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Total Ownership Cost a Decade Into the 21st Century

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Naval Postgraduate School

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Preface & Acknowledgements

Welcome to our Ninth Annual Acquisition Research Symposium! This event is the highlight of the year for the Acquisition Research Program (ARP) here at the Naval Postgraduate School (NPS) because it showcases the findings of recently completed research projects—and that research activity has been prolific! Since the ARP's founding in 2003, over 800 original research reports have been added to the acquisition body of knowledge. We continue to add to that library, located online at www.acquisitionresearch.net, at a rate of roughly 140 reports per year. This activity has engaged researchers at over 60 universities and other institutions, greatly enhancing the diversity of thought brought to bear on the business activities of the DoD.

We generate this level of activity in three ways. First, we solicit research topics from academia and other institutions through an annual Broad Agency Announcement, sponsored by the USD(AT&L). Second, we issue an annual internal call for proposals to seek NPS faculty research supporting the interests of our program sponsors. Finally, we serve as a "broker" to market specific research topics identified by our sponsors to NPS graduate students. This three-pronged approach provides for a rich and broad diversity of scholarly rigor mixed with a good blend of practitioner experience in the field of acquisition. We are grateful to those of you who have contributed to our research program in the past and hope this symposium will spark even more participation.

We encourage you to be active participants at the symposium. Indeed, active participation has been the hallmark of previous symposia. We purposely limit attendance to 350 people to encourage just that. In addition, this forum is unique in its effort to bring scholars and practitioners together around acquisition research that is both relevant in application and rigorous in method. Seldom will you get the opportunity to interact with so many top DoD acquisition officials and acquisition researchers. We encourage dialogue both in the formal panel sessions and in the many opportunities we make available at meals, breaks, and the day-ending socials. Many of our researchers use these occasions to establish new teaming arrangements for future research work. In the words of one senior government official, "I would not miss this symposium for the world as it is the best forum I've found for catching up on acquisition issues and learning from the great presenters."

We expect affordability to be a major focus at this year's event. It is a central tenet of the DoD's Better Buying Power initiatives, and budget projections indicate it will continue to be important as the nation works its way out of the recession. This suggests that research with a focus on affordability will be of great interest to the DoD leadership in the year to come. Whether you're a practitioner or scholar, we invite you to participate in that research.

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

- Office of the Under Secretary of Defense (Acquisition, Technology, & Logistics)
- Director, Acquisition Career Management, ASN (RD&A)
- Program Executive Officer, SHIPS
- Commander, Naval Sea Systems Command
- Program Executive Officer, Integrated Warfare Systems
- Army Contracting Command, U.S. Army Materiel Command

- Office of the Assistant Secretary of the Air Force (Acquisition)
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- Director of Open Architecture, DASN (RDT&E)
- Program Executive Officer, Littoral Combat Ships

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

James B. Greene Jr.	Keith F. Snider, PhD
Rear Admiral, U.S. Navy (Ret.)	Associate Professor

Panel 23. Dimensions of Software Acquisition

Thursday, May 17, 2012	
3:30 p.m. – 5:00 p.m.	**Chair: Reuben Pitts,** President, Lyceum Consulting, LLC ***Total Ownership Cost a Decade Into the 21st Century*** Brad Naegle and Michael W. Boudreau *Naval Postgraduate School* ***Navigating Beyond the SLOC: Exploring Alternatives for Software Estimating*** Kathlyn Loudin and Eric D. Rocholl *Naval Surface Warfare Center, Dahlgren Division* ***Comparing Software Acquisition Models Against Each Other: The "Build" vs. "Buy" vs. "Rent" Trade Study*** Ron Kohl, *R.J. Kohl & Associates*

Reuben Pitts—Mr. Pitts is the president of Lyceum Consulting. He 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.

Total Ownership Cost a Decade Into the 21st Century

Brad Naegle—Naegle, LTC, U.S. Army (Ret.), is a senior lecturer and academic associate for Program Management Curricula, Graduate School of Business and Public Policy, Naval Postgraduate School. While on active duty, LTC (Ret.) Naegle was assigned as the product manager for the 2 ½-ton Extended Service Program (ESP) from 1994–1996 and served as the deputy project manager for Light Tactical Vehicles from 1996–1997. He was the 7th Infantry Division (Light) division materiel officer from 1990–1993 and the 34th support group director of security, plans, and operations from 1986–1987. Prior to that, LTC (Ret.) Naegle held positions in test and evaluations and logistics fields. He earned a master's degree in systems acquisition management (with distinction) from the Naval Postgraduate School and an undergraduate degree from Weber State University in economics. He is a graduate of the Command and General Staff College, Combined Arms and Services Staff School, and Ordnance Corps Advanced and Basic Courses. [bnaegle@nps.edu]

Michael W. Boudreau—Boudreau, COL, U.S. Army (Ret.), has been a senior lecturer at the Naval Postgraduate School since 1995. While an active duty Army officer, he was the project manager, Family of Medium Tactical Vehicles, 1992-1995. He commanded the Materiel Support Center, Korea, from 1989–1991 and the Detroit Arsenal Tank Plant from 1982–1984. COL Boudreau is a graduate of the Industrial College of the Armed Forces; Defense Systems Management College; Army Command and General Staff College; Long Armour-Infantry Course, Royal Armoured Corps Centre, United Kingdom; and ordnance officer basic and advanced courses. He holds a Bachelor of Mechanical Engineering degree and Master of Business degree from Santa Clara University, California. [mboudreau@nps.edu]

Abstract

The intent of this research is to gather together the various approaches for controlling and reducing Total Ownership Cost (TOC) and to describe tools and methods to assist PMs and others in addressing TOC more effectively. This study examines TOC from the perspective of congressional direction, the perspective of the OSD and Service leadership's governance, the perspective of PM execution, and the perspective of available infrastructure support.

Purpose

The intent of this research is to gather together the various approaches for controlling and reducing Total Ownership Cost (TOC) and to describe tools and methods to assist PMs and others in addressing TOC more effectively.

Scope of This Study

This study examines TOC from the perspective of congressional direction, the perspective of the OSD and Service leadership's governance, the perspective of PM execution, and the perspective of available infrastructure support.

Introduction

This report extends our research that was first published in 2003. At that time, just as currently, there was significant attention being paid to TOC. There were a number of initiatives collected and shared on a TOC website constructed by the Institute for Defense Analyses (IDA; www.ida.org). Additionally, the DAU Acquisition Community Connection website (https://acc.dau.mil/CommunityBrowser.aspx?id=22509&lang=en-US) also contains useful approaches to TOC and R-TOC. Looking over the TOC landscape in 2003, one would not conclude that there was a shortage of ideas related to reducing TOC. The same appears true today—there are many useful approaches for reducing TOC, or weapon system life cycle costs, reflecting the increasing anxiety over skyrocketing costs of ownership. Many aspects of Defense acquisition have continued to evolve, making it difficult to know what has helped to control costs and what may have had the opposite effect or had no significant effect. The following paragraphs provide a few examples to help make the point.

There are increased acquisition reviews (USD[AT&L], 2008). PMs and those working in program offices know that reviews are expensive and divert attention from other management activities. Have increased reviews contributed to increased cost or have they reduced it? Has developmental cost increased while the larger sustainment costs have decreased? Does anyone really know?

Acquisition reforms, launched in the mid-1990s, resulted in many changes to the way we do acquisition business. For example, acquisition programs have reduced their preparation for sustainment. MIL-STD-1388-2A and -2B, which became obsolete under the Acquisition Reform initiatives of the 1990s, were very detailed and for many years had guided acquisition logistics planning; they were mandatory until circa 1995.[1] These standards governed supportability analyses and served to inform sustainment planning, but they were onerous requirements and sometimes resulted in analyses that languished on the shelf and were never put to use. Did the discontinued use of these standards result in the de-emphasis and de-funding of rigorous sustainment planning, in turn causing an increase in the cost of sustainment and a corollary reduction in warfighting system readiness?

Another acquisition reform initiative during the mid-1990s created a bias against purchasing technical data packages (TDPs).[2] Did that result in the avoidance of unnecessary and unneeded TDPs, or might this initiative have prevented the purchase of technical data, leaving a program with few good options related to re-buys and purchase of repair parts? Did it narrow the range of choices related to component- and system-level maintenance?

Has performance-based logistics (PBL)—mandated in the DoD by the *QDR* in September 2001 and implemented in 2002 (USD[AT&L], 2002)—*reduced* the cost of sustainment or has it *increased* those costs? Coupled with early tech data choices, have logisticians been forced into choices that make sustainment more expensive throughout the weapon system's life cycle (Kratz & Buckingham, 2010)?

First Gut Question

Have Acquisition Reform and Acquisition Excellence initiatives removed acquisition controls and opened up an array of poor choices for PMs that have increased system life cycle costs (LCC)? Might well-meaning Acquisition Reform and Acquisition Excellence initiatives have offered shortcuts that have ended badly (Kratz & Buckingham, 2010)?

Second Gut Question

Has one of the principal problems been lack of discipline? In our 2003 paper (Boudreau & Naegle, 2003), we addressed leadership resolve and the need to speak with one voice about *affordability*. In 2003, the new JCID's directives did not emphasize affordability. Today those directives *do* (for example, CJCS, 2009a, Enclosure A, paragraph 2-b and Enclosure B, paragraph 3-d; CJCS, 2009b, Enclosure G, paragraph 1-d and Appendix A to Enclosure G, paragraph 16; Weapon System Acquisition Reform Act

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[1] In the mid-1990s, there were numerous Acquisition Reform initiatives intended to streamline acquisition processes and reduce cost. One of these initiatives was "specs and standards" reform. Many government specs were rescinded to reduce the government burden and cost of maintaining specs; in many cases, the government switched to commercial specifications that were maintained by various technical societies or associations. Other mandatory specs were rescinded because they were thought unnecessary or provided insufficient benefit for the cost expended. MIL-STD 1388-2A and -2B were thought by some to fall into the latter category.

[2] Another Acquisition Reform initiative was avoiding the purchase of technical data packages in support of new systems.

[WSARA], 2009, § 201). Yet one must ask, do user study groups understand their emerging system's slice of mission area funding over its life cycle? Do users take ownership control of these costs by establishing key performance parameters (KPPs) or key system attributes (KSAs) for O&S cost or system life cycle cost? Do SoS and net-centric system PMs understand and account for TOC drivers associated with system changes (especially software) that impact system platforms and platform changes that impact overarching systems? Do materiel developers insist on clear, unambiguous sustainment cost goals and establish solid, well-reasoned CAIV targets? Do contractors structure their developments to deliver warfighting systems that meet customer cost constraints? A dominant problem might be *discipline—cost discipline*—starting with the OSD and Service leadership and including users, materiel developers, and contractors.

Third Gut Question

Is ownership cost data being collected and placed in databases that facilitate analysis and comparison to ownership cost targets such that, program by program, interested parties can see whether DoD programs are performing within their affordability constraints? Acquisition leaders must be able to measure cost performance. If they really want to get TOC under control, O&S cost must be sufficiently accurate and detailed that it can be used to suggest where system, subsystem, or component improvements are needed.

Congressional Intervention

Interestingly, the questions posed above appear to have been congressional questions, too. Congress already seems to have responded to an array of similar concerns, in its own unique way. This is what the WSARA of 2009 is all about. This is what Congress is addressing in its changes to Nunn–McCurdy. This is what motivated Congress to require certificates at Milestones A and B (10 U.S.C. § 2366a, b). This appears to be the congressional motive in Public Law 111-84 (National Defense Authorization Act, 2009), which institutes product support managers. Having witnessed a lack of cost and process discipline spanning many years, particularly in the area of sustainment costs, Congress has acted to enforce discipline, instituting procedures with force of law to get weapon system costs under control.

The Weapon System Acquisition Reform Act of 2009

The Weapon System Acquisition Reform Act of 2009 is a congressional initiative to increase rigor in development of DoD Major Defense Acquisition Programs (MDAPs). The principal intent seems directed at controlling the ownership cost of the DoD's warfighting systems. The WSARA advances on a number of different fronts, as follows.

The WSARA named a series of appointive positions in the Office of the Secretary of Defense (SECDEF) that would have key authorities and responsibilities in controlling the acquisition process. One such position is the Director of Cost Assessment and Program Evaluation (Director CAPE), who has major responsibilities in the areas of cost estimating, cost analysis, and advice in planning PPBE, advising the JROC, and formulating study guidance used to conduct analysis of alternatives of new major defense acquisition programs. These responsibilities place the Director CAPE in a position to provide advice and direction related to the accuracy of acquisition cost estimates and the affordability of acquisition programs. The Director CAPE is specifically charged by Congress with ensuring the accuracy of cost estimation and cost analysis by prescribing policies and procedures specifically related to acquisition programs. The Director CAPE provides guidance to and consults with OSD leadership and the secretaries of the military departments regarding specific cost estimates and cost analyses to be conducted for a major MDAP or major automated information system (MAIS) program.

JROC

The WSARA specifically charges the SECDEF to ensure that the JROC is engaged in consideration of trade-offs among cost, schedule, and performance objectives (§ 201). It was noted in our 2003 R-TOC report that the JROC was not focused on TOC and that the leadership was not “speaking with one voice” concerning the importance of TOC (Boudreau & Naegle, 2003, p. 49). This now appears to have been addressed as a matter of law.

Milestone Decision Authority (MDA)

The WSARA mandates that MDA ensure appropriate trade-offs among cost, schedule, and performance objectives to increase confidence that the program is affordable (WSARA, 2009, § 201).

Competition Throughout the Life Cycle

The WSARA identifies 10 different approaches that may be incorporated into an MDAP acquisition strategy to ensure competition be used if cost effective (WSARA, 2009, § 202). The list includes competitive prototyping; dual-sourcing; unbundling of contracts; use of modular, open architecture to enable competition for upgrades; use of build-to-print approaches; and acquisition of complete TDPs—along with several other approaches. These suggested measures involve competition among prime contractors and also among subcontractors at such tiers as appropriate. The WSARA views competition as extending into operations and sustainment of MDAPs.

The WSARA of 2009 Summary

There is no doubt that the demands made in WSARA have increased the rigor and discipline required in acquisition and will be reflected in more careful cost estimation, increased caution in reviewing technological maturity before advancing programs to the next acquisition step or phase, better systems engineering and test planning, and renewed reliance on competition. All of these facets have the potential to better control LCC. Conversely, all the same facets introduce the potential for added bureaucracy and unnecessary delay. The WSARA initiatives address past shortcomings in MDAP acquisitions that have contributed to the increase of LCC. Whether these initiatives will reduce cost through better management or increase cost through additional bureaucracy remains to be seen.

Many other facets of WSARA are described in our 2011 paper, *Total Ownership Cost—Tools and Discipline* (Naegle & Boudreau, 2011).

National Defense Authorization Act for Fiscal Year 2010, Section 805

The National Defense Authorization Act for FY2010 has special relevance to life cycle cost, as will be explained. In this law Congress mandated Product Support Manager (PSM) participation in MDAPs. The law emphasized that the PSM works for the PM, but is also specifically tasked to focus on product sustainment (O&S) cost. The PSM is tasked to balance PBL support for optimization. He or she must review and revalidate product support strategies prior to a change in strategy or every five years (National Defense Authorization Act, 2010, § 805). The congressional conferees recognized that product support encompasses a wide range of logistics functions, including readiness, reliability, availability, logistics burden (footprint) reduction—all of which explicitly or implicitly impact ownership cost (Kobren, 2010, p. 192). The National Defense Authorization Act for FY2010 very apparently established a position within the MDAP PM office that is responsible for sustainment cost, to include reliability, which directly influences sustainment cost.

Duncan Hunter National Defense Authorization Act for Fiscal Year 2009, Section 814, Configuration Steering Boards for Cost Control Under Major Defense Acquisition Programs

This law introduced a strong bias toward limiting design changes to systems. Note that the Service user representative is not named as a member of the CSB. The presumption may be that the user would tend to encourage requirements growth and costly changes. The CSB, for its part, will listen to the proposed change and make the board recommendations to the program MDA. In Part 2, the PM is *directed* to propose de-scoping options to reduce cost and requirements. The MDA is required to coordinate changes with the Joint Staff and component requirements officials (i.e., user representatives). The wording clearly indicates a bias against changes that will increase cost, or at the least deferring such changes to a future block or increment.

Relevant Studies and Reports

GAO/T-NSIAD-98-123 and Other GAO Reports on Knowledge Point Management

Knowledge point management can be used to avoid program delays and the additional cost that accompanies schedule delays. For more than 12 years the GAO has advocated the use of knowledge point management to guide development of warfighting systems and to control the advancement of programs until said systems have demonstrated their *readiness* to proceed to the next step in the development process (*Defense Acquisition: Improved Program Outcomes*, 1998). The three knowledge points recommended by the GAO are described in the following paragraphs.

Knowledge Point 1 occurs near Milestone B. The user's requirements must be synchronized with technology that is mature enough to support the endeavor, allow sufficient time scheduled to succeed, and provide sufficient funding to complete the development (GAO, 2003, p. 16). This knowledge point became relatively better understood when the *Technology Readiness Level Deskbook* was published in 2005 (Deputy Under Secretary of Defense for Science and Technology [DUSD(S&T)], 2005). Matching requirements against resources is a matter of discipline and having the requisite knowledge before proceeding is necessary because if any one of the several elements is absent (such as the application of required technologies while they are still immature), the program will likely be delayed and the impact on cost may be severe. Continuing GAO reviews have shown that Knowledge Point 1 demands enormous discipline that has, unfortunately, often been beyond the discipline demonstrated by DoD leadership over many years.

Knowledge Point 2 occurs when the design demonstrates that it is able to meet performance requirements. The design must be stable (i.e., 90% of the engineering drawings must be complete) and testing must show that the system performs at an acceptable level (GAO, 2003, p. 16). This point is verified at the post-CDR assessment.

Knowledge Point 3 occurs when the system can be manufactured within cost, schedule, and quality targets and operates reliably (GAO, 2003, p. 16). In statistical process control terms, critical manufacturing processes are in control and consistently producing within quality standards and design tolerances.

Knowledge point management is not new, but has been an industry practice. The same technique can, and should, be applied to DoD system acquisition.

Evolutionary Acquisition

The use of evolutionary acquisition fits conveniently with Knowledge Point 1, discussed previously. Sometimes technology does not become mature as soon as hoped.

Depending on the circumstances, technological immaturity might delay a Milestone B decision and the associated program new-start. In some cases, a technology that matures more slowly than needed may be substituted by an alternative technology that is mature and immediately available. Plainly, this decision hinges on whether or not the developing system can result in an increment of useful warfighting capability—as determined by the sponsor/user. Even when this happens, the program faces a difficult path that requires "extra" milestones that are exhausting to program office staff. Such is the nature of evolutionary acquisition—avoiding one dilemma and replacing it with another. The evolutionary approach places heavy demands on a program office, which must prepare for a series of otherwise unnecessary milestones. Is it worth it?

The logistics impact of evolutionary acquisition cannot be ignored, either. A result of evolutionary acquisition will either be multiple configurations or expensive modification/upgrades. Such cost impacts might play out for many years or even for the lifetime of the warfighting system. This may be associated training issues, repair parts configuration issues, software patches, and operational impacts. The cost of evolutionary acquisition could conceivably approach or even exceed the original cost of the program delay.

The right answer in acquisition depends on the circumstances. The effect on ownership cost should *always* be one of the metrics used to select the best course of action.

GAO Report 10-717

In July 2010, the GAO (2010) published Defense Management: DOD Needs Better Information and Guidance to More Effectively Manage and Reduce Operating and Support Costs of Major Weapon Systems (GAO 10-717). This report painted a dreary picture of relevant cost databases. The GAO found that important O&S cost-estimate documents for aviation systems had not been retained and that there were apparent gaps in the DoD's ability to capture actual O&S costs through the Services' Visibility and Maintenance of Operations and Support Costs (VAMOSC) databases (GAO, 2010, p. 16). Data in VAMOSC and other Service information systems or sources was inaccurate and incomplete (GAO, 2010, pp. 16–20). The report stated that the important MDAP system life cycle cost estimates were not being routinely retained or updated, nor was there policy requiring that this be done. The GAO pointed out that there were no agreed-to O&S cost elements or metrics for tracking and assessing actual O&S cost performance for the various categories of weapon systems. Additionally, operational costs also were affected by unexpected changes in OPTEMPO (specifically, flying hours; GAO, 2010, p. 22). Although both those factors might upset budget predictions, they need not upset performance predictions; rather, if shown as "cost per usage," reasonable comparisons might show the weapon system's performance against baseline performance. Cost per mile or cost per flying hour or round fired could be compared to early cost estimates, as-tested costs, and changes in cost per year. Such comparisons would never be perfect, but they would suggest whether a weapon system was performing within the expected range.

Looking specifically at aviation systems across the Services, the GAO reported that most systems had no record of O&S cost estimates related to key milestone decisions. Two aircraft systems, the Air Force F-22A fighter and the Navy F-A 18F/G, did have some recorded O&S cost estimates (GAO, 2010, pp. 24–26). The two cited examples suggest the seriousness of O&S cost-estimating inaccuracy and/or cost growth. F-22A actual cost per flight hour in 2007 was $55,783—67% higher than the $33,762 that had been projected in the 2007 President's Budget. Similarly, on a flight-hour basis, the Navy F-A 18E/F cost $15,346 per flight hour of operation—40% higher than the $10,979 predicted in 1999.

Institute for Defense Analyses Study: The Major Causes of Cost Growth in Defense Acquisition

The 2009 Institute for Defense Analyses (IDA) study, led by Gene Porter, examined 11 MDAP systems that had exhibited significant cost growth between 1995 and 2006. The primary causes of cost growth stemmed from two defects: "weaknesses in management visibility, direction, and oversight" and "weaknesses in initial program definition and costing," neither of which was a new phenomenon (Porter et al., 2009, pp. ES-6–ES-14). Much of the blame for the first weakness was "a general lack of discipline" (Porter et al., 2009, p. ES-6).

Porter et al. (2009) make a series of recommendations that are intended to address the causes of cost growth reflected in their study; their recommendations are supportive of the goals of the WSARA of 2009 (Porter et al., 2009, pp. ES-15–ES-18).

DOT&E Initiative on Reliability Growth

In his memorandum, *State of Reliability,* J. Michael Gilmore, the Director of Operational Test and Evaluation (DOT&E, 2010), made the link that poor reliability is a major contributor to LCC. The implication is that the long-held 28-72 LCC statistics could be altered by front-end attention to reliability growth. That is, investing more RDTE funding in reliability improvement at the front end could result in higher reliability components that would cost less to operate, malfunctioning less often. The remarkable thing here is that program leadership has tried to improve reliability in many, if not all, programs. Gilmore made reference to a recently published reliability standard, ANSI/GEIA-STD-0009, which should be employed.

Policy Pronouncements

The OSD implemented the 2009 version of the WSARA on December 4, 2010, through the USD(AT&L) publication of Directive Type Memorandum (DTM) 09-027 (USD[AT&L], 2009). About 10 months later, on October 21, 2010, the USD(AT&L) amended the original document, establishing a date by which the DoDI 5000.02 had to be revised (USD[AT&L], 2010a).

Target Affordability and Control Cost Growth for ACAT I Programs

Corollary to WSARA implementation, the USD(AT&L) published the *Implementation Directive for Better Buying Power—Obtaining Greater Efficiency and Productivity in Defense Spending* (USD[AT&L], 2010b). The intent of this implementation directive was to reach beyond WSARA mandates to obtain greater affordability-based decision-making in warfighting system programs. Specifically, its goal was to mandate affordability as a requirement. PMs are now required to treat affordability as a key performance parameter (KPP) at Milestone A. The affordability target is to be stated in two metrics: average unit acquisition cost and average annual operating and support cost per unit. These metrics will be the basis for pre-Milestone B decision-making and systems engineering trade-off analysis to establish cost and schedule trade space. Such a mandate requires a database similar to the one Roper described (2010, pp. 71–73).

There have been significant other recent directive-type memoranda (DTMs) that affect ownership cost and affordability. Some of these DTMs are discussed in more detail in our 2011 paper, *Total Ownership Cost—Tools and Discipline* (Naegle & Boudreau, 2011).

A Specific Navy Initiative: Gate Reviews

The Navy has instituted a series of reviews, termed "gate reviews," to better control program development cost. The Navy *Total Ownership Cost Guidebook* (Department of the Navy [DoN], 2010; published concurrently with SECNAVINST 5000.2E) depicts a series of 10 gate reviews that stretch across the pre-acquisition and acquisition phases and into the sustainment phase. Each gate review asks tailored cost questions relevant to the specific life cycle event (DoN, 2010, pp. 4–32). The complete array of gate reviews is as follows:

- Gate 1—Initial Capabilities Document
- Gate 2—Analysis of Alternatives
- Gate 3—Capability Development Document
- Gate 4—System Design Specification
- Gate 5—RFP for Engineering and Manufacturing Development Contract
- Gate 6 Reviews—specifically, Integrated Baseline Review, Post Critical Design Review, Capability Production Document, Pre-Full Rate Production Decision Review, and Sustainment Sufficiency Review(s)

At each gate review, formal design review, and assessment, programs must demonstrate progress toward their affordability initiatives, with strong consideration in mitigation or reduction of TOC. The Navy's intent is to change the culture from what the authors of this working paper perceive as a shortsighted goal of obtaining funds for development and procurement to the more complete perspective of total life cycle cost affordability.

Gate Review 1, which is intended to shape the analysis of alternatives (AoA) study analysis, requires consideration of O&S costs based on current or similar systems. AoA study TOC guidance is intended to be sufficiently detailed to inform and support the selection of a materiel solution from among the various AoA candidates.

Intermediate gate reviews are coupled to existing systems engineering and acquisition milestone review points. These reviews become a forum to assess whether program trade-offs and decisions are controlling life cycle cost and whether the program is continuing on the correct affordability azimuth. Each of the gate reviews requires briefing of specific cost charts, making it unlikely that cost growth and schedule slippage can be obscured.

The Gate 6 Sustainment Review(s), accomplished post-IOC, examine the warfighting system's actual performance data compared to the system's KPP thresholds and the warfighting system's actual life cycle cost compared to its prior estimates of ownership cost.

In the aggregate, Gate Reviews provide for oversight and governance of MDAP system developments. In a wider sense, Gate Reviews provide a forum for lessons learned regarding TOC while controlling the affordability of individual systems—and, hence, the broader portfolios of warfighting systems—throughout the developmental, production, and sustainment phases of warfighting systems.

Other Initiatives

Controls on Software Development

Driving the Software Requirements and Architectures for System Supportability

While the tools and techniques described in this section were designed for the software components, they would be just as effective for any non-software component as they are systems engineering (SE) oriented. The systems engineering process (SEP) focus used does not attempt to separate software from other components, so all system components would benefit from using these tools and techniques.

Software Supportability Analysis

As with hardware system components, software supportability attributes must be designed into the system architecture. Many hardware-oriented engineering fields are now quite mature, so that a number of supportability attributes would be automatically included in any competent design, even if they were not specified by the user community. For example, the state of maturity for the automotive engineering field means that, in any automotive-related program, there would be supportability designs allowing for routine maintenance of system filters, lubricants, tires, brakes, batteries, and other normal wear-out items. There are few, if any, corresponding supportability design attributes that would be automatically included in even the best software construct. Virtually all of the software supportability attributes required must be explicitly specified because they would not likely be included in the design architecture without clearly stated requirements. With software, you get what you specify and very little else. So how does one ensure that required software supportability attributes are not overlooked?

Logistics Supportability Analysis (LSA), performed extremely early, is one of the keys for developing the system supportability attributes needed and expected by the warfighter. The F/A 18 Super Hornet aircraft was designed for higher reliability and improved ease of maintenance compared to its predecessors ("F/A 18," 2011) because of warfighter needs for generating combat power in the form of available aircraft sorties. The LSA performed on the F/A 18 determined that a design fostering higher reliability and faster maintenance turnaround time (the engines are attached to the airframe at 10 locations and can be changed in about 20 minutes by a four-man team) would result in more aircraft being available to the commander when needed. The concept for software LSA is no different, but implementing sound supportability analyses on the software components has been, at best, spotty and, at worst, completely lacking.

To assist in effective software LSA, a focus on the following elements is key: Maintainability, Upgradeability, Interoperability/Interfaces, Reliability, and Safety & Security—MUIRS.

Maintainability

The amount of elapsed time between initial fielding and the first required software maintenance action can probably be measured in hours, not days. The effectiveness and efficiency of these required maintenance actions is dependent on several factors, but the software architecture that was developed from the performance specifications provided is critical. The DoD must influence the software architecture through the performance specification process to minimize the cost and time required to perform essential maintenance tasks.

Maintenance is one area in which software is fundamentally different from hardware. Software is one of the very few components in which we know that the fielded product has shortcomings, and we field it anyway. There are a number of reasons why this happens; for instance, there is typically not enough time, funding, or resources to find and correct every error, glitch, or bug, and not all of these are worth the effort of correcting. Knowing this, there must be a sound plan and resources immediately available to quickly correct those shortcomings that do surface during testing and especially those that arise during warfighting operations. Even when the system software is operating well, changes and upgrades in other interfaced hardware and software systems will drive some sort of software maintenance action to the system software. In other words, there will be a continuous need for software maintenance in the planned complex SoS architecture envisioned for net-centric warfare.

Because the frequency of required software maintenance actions is going to be much higher than in other systems, the cost to perform these tasks is likely to be higher as well. One of the reasons for this is that software is not maintained by "maintainers," as are most hardware systems, but is maintained by the same type of people that originally developed it—software engineers. These engineers will be needed immediately upon fielding, and a number will be needed throughout the lifespan of the system to perform maintenance, add capabilities, and upgrade the system. There are several models available to estimate the number of software engineers that will be needed for support; planning for funding these resources must begin very early in the process. Because the DoD has a very limited capability for supporting software internally, early software support is typically provided by the original developer and is included in the RFP and proposal for inclusion into the contract or as a follow-on Contractor Logistics Support (CLS) contract.

Upgradeability

A net-centric environment composed of numerous systems developed in an evolutionary acquisition model will create an environment of almost continuous change as each system upgrades its capabilities over time. System software will have to accommodate the changes and will have to, in turn, be upgraded to leverage the consistently added capabilities. The software architecture design will play a major role in how effective and efficient capabilities upgrades are implemented, so communicating the known, anticipated, and likely system upgrades will impact how the software developer designs the software for known and unknown upgrades.

Trying to anticipate upgrade requirements for long-lived systems is extremely challenging to materiel developers, but is well worth their effort. Unanticipated software changes in the operational support phase cost 50–200 times the cost in early design, so any software designed to accommodate an upgrade that is never realized costs virtually nothing when compared to changing software later for a capability that could have been anticipated. For example, the Army Tactical Missile System (ATACMS) Unitary was a requirement to modify the missile from warhead air delivery to surface detonation—that is, flying the warhead to the ground. The contract award for the modification was $119 million. The warhead was not new technology, nor particularly challenging to integrate with the missile body. The vast majority of this cost was to reengineer the software to guide the missile to the surface. Had there been an upgrade requirement for this type of mission in the original performance specification, this original cost (including potential upgrades, even if there were 10 other upgrade requirements that were never applied) would have been a fraction of this modification cost.

Interfaces/Interoperability

OA design focuses on the strict control of interfaces to ensure the maximum flexibility in adding or changing system modules, whether they are hardware or software in nature. This presupposes that the system modules are known—which seems logical, as most hardware modules are well-defined and bounded by both physics and mature engineering standards. In sharp contrast to hardware, software modularity is not bounded by physics, and there are very few software industry standards for the modular architecture in software components. This is yet another area in which the software developer needs much more information about operational, maintenance, reliability, safety, and security performance requirements, as well as current, planned, and potential system upgrades. These requirements, once well defined and clearly communicated, will drive the developer to design a software modular architecture supporting OA performance goals. For example, if a system uses a Global Positioning System (GPS) signal, it is likely that the GPS will change over the life of the system. Knowing this, the software developer creates a corresponding discrete software module that is much easier and less expensive to interface with, change, and upgrade along with the GPS system.

With the system software modular architecture developed, the focus returns to the interfaces between hardware and software modules, as well as to the external interfaces needed for the desired interoperability of the net-centric force. Software is, of course, one of the essential enablers for interoperability and provides a powerful tool for interfacing systems, including systems that were not designed to work together. Software performing the function of “middleware” allows legacy and other dissimilar systems to interoperate. Obviously, this interoperation provides a significant advantage, but it comes with a cost in the form of maintainability, resources, and system complexity. As software interfaces with other components and actually performs the interface function, controlling it and ensuring the interfaces provide the desired OA capability become major software-management and software-discipline challenges.

One method being employed by the DoD attempts to control the critical interfaces through a set of parameters or protocols rather than through active management of the network and network environment. This method falls short on several levels. It fails to understand and control the effects of aggregating all of the systems in a net-centric scheme. For instance, each individual system may meet all protocols for bandwidth, but when all systems are engaged on the network, all bandwidth requirements are aggregated on the network—overloading the total bandwidth available for all systems. In addition, members of the Software Engineering Institute (SEI) noted,

> While these standards may present a step in the right direction, they are limited in the extent to which they facilitate interoperability. At best, they define a minimal infrastructure that consists of products and other standards on which systems can be based. They do not define the common message semantics, operational protocols, and system execution scenarios that are needed for interoperation. They should not be considered system architectures. For example, the C4ISR domain-specific information (within the JTA) identifies acceptable standards for fiber channels and radio transmission interfaces, but does not specify the common semantics of messages to be communicated between C4ISR systems, nor does it define an architecture for a specific C4ISR system or set of systems. (Morris et al., 2004, p. 38)

Clearly, understanding and controlling the interfaces is critical for effective interoperation at both the system and SoS levels. The individual PM must actively manage all systems’ interfaces impacting OA performance, and a network PM must do the same for the critical network interfaces. Due to this necessity of constant management, a parameters-and-protocols approach to net-centric OA performance is unlikely to produce the capabilities and functionality expected by the warfighter.

Understanding the software interfaces begins with the software architecture; controlling the interfaces is a unique challenge encompassing the need to integrate legacy and dissimilar systems and the lack of software interface standards within the existing software engineering environment. As stated earlier, the architecture needs to be driven through detailed performance specifications, which will help define the interfaces to be controlled. An effective method for controlling the interfaces is to intensely manage a well-defined Interface Control Document (ICD), which should be a Contract Data Requirements List (CDRL) deliverable on any software-intensive or networked system.

Reliability

While the need for highly reliable weapon systems is obvious, the impact on total system reliability of integrating complex software components is not so obvious. Typically, as system complexity increases, maintaining system reliability becomes more of a challenge. Add the complexity of effectively networking an SoS (all of which are individually complex) to a critical warfighting capability that is constantly evolving over time, and reliability becomes daunting.

Once again, the software developer must have an understanding of reliability requirements before crafting the software architecture and developing the software applications. Highly reliable systems often require redundant capability, and this holds true for software components as well. In addition, software problems tend to propagate, resulting in a degradation of system reliability over time. For example, a Malaysian Airlines Boeing 777 suffered several flight control problems, resulting in the following: a near stall situation, contradicting instrument indications, false warnings, and difficulty controlling the aircraft in both autopilot and manual flight modes. The problems were traced to software in an air data inertial reference unit that was feeding erroneous data to the aircraft's primary flight computer (PFC), which is used in both autopilot and manual flight modes. The PFC continued to try to correct for the erroneous data received, adjusting flight control surfaces in all modes of flight, displaying indications that the aircraft was approaching stall speed and overspeed limits simultaneously, and causing wind shear alarms to sound close to landing (Dornheim, 2005, p. 46). It is critical for system reliability that the software developers understand how outputs from software applications are used by interfaced systems so that appropriate reliability safeguards can be engineered into the developed software.

Software that freezes or shuts down the system when an anomaly occurs is certainly not reliable nor acceptable for critical weapon systems; yet, these characteristics are prevalent in commercially based software systems. Mission reliability is a function of the aggregation of the system's subcomponent reliability, so every software subcomponent is contributing to or detracting from that reliability. The complexity of software makes understanding all failure modes nearly impossible, but there are many techniques that software developers can employ when designing the architecture and engineering the applications to improve the software component reliability. Once requirements are clearly communicated to the developers, the software can be engineered with redundancy or "safe mode" capabilities to vastly improve mission reliability when anomalies occur. The key is identifying the reliability requirements and making them clear to the software developers.

Safety & Security

Very few software applications have the required safety margins associated with critical weapon systems used by warfighters in combat situations—where they are depending on these margins for their survival. Typically, the software developers have only a vague idea of what their software is doing and how critical that function is to the warfighter employing the weapon system. Safety performance must be communicated to the software developers from the beginning of development so they have the link between software functionality and systems safety. For example, suppose a smart munition senses that it does not have control of a critical directional component, and it calculates that it cannot hit the intended target. The next set of instructions the software provides to the malfunctioning system may well be critical to the safety of friendly troops, so software developers must have the necessary understanding of operational safety to decide how to code the software for what will happen next.

Software safety is clearly linked with reliability since software that is more reliable is inherently safer. It is critical that the software developer understands how the warfighter expects the software to operate in abnormal situations, in degraded modes, and when inputs are outside of expected values. Much commercially based software simply ceases to function under these conditions or gives error messages that supersede whatever function was being performed, none of which are acceptable in combat operations.

With software performing so many critical functions, there is little doubt that software applications are a prime target for anyone opposing U.S. and Allied forces. Critical weapon system and networking software must be resistant to hacking, spoofing, mimicking, and all other manner of attack. There must be capabilities for isolating attacks and portions of networks that have been compromised without losing the ability to continue operations in critical combat situations. The software developer must know that all of these capabilities are essential before he or she constructs software architectures and software programs, as this knowledge will be very influential for the software design and application development. The SEI's *Quality Attribute Workshop* states, "As an example, consider security. It is difficult, maybe even impossible, to add effective security to a system as an afterthought. Component as well as communication mechanisms and paths must be designed or selected early in the lifecycle to satisfy security requirements" (Barbacci et al., 2003, p. 2).

Interoperability challenges are increased when the SoS has the type of security requirements needed by the DoD. Legacy systems and existing security protocols will likely need to be considered before other security architecture can be effectively designed. OA capabilities will be hampered by the critical need for security; both must be carefully balanced to optimize system performance and security. This balance of OA and security must be managed by the DoD and not the software developer.

Physical security schemes and operating procedures will also have an impact on the software architecture. For example, many communication security (COMSEC) devices need only routine security until the keys, usually software programs, are applied; then, much more stringent security procedures are implemented. Knowledge of this security feature would be a key requirement of the developer; he or she must understand how and when the critical software pieces are uploaded to the COMSEC device. The same holds true for weapon systems that upload sensitive mission data just prior to launch.

Residual software on equipment or munitions that could fall into enemy hands presents another type of security challenge that needs to be addressed during application development. For example, the ATACMS missile air-delivers some of its warheads, leaving the missile body to free fall to the surface. It is very conceivable that the body could be intact and, of course, unsecured. If critical mission software was still within the body and found by enemy forces, valuable information might be gleaned from knowing how the system finds its targets. The government would certainly want the developer to design the applications in a way that would make anything recovered useless to the enemy, but this is a capability that is not intuitive to software developers (Naegle, 2006, pp. 17–25).

Effective Software Development Tools Supporting System TOC Analyses

Software Engineering Institute's (SEI) Quality Attribute Workshop (QAW)

The QAW is designed to help identify a complete (or as complete as possible) inventory of system software requirements through analysis of system quality attributes. One of the intents is to develop the derived and implied requirements from the user-stated requirements, which is a necessary step when user-stated requirements are provided in terms of capabilities needed as prescribed by the Joint Capabilities Integration Development

System (JCIDS) process. A system's TOC, and those elements that contribute to TOC, are system quality attributes. Although obviously important to the warfighter, the associated operations and support, training/education, and facility costs are rarely addressed in much detail and need to be derived from stated requirements or augmented with implied requirements through the QAW process, or something similar.

The QAW helps provide a facilitating framework and process designed to more fully develop the derived and implied requirements that are critical to clearly communicate to potential contractors and software developers. Including a robust LSA process using the MUIRS focus elements, described previously, within the QAW process will likely significantly improve requirements analysis for those associated TOC elements and vastly improve the accuracy of system TOC projections. While improving system requirements development, the QAW is designed to work with another SEI process called the Architectural Trade-off Analysis Methodology^{SM} (ATAM^{SM}) to further improve the understanding of the system for potential contractors and software developers.

SEI's Architectural Trade-Off Analysis Methodology^{SM} (ATAM^{SM})

The SEI's ATAM^{SM} is an architectural analysis tool designed to evaluate design decisions based on the quality attribute requirements of the system being developed. The methodology is a process for determining whether the quality attributes, including TOC attributes, are achievable by the architecture as it has been conceived before enormous resources have been committed to that design. One of the main goals is to gain insight into how the quality attributes trade off against each other (Kazman, Klein, & Clements, 2000, p. 1).

Within the systems engineering process (SEP), the ATAM^{SM} provides the critical requirements loop process, tracing each requirement or quality attribute to corresponding functions reflected in the software architectural design. Whether ATAM^{SM} or another analysis technique is used, this critical SEP must be performed to ensure that functional- or object-oriented designs meet all stated, derived, and implied warfighter requirements. In complex systems development, such as weapon systems, half or more than half of the total software development effort will be expended in the architectural design process. Therefore, DoD PMs must ensure that the design is addressing requirements in context and that the resulting architecture has a high probability of producing the warfighters' JCIDS stated, derived, or implied requirements.

The ATAM^{SM} focuses on quality attribute requirements, so it is critical to have precise characterizations for each. To characterize a quality attribute, the following questions must be answered:

- What are the stimuli to which the architecture must respond?
- What is the measurable or observable manifestation of the quality attribute by which its achievement is judged?
- What are the key architectural decisions that impact achieving the attribute requirement? (2000, p. 5)

The ATAM^{SM} scenarios are a key to providing the necessary information to answer the first two questions, driving the software engineer to design the architecture to answer the third. This is a critical point at which all of the MUIRS elements need to be considered and appropriate scenarios developed.

The ATAM^{SM} uses three types of scenarios: *use-case scenarios* involve typical uses of the system to help understand quality attributes in the operational context; *growth* *scenarios* involve anticipated design requirements, including upgrades, added interfaces supporting SoS development, and other maturity needs; and *exploratory scenarios* involve extreme conditions and system stressors, including Failure Modes and Effects Criticality Analysis (FMECA) scenarios (Kazman et al., 2000, pp. 13–15). As depicted in Figure 1, the scenarios build on the basis provided in the JCIDS documents and requirements developed through the QAW process. These processes lend themselves to development in an Integrated Product Team (IPT) environment led by the user/combat developer and including all of the system's stakeholders. The IPT products will include a set of scenarios, prioritized by the needs of the warfighter for system capability. The prioritization process provides a basis for architecture trade-off analyses. When fully developed and prioritized, the scenarios provide a more complete understanding of requirements and quality attributes in context with the operation and support (including all of the MUIRS elements) of the system over its life cycle. A more complete understanding of the system's TOC elements should emerge from this type of analysis.

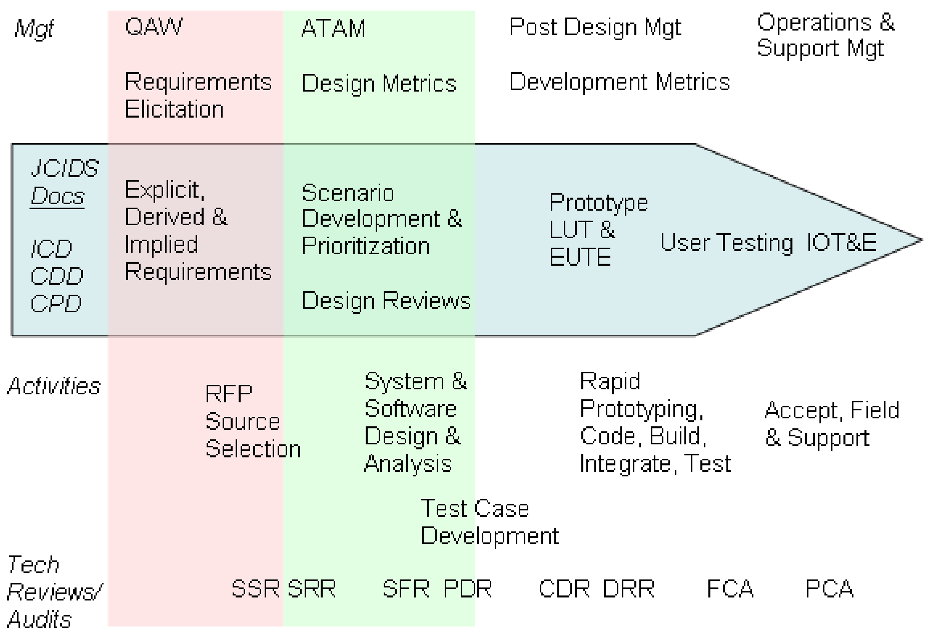

Figure 1. QAW & ATAM^{SM} Integration Into Software Life Cycle Management

Just as the QAW process provides a methodology supporting RFP, source-selection activities, and the Software Specification and System Requirements Reviews (SSR and SRR), the ATAM^{SM} provides a methodology supporting design analyses, test program activities, and the System Functional and Preliminary Design Reviews (SFR and PDR). The QAW and ATAM^{SM} methodologies are probably not the only effective methods supporting software development efforts, but they fit particularly well with the DoD's goals, models, and SEP emphasis. The user/combat developer (blue arrow block in Figure 1) is kept actively involved throughout the development process—providing key insights the software developer needs to successfully develop warfighter capabilities in a sustainable design for long-term effectiveness and suitability. The system development activities are conducted with superior understanding and clarity, reducing scrap and rework, and saving cost and schedule. The technical reviews and audits (part of the DoD's overarching SEP) are supported with methodologies that enhance both the visibility of the necessary development work as well as the progress toward completing it.

One of the main goals in analyzing the scenarios is to discover key architectural decision points that pose risks for meeting quality requirements. Sensitivity points are determined, such as real-time latency performance shortfalls in target tracking. Trade-off points are also examined so that TOC impacts resulting from proposed trade-offs can be analyzed. The SEI explained, “Trade-off points are the most critical decisions that one can make in an architecture, which is why we focus on them so carefully” (Kazman et al., 2000, p. 23).

The ATAM^SM provides an analysis methodology that complements and enhances many of the key DoD acquisition processes. It provides the requirements loop analysis in the SEP, extends the user/stakeholder JCIDS involvement through scenario development, provides informed architectural trade-off analyses, and vastly improves the software developer’s understanding of the quality requirements in context. Architectural risk is significantly reduced, and the software architecture presented at the Preliminary Design Review (PDR) is likely to have a much higher probability of meeting the warfighters’ need for capability, including TOC elements.

Together, the QAW and ATAM^SM provide effective tools for addressing problem areas common in many DoD software-intensive system developments: missing or vaguely articulated performance requirements, significantly underestimated software development efforts (resulting in severely underestimated schedules and budgets), and poor communication between the software developer and the government (both user and PM). Both tools provide frameworks for more detailed requirements development and more effective communication, but they are just tools—by themselves, they will not replace the need for sound planning, management techniques, and effort. Both the QAW and ATAM^SM provide methodologies for executing SEP requirements analysis and requirements loop functions, effective architectural design transition from user to developer, and SEP design loop and verification loop functions within the test-case development.

A significant product resulting from the ATAM^SM is the development of test cases correlating to the use case, growth, and exploratory scenarios developed and prioritized. Figure 2 depicts the progression from user-stated capability requirements in the JCIDS documents to the ATAM^SM scenario development, and finally to the corresponding test cases developed. The linkage to the user requirements defined in the JCIDS documents is very strong as those documents drive the development of the three types of scenarios, and, in turn, the scenarios drive the development of the use cases. The prioritization of the scenarios from user-stated KPPs, Critical Operational Issues (COIs), and FMECA analysis flows to the test cases, helping to create a system test program designed to focus on effectiveness and suitability tests—culminating in the system Operational Test and Evaluation (OT&E). FMECA is one of the focus areas that will have a dynamic impact on TOC analysis because it will help identify software components that need higher reliability and back-up capability. The MUIRS focus helps ensure that TOC elements are addressed in design and test.

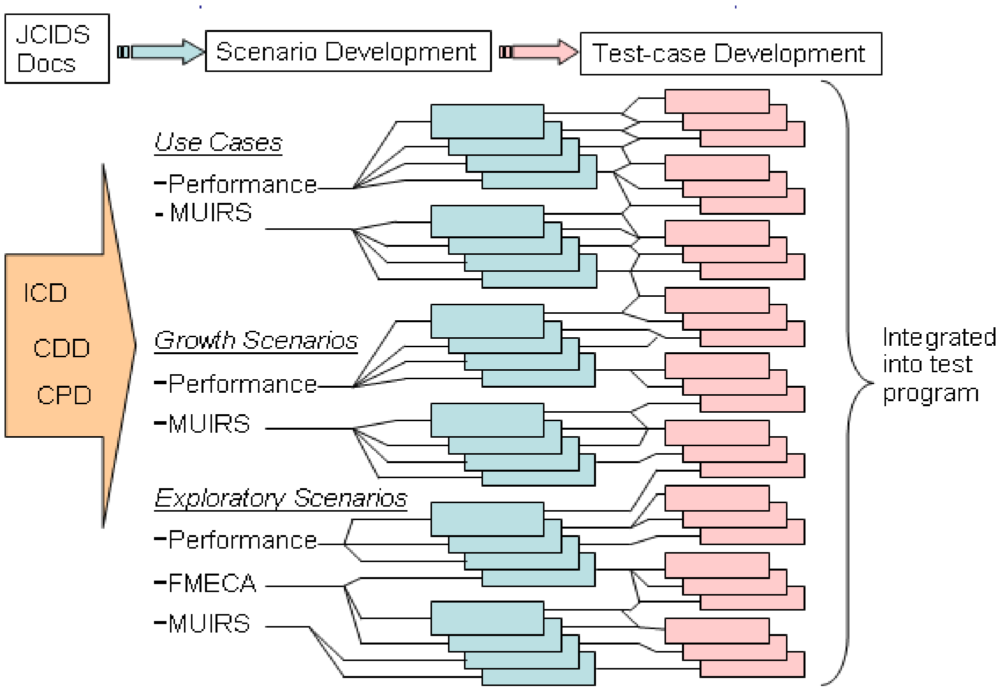

Figure 2. Capabilities-Based ATAM^SM Scenario Development

The traceability from user-stated requirements through scenario development to test-case development provides a powerful communication and assessment methodology. The growth scenarios and resulting test cases are particularly suited for addressing and evaluating TOC design requirements because the system evolves over its life cycle, which is often overlooked in current system development efforts.

The software developer's understanding of the eventual performance required in order to be considered successful guides the design of the architecture and every step of the software development, coding, and testing through to the Full Operational Capability (FOC) delivery and OT&E. Coding and early testing of software units and configuration items is much more purposeful due to this level of understanding. The MUIRS and FMECA focus will help the design process for better TOC performance.

The resulting test program is very comprehensive as each prioritized scenario requires testing or other verification methodologies to demonstrate how the software performs in each related scenario and satisfies the quality attributes borne of the user requirements. The testing supports the SEP design loop by verifying that the software performs the functions allocated to it and, in aggregate, performs the verification loop process by demonstrating that the final product produces the capability identified in the user requirements through operational testing.

Both the QAW and ATAM^SM require the capturing of essential data supporting decision-making and documenting decisions made. These databases would be best used in a collaborative IT system, as described in the next section.

Collaborative IT Systems

Collaborative IT tools are being used today in the private sector to connect various stakeholders—designers, logisticians, cost analysts, field service representatives (FSRs), system users—who have the need to communicate. Such tools could be used to support current and emerging warfighting systems. Collaborative tools could be adapted to address reliability and ownership cost concerns related to warfighting systems. Tools that facilitate improved communications would likely have immediate payoff in being able to speed up solutions to problems. For example, FSRs and users could quickly raise problems to technical staff for resolution. Cost analysts could more quickly identify emerging cost drivers and initiate business case analyses (BCAs). Production and quality technicians could rapidly learn of field defects that are the result of production defects. Other FSRs and users could be alerted to emerging problems and be armed with advance knowledge that might avert impending failures.

The reliability improvement process could be enhanced by the use of collaborative tools, because of the ease with which LCL professionals could bring repair parts databases to bear on design decisions. This would be helped by Pareto, that is, a focus on the cost drivers or reliability drivers, especially the expensive items that fail more often than predicted. This approach could be used up front in pre-acquisition phases, too, by tying in legacy databases that contain performance information of similar or predecessor systems.

Think of the impact to BCA. Cost estimates depend on solid cost databases that are continually updated by current systems in order to identify major cost drivers that might be candidates for redesign or improved manufacturing processes to achieve better reliability and reduced LCC. Collaborative IT could contribute to the accuracy and completeness of cost estimates.

Component improvements that result from collaborative databases would pay off in legacy systems, but might deliver a second payoff in reduced ownership cost of future systems as well. Collaborative databases could be cross-referenced in an architecture that would arrange cost and reliability information in system, subsystem, or component databases, enabling better cost estimating of emerging systems. In her 2010 article in the *Defense Acquisition Review Journal*, Marti A. Roper discussed the need for databases that support acquisition cost estimates—down to subsystem or component levels, showing cost ranges. Such a knowledge base is critical for the development of follow-on systems so that known cost drivers can be addressed for potentially significant LCC savings with deployment of the replacement system. Roper referred to this as capabilities-based parametric data analysis (2010, pp. 71–73).

An example of the potential value of collaborative efforts in improving reliability and reducing TOC is the microwave tube on the Aegis program, developed in the early 1980s. The tubes were expensive to maintain (an estimated $8.20 per operating hour) and ubiquitous (nearly 30,000 units in 2010), and initial reliability numbers were lower than expected (as low as 1,300 hours MTBF). Through a collaborative effort between the PM, NAVSEA, and several commercial vendors, design and manufacturing improvements increased the MTBF to 40,000–45,000 hours, drastically reducing the associated TOC from $8.20 to $0.45 per operating hour for all associated Naval combat systems (Apte & Dutkowski, 2006, pp. 3–21).

Collaborative IT tools could potentially be implemented through apps to smart handheld devices, such as iPhones, Androids, or Blackberries. These devices, which are ubiquitous at systems commands and contractor design and logistics facilities, could be very valuable and convenient for FSRs, military maintenance personnel, and even users in some environments.

Very possibly, collaborative IT tools are in use, contributing to better data and faster solutions to service member problems on legacy systems. On its face, the DoD needs to embrace such tools to improve the flow of technology, acquisition, and logistics information.

Databases

The Defense Acquisition Management Information Retrieval (DAMIR)—MDAP Systems database is a “virtual” repository used by the acquisition community and others to manage MDAP and MAIS systems and to provide relevant information about those systems across the DoD. The database arrays Selected Acquisition Reports (SAR), Defense Acquisition Executive Summary (DAES) reports, Acquisition Program Baselines (APBs), and SAR Baselines. It contains other program information, such as missions and descriptions, system performance, schedules, cost and funding (including operations and support costs), Nunn–McCurdy breaches, contracts performance, and manufacturing and deliveries. The DAMIR database contains some capability to compare programs in terms of cost and schedule performance and to summarize cost and schedule information (e.g., by warfighting system or Service).

VAMOSC databases that collect O&S cost information should be improved or replaced for better support of cost estimating. Current GAO reports indicate that VAMOSC is inaccurate, incomplete, and internally inconsistent. VAMOSC should be able to provide data on similar or predecessor systems, subsystems, and components in support of programs in development, in addition to providing accurate O&S cost performance for legacy systems in their sustainment phase.

Software component analysis and decision databases, like those that would be developed using the QAW and ATAM^{SM} tools, should be required for every software-intensive system. Software continues to be a “wildcard” in estimating both acquisition costs and O&S costs, so front-end analyses must be improved, cataloged, and shared widely through a collaborative environment.

Collaborative databases to gather enterprise/system/subsystem/component cost information should be established to facilitate collaboration among experts who are widely dispersed. One can envision collaborative IT systems being employed by systems commands and the DLA. Such systems could support national-level enterprise requirements at one end of the spectrum or components at the opposite end. In any case, collaborative IT systems could be set up for broad sharing of information that might be useful to developers of new systems, to maintainers of legacy systems, or to O&S cost analysts trying to improve the performance of components that are cost drivers.

Conclusions and Recommendations: Major Thrusts to Control TOC

Many of the TOC initiatives implemented since our TOC research report in 2003 are definitely steps in the right direction for understanding, assessing, and, ultimately, reducing the TOC financial burden. In this research, we have identified several areas that remain as significant hindrances to effective TOC assessment and reduction, including conflicting policy guidance, inadequate or missing databases, and inadequate process controls for software and SoS/net-centric TOC drivers. Future policy and guidance should address these shortfalls to more fully address TOC issues.

Controls

Cost Estimates

The DoD has not yet demonstrated its ability to estimate program costs within reasonable confidence limits. Estimation of developmental costs is challenging at best and is not yet well enough supported by solid cost databases. The addition of O&S cost requirements makes sense from the perspective of life cycle affordability, but again, this effort is not supported by sufficient O&S cost databases. The development of SoS and net-centric systems exacerbates the cost-estimating problem as system-wide changes drive platform costs, but may not be attributable to the platform absorbing the cost. Platform changes may also drive system-wide changes, again driving costs that are not attributable to the system level. While these costs may not be attributable, we recognize that they still need to be tracked so that they can be estimated in future developments and so that root-cause analyses can be applied to help eliminate the sources in the future.

Certifications at MS A and MS B

The certifications at Milestones A and B, along with the attention of the Director CAPE, undoubtedly bring attention and scrutiny to program cost estimates and concerns regarding program affordability in the context of the larger warfighting portfolio. The mandate for cost certificates is a major improvement, as compared to our 2003 research. Cost certificates are a necessary forcing function to push the DoD toward more reliable cost estimating. Again, SoS and net-centric system development may add certification challenges as the associated costs are typically not foreseeable, and attributing the costs to a specific PM may be difficult.

Changes to Nunn–McCurdy to Include an O&S Cost Metric

Unquestionably, Nunn–McCurdy requirements have become more demanding and onerous. As challenging as acquisition costs (APUC and PAUC) are, they are not the correct metrics when viewed from a life cycle cost perspective. Nunn–McCurdy metrics need to evolve into measures of life cycle cost, including O&S cost portion (e.g., average O&S cost per system per hour or average O&S cost per system per mile). To do otherwise is to encourage poor system development choices that may add to life cycle cost rather than constrain it.

Mandated Reviews

Moving the PDR Assessment to precede or coincide with Milestone B, as mandated in WSARA, should improve decision-making. That is, required warfighter capabilities, technological maturity, affordable resources, and available schedule must be compatible with the system specification at Milestone B. This cannot be properly assured without completion of the preliminary design because PDR supports preparation of resource and schedule estimates. To that end, we recommend that software-intensive systems employ the SEI's QAW and ATAM^{SM} process tools (or similar-type processes) to accomplish the following: more fully define derived and implied software-related requirements; improve the software developer's understanding of how the warfighters use and maintain the system; understand how the system is likely to be changed, modified, or made interoperable over its life cycle; and improve the developer's understanding of the performance the warfighter expects under stressful or unusual operating scenarios. These process tools should vastly improve the reliability of information resulting from the PDR with regard to the software components.

Technological Maturity

The *Technology Readiness Assessment Deskbook* was published in 2003 and has greatly clarified understanding of technological maturity, yet it is difficult to apply to software development. The DoD has a long track record of moving into detailed design after Milestone B without the necessary maturity of technology to complete the system design. The result is almost always program delays and substantial cost growth. Lack of technological maturity is one of the major causes of cost growth and reflects the importance of Knowledge Point 1, as described by the GAO. Because software development defies early maturity estimation, it must be considered separately and include the maturity evaluations of the software developer (CMMI or equivalent), as well as the maturity evaluations of the materiel developer/PM (SA-CMM or equivalent).

Today, we have a useable template to discuss and reach a common understanding of technological maturity; we know the importance of technological maturity; we have a mandated certification—in law and regulation—to assure the intersection of technological maturity, affordability, available budget, and schedule. The DoD knows the elements of knowledge that are necessary for sound decision-making to launch development of a new warfighting system. This also applies to COTS or GOTS software, but software *development* depends on assessing the maturity of the developer and the PM office, as stated previously.

Navy Gate Reviews

The DoD should require gate reviews for use by all the Services. Gate reviews provide for oversight and governance of MDAP life cycle cost. These reviews establish a process to bring attention to ownership cost throughout the developmental cycle of warfighting systems. In a wider sense, gate reviews provide a forum for lessons learned regarding TOC. While emphasizing affordability through the developmental and production phases of individual warfighting systems, gate reviews provide the opportunity to balance the resources provided among capability portfolios, and potentially to assist in balancing resources across all of the department's family of capability portfolios.

Configuration Steering Boards

The opportunity to grow requirements for ongoing programs that are beyond Milestone B has been largely taken away from the user community and placed into the hands of each Service's Configuration Steering Board. This is likely to curtail major cost increases in programs and encourages cost reductions based on PM recommendations in program requirements and within program objectives. Congressional language on changes to user requirements has been accommodated in the most recent version of DoDI 5000.02, dated December 2, 2008. Implementation of this guidance entails a major change in culture; whether it is successful in reducing ownership cost will be shown over time.

Performance-Based Logistics

The DoD is very familiar with the demands of sustainment—but the OSD has not insisted on proper planning and implementation of affordable sustainment. The OSD has not focused enough on the metrics that indicate success of warfighting systems or on the cost to achieve required metrics. Instead, focus has been on commodity management, with the DLA being a prime example, where metrics have reflected performance of the support organization, but not weapon system readiness.

PBL must be applied more widely, such that non-PBL systems should be an unusual occurrence. PBL requirements initially should be analyzed vertically by an individual system such that the warfighting system is able to achieve its mission and is affordable. However, PBL arrangements also should be analyzed horizontally to take advantage of economic quantities and other efficiencies that might be provided by using common support systems. PBL metrics also should be devised to reflect the individual warfighting system (i.e., vertical) and the broader support system or enterprise (i.e., horizontal).

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