFOP system was required to undergo Information Assurance (IA) certification by NAVNETWARCOM. An Interim Authority To Test (IATT) was sought for a six-month test period. Leading up to the OA/MFOP demonstration test date, there were no known Navy ship systems that had been granted approval to use remote connectivity for maintenance of tactical systems over SIPRNET. It is noteworthy that the ROHMS capability had been granted a one-day test on SIPRNET, but had not been approved for use on a deployed submarine. Although the data being collected over ROHMS is UNCLASSIFIED, the system application (CNI) was designed to interface to classified sensors (Link 16) and to "Text Chat" among various units of the strike group, rendering the entire system "SECRET."

Developers beware: The concept of operations (CONOPS) and bandwidth used on Navy networks is of particular importance to those who validate and approve Defense Information Assurance Information Assurance Certification And Accreditation (DIACAP) application packages. Generally, a candidate system will be required to demonstrate network communications behavior with all vulnerability patches applied. Depending on the scope and intensity of network interaction, as well as mission assurance category (MAC) level, a number of interoperability tests, conducted on a simulated tactical network will likely be necessary to gain approval of the DIACAP document. This certification is then used to request NAVNETWARCOM approval for the desired level of network connectivity, that is, *Authority to Operate. Collaboration with the Echelon II IA representative should begin at least one year in advance of the accreditation need date.*

The OA/MFOP demonstration project reused ROHMS and CNI from prior programs that had already undergone Navy network testing. There were sufficient elements of similarity among the systems and their interfaces to the network that OA/MFOP met the demonstration requirement "by analysis."

Surface Ship OA/MFOP Demonstration Results

The demonstration completed in January 2011. The TEMPALT system was then removed over the last week of February 2011. Statistical performance details will be published in a report in late summer 2011. A quick-look report includes the following highlights:

- The measured operational availability of the CNI operational software was 99.67% over the deployment period. The remaining unreliability level (0.33%) was due to the two (test team) induced failures used to measure the automatic failover response of the system. The operational availability of the ROHMS application server was measured at 100%, as ROHMS was not intentionally failed while deployed.
- The physical environment was relatively benign. Temperatures hovered around 25° C, while humidity and power were stable and generally reflective of laboratory conditions.
- There were no actual hardware failures over the course of the MFOP deployment period. In fact, the system has virtually been in continuous operation for two years with no physical failures noted. This speaks to the inherent reliability of today's Enterprise IT systems.
- Six Distance Support objectives were successfully demonstrated. These were designed to eliminate the need for shipboard ILS products, as well as Fleet Technical Assistance "Fly-Away" time and cost. These Included the following:
    - Monitoring All Hardware Status;
    - Monitoring Server Operations/ Resources;
    - Collecting System Availability and Environmental Data;
    - Remotely Inducing Simulated Failures/Observed Automatic Failover and Recovery Using Embedded Spares; and
    - Performing Remote IT, including Restarts, Pushing Files, Adding Applications, and Correcting Code Errors.

OA/MFOP in the Context of Total Ownership Cost

Operation and support costs can make up 70% of the total ownership cost of the system. A significant portion of these costs are attributable to spares, maintenance training, and their associated infrastructure. OA/MFOP targets these specific cost contributors for elimination.

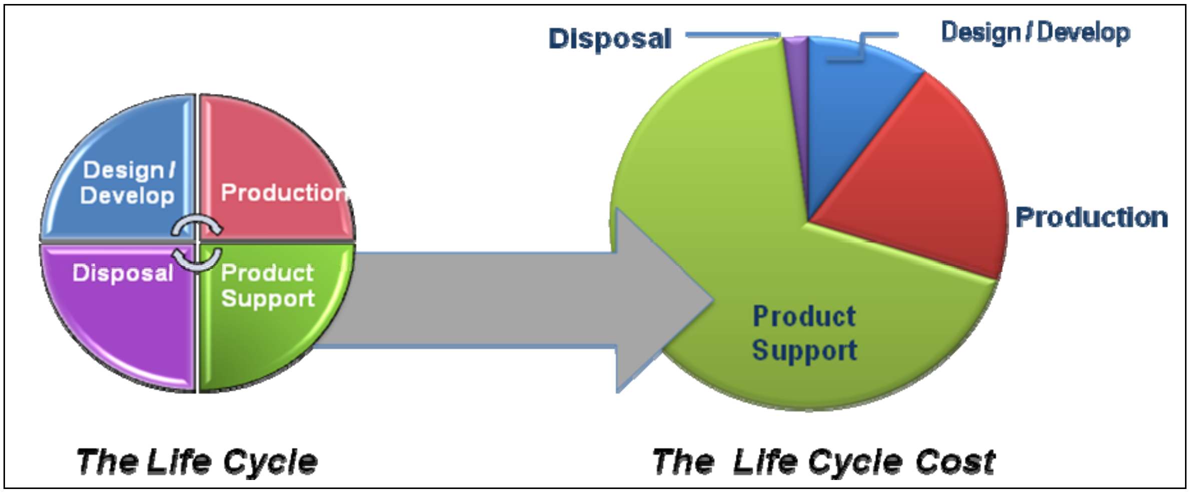

Figure 5. Impact of MFOP Design in Overall Program Costs

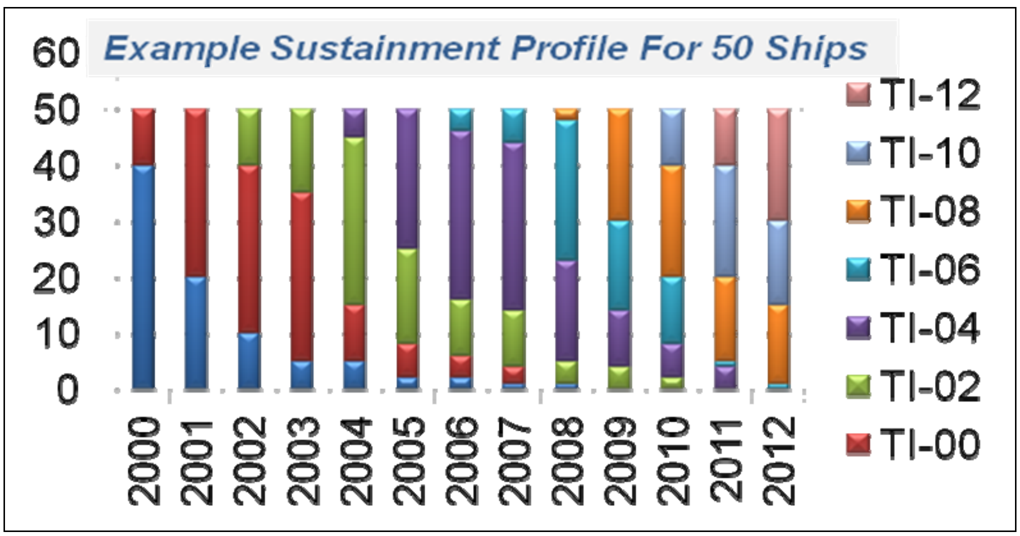

Figure 6. Impact of MFOP in Technology Insertion Life Cycle Strategy

ILS development tasks are redirected to Life Cycle Engineering purposes (Failure Modes Effects and Criticality Analysis, and the like) which feed back to System Engineering for evolutionary improvement. Thus, the modernization schedule becomes the life cycle support strategy.

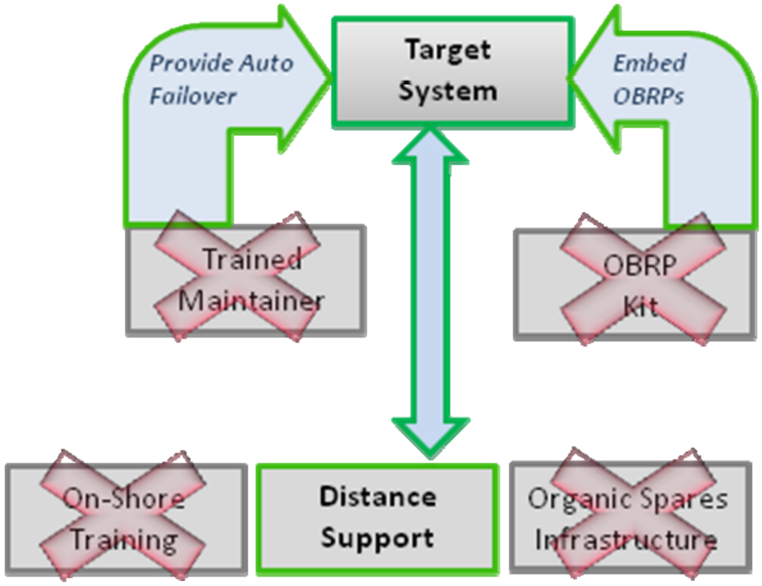

Figure 7. Cost Elements Targeted for Elimination by MFOP Design

Bounding the MFOP Environment

The OA/MFOP boundary determines the level of savings. The goal should be to include the entire system within the OA/MFOP boundary. Figure 8 shows the MFOP boundaries of the submarine sonar pilot (2005) through the surface ship demonstration (2010). Based on the market research and implementation of COTS technologies in the surface ship design, it is suggested that a majority of the Navy's tactical Information systems can implement the OA/MFOP design model across the entire system. The benefit is obvious; complete elimination of the traditional ILS support package, and the corresponding reduction in infrastructure.

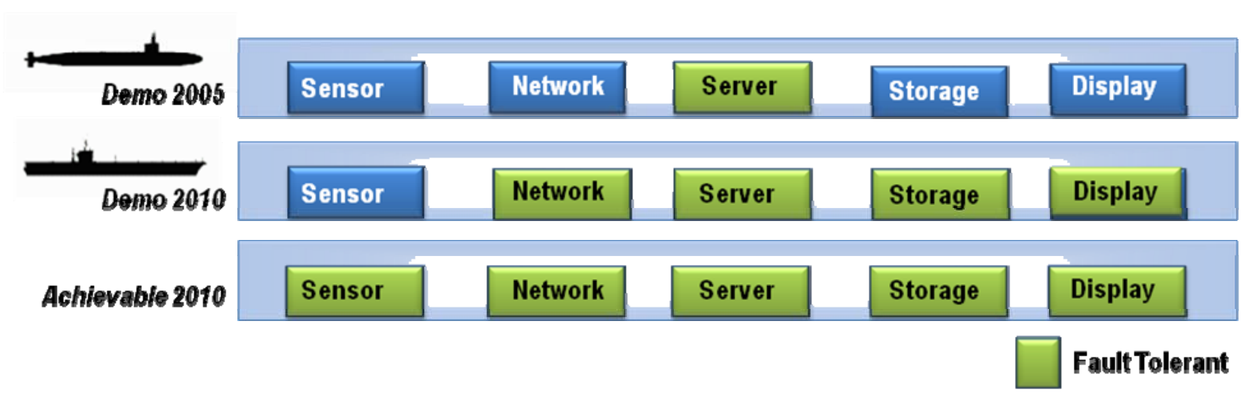

Figure 8. MFOP Boundaries Determine Level of Savings

Phased Implementation in a Strategic Stepwise Manner

Designing to an MFOP solution for sustaining capability in the field can be accomplished with low risk when starting with a new system design. However, many programs in the Navy today are doing product improvements to existing systems. For this case, MFOP capability can be achieved in a stepwise manner. We prescribe a set of steps to get the most value in the shortest time while ultimately driving to reduce shipboard maintenance to the point of elimination.

The first step is to capture the value of distance support from ship to shore through a network connection that bridges between the organic system maintainers (O) to intermediate subject-matter experts and tech assist (I) levels. This O-to-I Level Maintenance Bridge requires little product integration and will immediately generate cost savings. Table 1 highlights an example program that achieved a 15:1 cost savings ratio when employing distance support services over deploying tech assists.

Table 1. Cost Data for Fleet Technology Assistance

Fleet Tech Assist Data For Submarine Enterprise

- 120 FTA Events Performed
  - 93 Local (Norfolk)
  - 27 Out-Of-Area
- 100% Distance Support (DS) Attempts (CFFC / Command Policy)
  - 16% Success Rate Overall On All FTA Events
  - 37% Success Rate On Out-Of-Area Events
- Average MHs Per Event
  - 19 MH Via DS
  - 164 MH Via On-Site Support
- Average Cost Per Event (Based On $60.00 Per Hour)
  - $1,140.00 For DS
  - $9,840.00 Labor and $5,550.00 Travel For On-Site ($15,390.00)

15:1 Cost Savings When DS is Successful

These methods generated faster response time for solving the system problem, as well as lowering labor and travel costs. A secondary effect of preferentially using distance support vice on-site fleet tech assists is that more fleet problems per unit time can be solved by a single subject-matter expert.

The next step in this strategic path is to establish data collection in the system. The collected information can be used by the distance support elements to rapidly focus on problem areas and solve issues quickly. This will also support system health and status reporting to a variety of stakeholders, including operational commanders, so that they have up-to-date awareness on the ability for their platforms to support assigned missions. Instrumentation of system components can be quickly achieved through built in test (BiTe) and component information that is inherently available in commercial computer systems through such mechanisms as SNMP. There is a rich variety of SNMP collection agents on the market, including open source software, that provide facilities to capture data already available in any network system. Products such as ROHMS, the data collection, reduction, and dissemination utilities developed under the OA/MFOP program, have been designed to capture this data and provide reporting of system health and status information that specifically address low network bandwidth requirements.

Fault tolerant system design through built in spares and automated failover is the next of the strategic steps. This step requires a change in hardware baseline for the added resources to support failover and is the tipping point to facilitate the MFOP concept for a full deployment period. Several programs in the Navy have achieved some level of embedded redundancy and automated failover, but in the context of eliminating single points of failure, which traditionally would be immediately corrected by the O-level maintainer. MFOP designs include the elimination of single points of failure, but add the dimension of measuring the rest of the system and determining when in the future repairs need to take place in order to sustain a required probability of mission success. This is done through the development of reliability block diagrams and creating automated fault recovery routines and heuristics to sustain tactical function in the face of component failures. Prognostic maintenance decisions, vice reactive maintenance action represent the biggest shift in culture for the current fleet support environment.

The final step of reworking the life cycle planning can be quickly achieved through programmatic restructuring once the previous three technical steps are performed. When the facilities for distance support, data collection and dissemination, and fault tolerant MFOP designs are put in place, the next logical step is to retool the infrastructure to take advantage of the life cycle. This is where the fleet maintenance support infrastructure can be retooled to take full advantage of distance support and maximum elimination of open cabinet maintenance. This is also where Technology Insertion strategies can be revised to take full advantage of the MFOP concept to establish new life cycle strategies, as previously described.

How Does The Navy Drive Change?

To effectively eliminate support infrastructure, Program Sponsors must hand down strong top-level requirements (TLRs) for total ownership cost reductions to Program Managers for execution. This can be a significant challenge for a couple of reasons:

1. Modernization budgets rarely support the full range of proposed improvements, and capability enhancements are generally prioritized above those aimed at creating efficiencies in operating costs; and
2. The budget lines for O&MN infrastructure elements are carved out before the Program Sponsor level. These costs are distributed to training commands and supply chain management, and thus the acquisition offices have no insight into the potential cost savings possible with an OA/MFOP solution.

Only with full cost auditing at the highest levels of Program budget distribution can a complete cost profile be quantified.

In practice, it is common for TLRs to be collaborated on ahead of time by the Program Sponsors and Acquisition Managers (B. Johnson[2], personal communication, March 2011). (Strategies used by PMS 425 and OPNAV N87 to specify COTS requirements and methods for ARCI acquisition leading to Open Architecture implementation.) A hard operational requirement would certainly be the purview of the OPNAV Sponsor, with its technical

[2] Bill Johnson is the inaugural program manager for A-RCI.

implementation requirements left to the acquisition community. For example, if the Sponsor wants to reduce total ownership costs, the acquisition manager may offer OA/MFOP as a method of eliminating at sea maintenance cost and lowering support infrastructure. If agreed, a suitable requirement is then codified. This requirement may be transcribed as an improvement in Operational Availability, whereby the system must be restored within five minutes upon the detection and verification of a hardware failure. In practice, this requirement could only be met in a system designed to be fault tolerant. Similar requirements for maintenance data collection and distance support (over Navy networks) functionality could be specified in the solicitation (Request For Proposal) with incentives weighted toward full OA/MFOP proposals.

Commercial Trends

There are two areas where commercial IT needs are driving the development of high availability solutions: datacenter management software and redundancy/auto-recovery/failover solutions. Industry investment in cloud computing related technologies are racing ahead to support high availability solutions such as software as-a-service and virtual offices. Companies like IBM offer technologies and services under the monikers Resiliency Services, which address availability, and Recovery Services, which address failover. Both have the same purpose as, we require for an MFOP environment to protect the availability of their client's IT. The former is geared towards continuous 24X7 of the target system, while the latter maximizes the integrity of the data, with some flexibility in restoration time. The technology innovation itself is driven by large enterprise business needs for continuous data services that are secure. The business sectors driving these product development areas include the following:

1. Banking/Financial Services,
2. Distribution Centers,
3. Public Administration, and
4. Industrial.

Summary/Conclusion

The Naval Enterprise has made significant strides with Open Architecture and COTS technologies. Significant budget pressure, coupled with fleet operational demands, make it clear that we must reduce costs and increase availability using the resources we have and by combining them in new, smarter delivery packages. The techniques described in this paper, instantiated on USS *Iwo Jima*, graphically demonstrate the power and savings potential of the Maintenance Free Operating Period concept. MFOP will dramatically cut costs in training, repair, and sustainment logistics, while pushing availability to new levels of excellence. The only thing that stands in the way of an MFOP future where we purposefully reduce shipboard maintenance to the absolute minimum, thus allowing our warfighters to concentrate on fighting, is the will to require this in our systems, and grow it across the Naval Enterprise.

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