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# Total Ownership Cost -- Tools and Discipline

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**Total Ownership Cost—Tools and Discipline**

**16 March 2011**

**by**

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Graduate School of Business & Public Policy

**Naval Postgraduate School**

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# Abstract

Control of total ownership cost (TOC) is a continuing initiative to manage costs over the entire life cycle of a weapon system. There are several major categories of costs that contribute to Total Ownership Cost but the principal categories are (1) R&D, (2) Production, (3) Operating and Support, and (4) Disposal. System TOC is the same as Life Cycle Cost (LCC) and must be planned and controlled from requirements definition, system development, and sustainment—focusing on affordability, and cost to achieve required operational availability. The Program Manager (PM) is responsible for managing system TOC, with input from key stakeholders, such as the sponsor and users. This paper updates our work in 2003, addressing initiatives to control cost, congressional pressure to control cost, leadership guidance, controls, and incentives that can be employed to encourage emphasis on system affordability. There is some discussion of metrics to control life cycle cost and the requirements for databases to assist in estimating and comparing life cycle costs. The growing cost of software supportability and its impact on system TOC is also discussed, along with methodologies for reducing these costs.

**Keywords:** affordability, research and development cost, total ownership cost (TOC), reduction in total ownership cost (RTOC), life cycle cost, operating & support cost, sustainment cost, developmental cost, production cost, software supportability, post deployment software support (PDSS)

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# I. Background

In 2003, we prepared a report on the Reduction of Total Ownership Cost. At the time there was substantial effort ongoing, and in more than seven years since, much has happened. As is always the case with a very large organization such as the Department of Defense (DoD), change has come slowly and unevenly across the organization. In 2011, we see clearly a number of things that need to be done to control and reduce the life cycle cost of weapon systems. Many of the steps that need to be accomplished are well known but not practiced. Some aspects are not widely understood or are otherwise not in place. We begin this report with background extracted directly from our 2003 report. In some cases, we have made minor edits to update terminology.

The focus of our current research can be found in Chapters 2 through 6. Our conclusions and recommendations are located in Chapter 7.

## A. Definitions (Boudreau & Naegle, 2003, p. 1)

Total Ownership Cost (TOC) has two definitions; the first is very broad, looking from the DoD or Service perspective.

> DoD TOC is the sum of all financial resources necessary to organize, equip, train, sustain, and operate military forces sufficient to meet national goals in compliance with all laws, all policies applicable to DoD, all standards in effect for readiness, safety, and quality of life, and all other official measures of performance for DoD and its Components. DoD 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. (Under Secretary of Defense for Acquisition, Technology, and Logistics [USD(AT&L)], 1998, p. )

Much of the activity described in this definition is beyond the capability of a weapon system program manager to influence. However, it is deliberately broad in scope to include the many different possibilities for various stakeholders to reduce ownership cost.

The second definition is deliberately written from the vantage point of the program manager (PM) of the warfighting system.

> Defense Systems TOC is defined as Life Cycle Cost (LCC). LCC (per DoD 5000.4M) includes not only acquisition program direct costs, but also the indirect costs attributable to the acquisition program (i.e., costs that would not occur if the program did not exist). For example, indirect costs would include the infrastructure that plans, manages, and executes a program over its full life and common support items and systems. The responsibility of program managers in support of reducing DoD TOC is the continuous reduction of LCC for their systems. (USD[AT&L], 1998, p. 2)

As Dr. Gansler said in his 1998 memorandum from which the above definitions were extracted, the PM's job in trying to reduce TOC is a very difficult one, and PMs should seek help wherever they can to reduce ownership costs. Because of the extreme amount of focus on the authorized and appropriated budget, it is easy for PMs to likewise focus on the near-term acquisition cost and make decisions that appear to be beneficial in reducing acquisition costs but that are detrimental to operations and support costs because they increase future budgets. For example, if a program experiences a budget cut, which is a very typical occurrence, there is significant pressure to continue to deliver the same number of new systems, even though there has been a cut in funding. As a result, the PM looks for something else to cut out of the program. Logistics performance items are rarely deemed to be Key Performance Parameters (KPPs), so they become easy targets for cutting during budget cut drills. So the PM is faced with a choice: cut the number of systems to be acquired, or reduce the logistics performance (eliminate Built-in Test [BIT] capability, onboard diagnostics/prognostics/autonomics, etc.), which will add significant O&S costs well after the PM has moved to a different position. Which choice do you suppose is most appealing to the PM?

Even the definition of *system* is changing as we move to system-of-systems (SoS) and net-centric system concepts. For example, developing the Single Integrated Air Picture (SIAP) as a system means that all the Services' manned and unmanned aircraft, many guided and unguided missile platforms, and a host of command and control systems are now at least a part of SIAP. Changes to any of the platforms (especially software changes) could result in changes to others, impacting the TOC of the individual weapon platforms and of the SIAP system. How do we account for SoS or net-centric system-driven changes/maintenance in forecasting or even attributing cost elements? For example, consider the networking software for Force XXI Battle Command Brigade and Below (FBCB2) as updated for the M1 Main Battle Tank and several other platforms using the network. The software update did not integrate perfectly with the M1's onboard software suite, causing uncommanded turret movement (Federation of American Scientists [FAS], 2011a). Because the other platforms in the system did not experience interoperability problems, the PM for M1 was assigned responsibility for the diagnosis and repair of M1 software to be compatible with the FBCB2 update. This begs the questions of which program to attribute the TOC expense (FBCB2 or M1), how would such TOC factors be forecasted, and by whom would they be budgeted?

## B. TOC Processes: CAIV and R-TOC (Boudreau & Naegle, 2003, p. 2)

Pursuit of Total Ownership Cost reduction at the level of the warfighting system may be separated into two major approaches that are connected, end-to-end, along a life-cycle time line. During the developmental phases, the effort or process is called Cost As an Independent Variable (CAIV). For systems in the field or fleet, the process or goal becomes Reduction of Total Ownership Cost (R-TOC). The chart in Figure 1 is a typical depiction of the CAIV/R-TOC relationship.

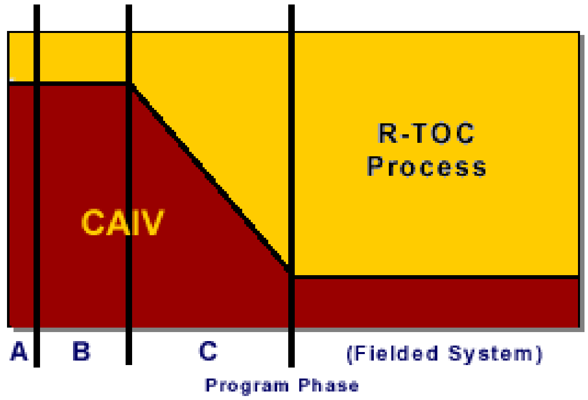


**Figure 1. CAIV/R-TOC Relationship**
(Kaye, Sobota, Graham, & Gotwald, 2000, p. 354)

The first approach, CAIV addresses TOC during the warfighting system's developmental phases, beginning with the Concept Refinement phase. The focus of CAIV is to establish cost targets based on affordability and requirements and then to manage to those targets, thereby controlling TOC. CAIV includes consideration of costs for development, production, operations and support, and disposal. An example of the CAIV process would be to set specific cost and reliability targets for each subsystem or component of a weapon system in development such that the warfighting system would be able to achieve the required operational availability ($A_O$) at the specified cost.

Employing the CAIV concept early in the developmental process offers, potentially, the greatest opportunity for TOC reduction at the lowest possible investment cost. As an example, the TOC impact of using two different power plants presents an opportunity to use the CAIV evaluation technique to estimate the TOC impact and make a best-value decision. For illustrative purposes, consider a standard internal combustion engine at a cost of $7,500 versus a hybrid-electric power plant costing $19,000. The impact to the acquisition cost is evident, but it excludes the cost savings associated with fuel consumption over the life of the system. If the system's operational mode indicates an average usage of 15,000 miles per year and an economic useful life (EUL) of 20 years, the total miles expected would be 300,000. If the standard engine in our comparison is estimated at 10 miles per gallon and the hybrid engine is estimated at 25 miles per gallon, the estimated fuel saved by the hybrid-powered system would be 18,000 gallons. At a current estimate of $1.25 per gallon, the operating and support impact is $22,500 per system (TOC improvement: $11,000 less expensive than the standard engine), and there are other reductions in fuel supply assets and attendant personnel that apply.

The second approach to TOC is the R-TOC and focuses on the reduction of average procurement unit cost (APUC) and weapon system sustainment cost (i.e., operating and support [O&S] costs). R-TOC is employed as the warfighting system is produced and placed in service. Examples of R-TOC would be a value engineering change proposal (VECP) to reduce the cost of manufacturing a component by improving the process yield (the percentage of the manufactured items that are defect free) or a VECP to reduce the operating and support cost by improving the reliability of an expensive subsystem or component. Often there are the secondary benefits of enhanced performance (i.e., improved reliability and operational availability), but the forcing function is the reduction of operating and support costs, the largest constituent of TOC.

System software has become an ever-increasing TOC driver the more systems rely on software functions.

## C. TOC Obstacles (Boudreau & Naegle, 2003, pp. 4–7)

Someone who is not involved with program management might wonder what is especially difficult about containing and controlling TOC. In truth, there are many difficulties. What follows is a description of some of the obstacles that get in the way of controlling or reducing TOC. All of these obstacles are well known but are entrenched and difficult to overcome.

The competing interests of users, developers, prime contractors, subcontractors, the Office of the Secretary of Defense (OSD), Service headquarters, maintainers, buying commands, and Congress may negatively impact TOC. The "user" who establishes requirements for a new system may be transfixed by the technical performance and may not clearly establish requirements for ownership cost to achieve specified system availability. Materiel developers may be too focused on acquisition cost and schedule (a typical complaint from the user community) and may ignore future logistics support issues. Prime contractors may concentrate on production costs, with less regard for system sustainment costs, particularly if their contract directs them toward reduction in production costs or if they sense that their customer is not interested in sustainment issues. The OSD and Service headquarters may encourage poor TOC decisions through funding instability and failure to demand life-cycle affordable solutions. Maintainers may contribute to poor R-TOC by failing to speak out loudly on lessons learned from previous systems. Buying commands may contribute to increased ownership costs by failing to look aggressively for cost drivers that need to be redesigned for lower cost of operation and improved reliability. The Congress may restrict R-TOC by constraining the choices of cost-effective sustainment approaches.

<u>Balancing Total Ownership Cost Goals That Are Conflicting</u>. Successful program management includes the ability to achieve balance within a program. Indeed, PMs are directed by DoDD 5000.1 to manage their programs in a balanced way (USD[AT&L], 2003, Encl. 1, para. E1.29). Facets and perspectives that need to be balanced are manifold. Four elements of TOC that require balancing are development costs, procurement costs, operating and support costs, and disposal costs. Development costs, the expenditure of resources during system development, may pay off in terms of reduced production and/or sustainment costs; producibility studies may save significant manufacturing costs; and reliability testing early in a program may allow for avoidance of sustainment costs over the service life of the weapon system. Occasionally, procurement or production cost constraints may conflict with sustainment cost targets; for example, heavy pressure to reduce production costs may lead to the selection of components that are inexpensive but not reliable. Such choices would reduce production cost but increase sustainment

costs and very possibly result in an increase of TOC. When such cost goals conflict, a reasonable metric for maintaining balance would appear to be minimization of TOC (i.e., life cycle cost, but, often, TOC is sub-optimized due to these competing pressures).

Balancing Cost, Schedule, System Performance, Sustainment, Quality, and Risk. In the same way that ownership cost goals must be balanced and harmonized, system solutions must be found that balance TOC against procurement cost goals, program schedule goals, system technical performance, equipment quality, supportability performance, and availability.

The DoD is relying on sophisticated, software-intensive systems to improve survivability and lethality, but software is susceptible to high TOC. Software "maintenance" is becoming a major TOC driver (Naegle, 2004, p. 1). Software is difficult to accurately estimate and sensitive to changing requirements. Its complexity, interface requirements, and relative ease in adding capability also tend to make it maintenance intensive (Humphrey, 1990, Chapter 4). Software's negative influence on TOC is exacerbated by the fact that software support is most often provided by contractors, with very little opportunity to move software support to Government sources. For example, the 1980s vintage B1B Bomber budgets were approximately $100 million annually for software maintenance, and the 2010 budget was $227 million because several software-intensive systems were also being upgraded (Naegle & Petross a., 2010, p. 25). The B1's software support is achieved through both contractor and Government software support organizations and is coordinated by an Air Force–supported Program Management Office (PMO).

During each life-cycle phase, the approach to TOC reduction and the methodology may change somewhat, while ownership cost goals and targets become more refined. For example, tradeoff processes used in the Materiel Solution Analysis phase may be beneficial during that phase but may be inadequate for the Engineering and Manufacturing Development (EMD) phase without the inclusion of specific contractor incentives.

Materiel Developer Instability. Key members of the materiel developer team change over time. For example, the PM during the Integrated System Design phase would be unlikely to remain in that position through the Production and Deployment phase. As key personnel—PMs, chief engineers, product support managers, business-financial managers—change, program emphasis shifts, at least subtly. These personnel changes, which are a fact of life, may reflect in program missteps, including missed TOC targets.

Funding Instability. Resources tend to be unstable and subject to unanticipated, unexpected changes. Funding instability is also a fact of life in Government acquisition programs. Each time that funding is cut from a program, decision-makers adjust the program by postponing or eliminating some activity or system attribute. Decisions are made that will keep the program viable, and often the choice is to omit a system feature or a near-term activity that will reflect negatively on TOC—but not until later. Easing back on O&S cost targets is a tempting sacrifice when program funding gets cut. For example, reliability-centered maintenance studies cut to reduce cost during EMD would not affect the program noticeably until later on, when operational systems are in the field or fleet; the associated effect on TOC might be substantial. Eliminating onboard diagnostics/prognostics would certainly help meet funding cuts during the Procurement phase, but would likely be extremely costly in terms of maintainer training, diagnostics time, erroneous fault isolation, errant parts ordering, and associated maintenance man-hours for the life of the system.

Sticker Shock. The fact that a system's TOC "price tag" is extremely high when compared to its contract unit price may tend to keep stakeholders from discussing TOC in any open forum, fearing that "sticker shock" might cause an adverse reaction from a decision-maker or politically powerful individual accustomed to seeing much lower cost figures. As an example, consider a system with an average procurement unit cost (APUC) of $1.5 million and a program acquisition cost of $2 million.[1] Typically, program acquisition cost would represent only about 28% of each individual system's TOC, with the remaining 72% representing O&S and disposal costs of about $5 million, for a TOC of $7 million per each weapon system. With an acquisition objective of 2,000 systems, the total procurement cost would be $3 billion, with a TOC estimate of approximately $14 billion. If unfamiliar with TOC estimates and without a readily available basis for comparison, a decision-maker might mistakenly conclude that the system would be unaffordable and cancel the program. Concern for such a scenario may create an impediment to widespread use of system life cycle cost numbers, which would have the effect of refocusing decisions onto the acquisition "price tag," not the TOC "price tag."

## D. Management of TOC

There is an increasing body of knowledge related to the control of TOC. In addition to specific congressional direction and ever more detailed DoD direction, very thoughtful articles have been published on the matter. Every PM tries different approaches to reduce costs. Additionally, commercial best practices have been recognized and suggested for use within the DoD (e.g., GAO-03-57 [GAO, 2003] in its entirety).

[1] APUC is the total procurement cost divided by the total procurement quantity. Program acquisition cost includes APUC, facilities, RDT&E, and other procurement costs. These terms are discussed in more detail, beginning on page 24.

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# II. The Focus of this Paper—Total Ownership Cost in 2011

## A. Purpose

The purpose of this working paper is to gather together the various approaches for controlling and reducing TOC and to describe tools and methods to assist PMs and others in addressing TOC more effectively.

## B. 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.

## C. 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 lots of 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], 2008c). 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 reduced it? Has developmental cost increased while the larger sustainment costs 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.[2] 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).[3] 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?

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[2] 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.

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

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, we addressed leadership resolve and the need to speak with one voice about *affordability*. In 2003, the new JCIDs 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; 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.

# III. Congressional Intervention

Interestingly, the questions posed in Chapter 2 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 Weapon System Acquisition Reform Act 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.

## A. 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, a portion of which are described in the following paragraphs (WSARA, 2009).

Director of Cost Assessment and Program Evaluation ("Director CAPE"). The Director CAPE is a new appointive position, devised to give independent advice and analysis to SECDEF and DEPSECDEF on matters that fall within his responsibility. Director CAPE is responsible for functions formerly accomplished by Program Analysis & Evaluation, the Defense PA&E (WSARA, 2009, § 101).

Director CAPE has two deputies (WSARA, 2009, § 101):

- the Director for Cost Assessment (formed initially from the Cost Analysis Improvement Group [CAIG]), and

- the Director for Program Evaluation (formed from the remnants of PA&E, that is, PA&E less the CAIG).

Responsibilities. Director CAPE is responsible for cost estimation and cost analysis for MDAP acquisition programs, analysis, and advice in the planning and programming phases of PPBE (WSARA, 2009, § 101). Additionally, Director CAPE provides analysis and advice to the Joint Requirements Oversight Council (JROC) and formulates study guidance used to conduct Analysis of Alternatives of new major defense acquisition programs (WSARA, 2009, § 201). These responsibilities place Director CAPE in a position to provide advice and direction related to the accuracy of acquisition cost estimates and the affordability of acquisition programs. Quite apparently, Director CAPE is charged with advising the (JROC) to strengthen that body's role in issues of cost and affordability, as noted in the short JCIDS discussion (i.e., Second Gut Question) in paragraph c of Chapter II, above.

Cost Estimation. 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 (WSARA, 2009, § 101). In this capacity, Director CAPE is required to provide guidance to and consult 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. This mandate includes specifics, such as selection of statistical confidence levels of cost estimates in consideration of life cycle costs of MDAP and MAIS programs. Director CAPE specifically reviews independent cost estimates (ICE) for the Defense Acquisition Board (DAB) prior to certifications, LRIP, or FRP. Director CAPE is further charged to review cost analyses and records for MDAP and DAIS and is given authority to participate in discussion of discrepancies between ICE and military department cost estimates. This includes disclosure of statistical confidence levels used by Director CAPE and the Services. Confidence levels below 80% must be justified and included in the next Selected Acquisition Report, SAR, which is sent from PMs, through their component and the OSD, to Congress. Director CAPE is required to report annually on cost-estimating accuracy and compliance with policy, along with consistent differences in cost-estimating methodology by the Services. This report goes to OSD leadership and congressional defense committees and is to be posted on the Internet for public review.

The WSARA specified that Director CAPE must report to the SECDEF on O&S costs for MDAPs within one year and to congressional defense committees within 30 days thereafter, followed by annual reports (WSARA, 2009, § 101). This represents another action that brings focus to the cost of operating and sustaining warfighting systems. This requirement has caused considerable consternation. See the discussion in the GAO Report 10-717 section of Chapter 4 for additional perspective on the accuracy of O&S cost databases.

Director of Program Assessment and Root Cause Analysis (Director PARCA). The WSARA (2009, § 103) mandated that the SECDEF designate a senior official responsible for conducting program assessment and root cause analysis for MDAPs. Director PARCA, is responsible for evaluating the utility of performance metrics used to measure cost, schedule, and performance of MDAPs and for making recommendations for improvement. This individual also advises on MDAP performance issues prior to certifications at Milestones A and B, prior to Full Rate Production (FRP), and in consideration of multi-year procurement decisions. Director PARCA accomplishes root cause analysis for MDAPs to determine causes for shortcomings in cost, schedule, or performance, including unrealistic performance expectations; unrealistic baseline estimates for cost or schedule; immature technologies; unanticipated design, engineering, manufacturing, or technology integration issues in program performance; changes in procurement quantities; inadequate funding or funding instability; or poor PM performance (Government and/or contractor). Director PARCA must report annually (initially March 2010) on root cause analyses for MDAPs and submit to congressional defense committees a report of activities undertaken during the preceding year.

Director of Defense Research & Engineering (DDRE; WSARA, 2009, § 104). Together with the Director of Developmental Test and Evaluation (Director DT&E), DDRE reviews and assesses the technological maturity and integration risks of MDAPs. The WSARA requires annual reports (initially March 2010) to the SECDEF and the congressional defense committees. This strongly encourages MDAs, PEOs, and PMs not to permit programs to move forward until they are technologically ready.

Director of Systems Engineering (WSARA, 2009, § 102). This director is required to develop policy and guidance for systems engineering master plans for MDAPs in support of life-cycle management, sustainability, and reliability growth in contractor proposals. This directly relates to life cycle cost (LCC) because of the focus placed on sustainability cost, typically the largest component of LCC. This is further discussed in the Other Documents section Chapter 4, specifically RADM (R) Don Eaton's published perspective that poor reliability estimates distort true sustainment costs and that poor reliability is a large cost driver. If the contention is accurate that poor reliability estimates are a major cost driver, this should soon begin to appear in the root cause analyses that are mandated for programs that experience significant cost overruns.

Director DT&E and Director of Systems Engineering are required by WSARA to issue guidance on and detailed measureable performance criteria related to Systems Engineering Master Plans (SEMPs) and Developmental Test and Evaluation (DT&E) plans for MDAPS. Among these measureable performance criteria would likely be reliability, availability, maintainability, and related O&S costs; WSARA mandates establishment of a database to record and track weapon system performance data (WSARA, 2009, § 102).

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). The words are straightforward and unambiguous, but the interpretation of the "cost" element must be correctly applied to system life cycle cost, not procurement cost.

Competition throughout the life cycle (WSARA, 2009, § 202). The WSARA identifies 10 different approaches that may be incorporated into a MDAP acquisition strategy to ensure competition be used if cost effective. 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.

Competitive Prototyping (WSARA, § 203). The WSARA mandates that MDAPs include competitive prototyping in their acquisition strategies prior to MS B approval—that is, during Technology Development Phase—unless waived by the Milestone Decision Authority. Waivers are specifically limited to cost effectiveness or failure to meet critical national security objectives. In the event of a waiver of competitive prototyping because it is not cost effective, non competitive prototyping of the system is still required prior to MS B, if benefits exceed cost and are consistent with national security objectives (WSARA, 2009, § 203). The importance of competitive prototyping is that contractors will feel competitive pressure earlier in the process. While generally considered good for the taxpayer, it is arguable that competitive prototyping has not resulted in cost reduction for the Joint Strike Fighter (JSF), which engaged in competitive prototypes but afterward experienced significant cost growth. While there may be multiple reasons for the cost growth experienced, the JSF program may reflect contractor “buy-in,” long a problem in DoD acquisition programs.

Milestone Decision Authority Certifications and Follow-on Notifications (WSARA, 2009, § 204). Title 10 U.S.C. 2366a has been tightened, requiring in the MDA’s Milestone A certifications that Congress be notified if a program experiences or anticipates a cost slip of 25% or anticipates a schedule slip of 25% or more in meeting Initial Operational Capability (IOC). The MDA shall notify Congress within 30 days of identifying root causes and appropriate performance measures to guide the rest of the program development, and specifically addressing (a) the essentiality of the program to national security, (b) the lack of less costly alternatives, (c) new estimates of reasonable cost and schedule for the program, and (d) the adequacy of the program’s management structure to control program cost and schedule.

Milestone B Certification Modification (WSARA, 2009, § 205). For programs that have gone through Milestone B decision, 10 U.S.C. 2366b certification has been amended by WSARA to require that Congress be notified of waivers by the MDA, in writing within 30 days, explaining the basis for a waiver. The MDA must review a troubled program at least annually to determine the extent that the program is satisfying the certification terms, until such time as the MDA determines that the program has satisfied all the elements of the certification. Budget documents submitted to Congress or the President must be clearly marked as not fully satisfying the certification until the program has made the necessary corrections.

Nunn-McCurdy Cost Breach Modifications (WSARA, 2009, § 206. Title 10 U.S.C. 2433 (generally known as the Nunn-McCurdy Cost Breaches) has been amended by WSARA to require that the MDA consult with the JROC regarding program requirements. Then the MDA must determine the root cause or causes of the cost growth and, in consultation with Director CAPE, assess the following: the cost of completing the program with and without reasonable modification, the rough order of magnitude of proceeding with an alternative system or capability, and the need to shift funds from other programs due to the cost growth. There is a presumption of program termination unless the MDA notifies Congress of a waiver within 60 days. If the program is not terminated, the Secretary shall restructure the program, rescind the most recent Milestone approval, require a new Milestone approval, and require onerous additional program reviews).

The WSARA of 2009 Summary. There is no doubt that the demands made in WSARA 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 life cycle cost. 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.

## B. National Defense Authorization Act for Fiscal Year 2010, Section 805

The National Defense Authorization Act for Fiscal Year 2010 has special relevance to life cycle cost, as will be explained. In this law Congress mandated the 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. This law increased the stature of the program's chief logistician, the individual who is responsible to develop product support strategy for the warfighting system. Although a logistician, the PSM is responsible for conducting cost analyses to validate the product support (sustainment) strategy, including cost-benefit analyses that are described in OMB Circular A-94. 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 FY 2010 very apparently established a position within the MDAP PM office that is responsible for sustainment cost, to include reliability, which directly influences sustainment cost.

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

DoD Instruction 5000.02 of December 2008 very succinctly promulgates the requirements of section 814 of the Duncan Hunter National Defense Authorization Act for FY 2009, specific to the formation of configuration steering boards (CSBs) as follows:

> The Acquisition Executive of each DoD Component shall establish and chair a CSB with broad executive membership including senior representatives from the Office of the USD (AT&L) and the Joint Staff. Additional executive members shall include representatives from the office of the chief of staff of the Armed Force concerned, other Armed Forces representatives where appropriate, the military deputy to the CAE and the Program Executive Officer (PEO) (section 814 of P.L. 110-417, Reference (w)).
>
> (1) The CSB shall meet at least annually to review all requirements changes and any significant technical configuration changes for ACAT I and IA programs in development that have the potential to result in cost and schedule impacts to the program. Such changes will generally be rejected, deferring them to future blocks or increments. Changes shall not be approved unless funds are identified and schedule impacts mitigated.
>
> (2) The PM, in consultation with the PEO, shall, on a roughly annual basis, identify and propose a set of descoping [sic] options, with supporting rationale addressing operational implications, to the CSB that reduce program cost or moderate requirements. The CSB shall recommend to the MDA (if an ACAT ID or IAM program) which of these options should be implemented. Final decisions on descoping [sic] option implementation shall be coordinated with the Joint Staff and military

> department requirements officials. (USD[AT&L], 2008c, Enclosure 2, p. 30, para 9.d.)

This law introduces a strong bias toward limiting design changes to systems. Note the Service user representative is not named as 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.

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# IV. Relevant Reports

## A. 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 at such time as 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 on 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. In addition, software *development* (not reuse, commercial off-the-shelf [COTS], or Government off-the-shelf [GOTS]) tends to behave as a new, immature technology, with each effort started from scratch. To combat this inherent problem, potential MDAP and MAIS software developers must undergo a maturity evaluation like the Software Engineering Institute's (SEI) Capability Maturity Model–Integrated (CMMI) and achieve a certain level of maturity through independent evaluation. For the Capability Maturity Models, the potential software developer must achieve Level 3 or higher to be eligible to compete for the development (USD[AT&L, 2003],). It is also advisable for the PM office to be similarly evaluated using something like the SEI's Software Acquisition (SA) CMM to help minimize the maturity risk with developing software. More often than not, programs are authorized to move into the Engineering and Manufacturing Development (EMD) phase before the technology is sufficiently mature to support a detailed design.

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. Although it would seem that completion of 90% of the engineering drawings is not a severe metric, this is quite demanding; failure to abide by this knowledge point is likely to slow down prototype build and result in prototype test failures caused by designs that were not quite ready for prime time.

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. Reliability is demonstrated in iterative testing (i.e., comparison testing of manufactured product). This point should be demonstrated during LRIP, prior to the FRP decision. Failure to achieve this knowledge point will result in manufacturing delays, high costs of reworking or repairing manufacturing defects, and customers unhappy with the weapon system quality.

Knowledge Point Management is not new. The GAO did not invent the approach in 1998. It borrowed the idea from industry, recognizing that the technique should, and could, be applied to DoD acquisition. Recent changes to the Defense

Acquisition System have largly embraced Knowledge Point Management. Getting acquisition programs synchronized with this approach has not happened overnight and is unlikely to happen for all programs if not strictly enforced by DoD leadership.

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 slower than needed may be substituted by an alternative technology that is mature and immediately available. Plainly, this 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 a 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 temptation might be to move the program ahead, betting that the required technology solution will miraculously arrive or mature just in time. While miracles sometimes happen, they should not be the anticipated substitute for a sound, well-planned, and executable strategy.

The logistics impact cannot be ignored, either. The result will either be multiple configurations or an expensive modification/upgrade program. Such 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.

## B. GAO Report 10-717

In July 2010, the GAO 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, 2010b). This report painted a dreary picture of relevant databases. The GAO found that important O&S cost-estimate documents 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 databases (VAMOSC; GAO, 2010b, p. 16). Data in VAMOSC and other Service information systems or sources was inaccurate and incomplete (GAO, 2010b, 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, but it noted that the Services should be required to collect and assess such data and maintain it in their VAMOSC databases. GAO singled out the Army in particular as needing to develop and implement a strategy for improving its VAMOSC system. On August 19, 2010, Director CAPE was quoted by *Inside the Pentagon* as asking for relief from the requirement to establish O&S baselines for warfighting systems, ostensibly reporting that this initiative would be "infeasible and not advisable" (Mishory, 2010) because the VAMOSC database was severely flawed. Director CAPE appears to be in agreement with the GAO that sustainment data is flawed or missing and not suitable for rigorous analysis and assessment. A review of the GAO report suggests an array of difficulties in comparing actual data to baselines. Aircraft systems reviewed by GAO appeared to cost less than expected because the quantities operating in the fleet were generally different (usually fewer) than expected (GAO, 2010b, p. 21). However, costs also were affected by unexpected changes in OPTEMPO (specifically, flying hours; GAO, 2010b, 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.

VAMOSC data, by its very nature, is collected from many and varied locations—sometimes in garrison or home port, sometimes in operational and combat areas. There should never be an expectation of perfect or highly refined data, but, outside of combat areas, data ought to be collected that is “good enough” to support assessments as to whether equipment is operating in the expected performance range, if metrics are established for expected cost drivers. As suggested in our 2003 report, sample data collection (SDC), although expensive, provides a method for improving the accuracy of logistics and O&S cost data.

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, 2010b, 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.

## C. GAO-08-1159T, *Defense Acquisitions: Fundamental Changes are Needed to Improve Weapon Procurement Outcomes*

In his testimony, the GAO Director of Acquisition and Sourcing Management, Michael Sullivan, succinctly identified systemic problems that led to poor acquisition outcomes (GAO, 2008). His findings identified disconnects in the three systems that are essential to the acquisition of military weapons—Planning, Programming, Budgeting, and Execution process (PPBE), Joint Capabilities Integration and Development System (JCIDS), and the Defense Acquisition System. He further characterized a breakdown of systems engineering at critical junctures, referred to as knowledge points. He also described a culture in the Services and the DoD that incentivize overpromising system performance and underestimating cost and schedule, a pervasive problem across the DoD for many years.

## *D. DoD Weapon System Acquisition Reform Product Support Assessment*

In the Product Support Assessment Team's (PSAT) November 2009 report *DoD Weapon System Acquisition Reform Product Support Assessment*, they listed eight areas to improve product support. At least five of the areas impact system life cycle cost (e.g., Product Support Business Model, Metrics, Operating and Support Costs, Analytical Tools, and Human Capital; PSAT, 2009, pp. 12–13).

## *E.* 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 WSARA of 2009 (Porter et al., 2009, pp. ES-15–ES-18).

## F. Other Documents

In his memorandum, *State of Reliability,* Dr. 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. Dr. Gilmore made reference to a recently published reliability standard, ANSI/GEIA-STD-0009, which should be employed. He quoted a May 2008 Defense Science Board (DSB) report, which stated that “high suitability (reliability) failure rates were caused by the lack of a disciplined systems engineering process, including a robust reliability growth program” (DSB, 2008 in the Task force Chairman’s cover letter). The DSB further emphasized that the “single most important step...is to...execute a viable systems engineering strategy from the beginning, including a robust reliability, availability, and maintainability (RAM) program” (DOT&E, 2010, pp.1–2; DSB, 2008 p.23).

Dr Gilmore made his case further by stating,

> I understand that directing use of ANSI/GEIA STD-0009 is a change from business as usual. That change is urgently needed. Requiring the use of 0009 is appropriate for the following reasons:

- 0009 is credible. To obtain an ANSI certification, 0009 was peer reviewed by 350 subject matter experts (SMEs) from all walks of the reliability community, including government, Services, academia, and industry.

- 0009 is new, different, necessary. ANSI/GEIA STD-0009 is not similar to MIL-STD-785B. The two standards are quite different, and MIL-STD-785B will not suffice. MIL-STD-785B required a “level-of-effort” and discrete tasks, but not system engineering processes. MIL-STD-785B had no systematic processes to identify and mitigate failure modes throughout the product life cycle. 0009 corrects the failings of 785B.

- 0009 has become a model for others. Since publication of ANSI/GEIA STD-0009, major standards such as SAE JA 1000 and IEEE 1332 are now being rewritten to embrace the science-based, closed-looped approach of ANSI/GEIA STD-0009.

- 0009 has been formally adopted by DoD for use (August 20, 2009). ANSI/GEIA STD-0009 will ensure a systems level approach to identify and mitigate failure modes until requirements are met. (DOT&E, 2010, p. 3)

In his own words, Dr. Gilmore has publically entered into the reliability dialog because

> discussions that have occurred among our staffs participating in the re-convened Reliability Working Group indicate that there is some question as to whether reliability is an important issue, and there also appear to be questions about the merits of the reliability standard ANSI/GEIA-STD-0009. (DOT&E, 2010, p. 1)

Dr. Gilmore emphatically stated in the very next paragraph of his memo that there is no question about it. That is, defense acquisition systems completing R&D are often not reliable, and he linked poor reliability to sustainment costs that are higher than necessary (DOT&E, 2010, p. 1). This is reflective of findings in RADM (R) Don Eaton’s 2004 paper, discussed below:

RADM Don Eaton, retired Arthur Chair in Logistic Management at the Naval Postgraduate School, said in a July 24, 2010, e-mail, “If we thoughtfully analyzed the FOMs [figures of merit] of COST, SCHEDULE AND PERFORMANCE we would always conclude poor reliability is THE dominant cost driver as well as a key player in mission failure."  In his August 2004 paper *Improving the Management of Reliability*, he provided a stunning example from naval aviation, the trailing edge flap actuator for the F/A-18 A-D.  He pointed out that the component reliability was set at 4,000 hours mean time between failure (MTBF). In operation, the demonstrated performance in MTBF was 138 hours, 3.45% of what it was supposed to be (Eaton, 2004, pp. 5–6).  RADM Eaton did not attempt to calculate the impact to sustainment cost because that was not the purpose of his paper.  Nevertheless, without calculating the impact in dollars, one can see that such poor performance reflects in significantly increased costs in maintenance man-hours for repair, repair parts consumed, transportation of repair parts and/or replacement components, and required stockage levels that had to be maintained, not to mention the impact on the aircraft's mission availability rate.  Such examples are not unique to aircraft, or to the Navy.  Many, if not all, programs have reliability "bad actors" that need to be redesigned and replaced because of what they are costing in maintenance time, repair parts expense, and transportation.  This situation could be improved by rigorous reliability improvement programs during system development, as described in the statements by Dr. Gilmore referred to previously.  This would require disciplined leadership, PMOs determined to get the design right, and user insistence that reliability goals are set—and achieved—for warfighting systems.

Collaborative Tools. Reliability improvement is bolstered by the involvement of product support managers as encouraged in the National Defense Authorization Act for Fiscal Year 2010, Section 805.  The reliability improvement process can be enhanced by the use of collaborative tools to involve life cycle logistics professionals and make available repair parts databases to sharpen design decisions.  This effort can be further helped by Pareto analysis—that is, focus on the cost drivers, primarily the expensive items that break more often than predicted.  This approach can be used early in the design process, too, by searching systems command and DLA databases to examine performance of similar or predecessor systems.

Wider View of the Need for O&S Cost Databases. It is easy for field users, maintainers, and PMs to visualize cost databases that can be used to identify cost drivers in fielded, legacy systems. This is important work and a principal focus of VAMOSC databases, maintained by each of the Services. However, it must also be recognized that O&S databases are needed to support early O&S calculations of emerging systems, still in pre-acquisition. In her 2010 report, 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 life cycle cost savings with deployment of the replacement system. Roper referred to this as capabilities-based parametric data analysis (2010, pp. 71–73).

# V. Policy Pronouncements

The OSD implemented the 2009 version of 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], 2010).

## A. 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], 2010d). The intent of this implementation directive was to reach beyond WSARA mandates to obtain greater affordability-based decision-making in warfighting system programs. Pertinent specifics are as follows.

- Mandate affordability as a requirement. PMs are now required to treat affordability like 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 tradeoff analysis to establish cost and schedule trade space. Such a mandate requires a Database similar to the one Roper described (2010, pp. 71–73). This will provide a basis for comparison against the applicable portfolio or mission area, and will reflect acquisition and O&S budget suitability to absorb the proposed program new start. Analysis must address specific adjustments to fit new programs *affordably* into their portfolio or mission area (USD[AT&L], 2010d, p. 1).

- The Milestone B acquisition decision memorandum will include an affordability requirement for acquisition cost and O&S cost that will be the functional equivalent to a KPP and will be established as Acquisition Program Baseline (APB) metrics (USD[AT&L], 2010d, p. 2).

- Productivity growth through will cost/should cost. Should-cost targets will be set for all ACAT I, II, and III programs under consideration for major milestone decisions. Should-cost targets will be based on thoroughly scrubbed bottom-up assessments, assuming reasonable efficiency and productivity enhancement effort. Should-cost will be used as the basis of contract negotiation and incentives to track contractor and PEO/PM performance annually (USD[AT&L], 2010d, p. 2). Independent cost estimates will establish "forecasts of what a program *will cost* based on reasonable extrapolations from historical experience—to support budgeting and programming" (USD[AT&L], 2010a, p. 3). The motivation for industry is higher profit for better performance.

- Eliminate redundancy within warfighter portfolios. The DoD and the components have begun portfolio reviews to identify and eliminate system redundancy in warfighting systems. This function will be accomplished annually by the military departments and agencies (USD[AT&L], 2010d, p. 2).

- Make production rates economical and stable. This element is intended to synchronize production to portfolio affordability targets set at MS A, as adjusted at MS B, and economic order quantity (EOQ). Production rates will be part of the affordability analysis at MS A and MS B. MS C now requires a range of production rates, and deviation from that range without prior approval will lead to revocation of the milestone (USD[AT&L], 2010a, p. 4).

- Set shorter program timelines.  Schedule slips are very expensive and delay the arrival of needed equipment into the hands of warfighters. Unfortunately, long developmental programs have been the norm for many years USD[AT&L], 2010a, pp. 4–5).  For future programs, the program schedule will be set at MS B, consistent with the cost tradeoff analysis.  This is logical because cost and schedule must be synchronized to meet affordability targets.  Deviation from schedule without prior approval will lead to revocation of the milestone (USD[AT&L], 2010d, p. 2).

## B. Promote Real Competition

Present a competitive acquisition strategy at each Milestone.  ACAT I, II, III, and IV are all required to include a competitive strategy prior to each milestone and to include reduction of single-bid competitions.  The strategy will include discussion of market research, restricted specifications, and adequate time for proposal preparation.  A 2% improvement goal of one-bid statistics has been established for 2011 (USD[AT&L], 2010d, p. 4).

Remove Obstacles to Competition.  Contract officers are required to conduct negotiations with all single-bid offerors, unless waived by the Head of Contracting agency (HCA), and the basis of negotiation shall be cost or price analysis, using non-certified data.  Component or agency competition advocates are required to achieve an improvement rate of 10% per year in effective competition (USD[AT&L], 2010d, p. 4).

Require open systems architecture and acquisition of tech data rights.  Use of open system architecture and tech data rights will both be pursued to ensure the programs' lifetime consideration of competition.  The results of these initiatives will be reported in the Acquisition Strategy Reports (USD[AT&L], 2010d, pp. 4–5). .

In summary, the several USD(AT&L) initiatives cited previously from the *Implementation Directive for Better Buying Power—Obtaining Greater Efficiency and Productivity in Defense Spending* and from the Memorandum for Acquisition Professionals entitled *Better Buying Power: Guidance for Obtaining Greater Efficiency and Productivity in Defense Spending* specifically addressed improvements that may be made through the diligent efforts of PMs, contracting officers, and trained acquisition professionals.

## C. Software Acquisition Process Improvement Programs

On March 21, 2003, the OSD issued a memorandum to the secretaries of the military departments and other selected recipients, establishing the DoD's Software Acquisition Process Improvement Program and directing each Service to establish a similar program (OSD, 2003).

While clearly focused on the software acquisition process, this memorandum established the need for a more systemic approach that would include requirements development, configuration management, risk management, and test and evaluation, as well as all relevant stakeholders. These are all key tenets in designing systems with desirable TOC characteristics, and including logisticians as relevant stakeholders is necessary to help ensure that the Post Deployment Software Support (PDSS) planning produces a robust and supportable software architecture. As with any other system component, the software design architecture will determine the supportability performance that helps drive the system's TOC.

## D. 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 (Department of the Navy, 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
    - Integrated Baseline Review
    - Post Critical Design Review
    - Capability Production Document
    - Pre-Full Rate Production Decision Review
    - 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 alternative candidates.
- Intermediate gate reviews are coupled to existing systems engineering and acquisition milestone review points. These reviews become a forum to assess whether program tradeoffs 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.

# VI. Other Initiatives

## A. Controls on Software Development

### 1. 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 SEP focus used does not attempt to separate software from other components, so all system components would benefit from using these tools and techniques.

#### a. 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 aircraft sorties available. 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 spotty, at best, and completely lacking, at worst.

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

## B. 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.

## C. 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 to 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.

## D. 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, change, and upgrade as the GPS system does so.

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 becomes a major software-management and software-discipline challenge.

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.

## E. 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.

## F. 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 Software Engineering Institute'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 the application development. For example, the ATACMS missile air-delivers some of its warheads, leaving the missile body to freefall 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 the software developers (Naegle, 2006, pp. 17–25).

## G. Effective Software Development Tools Supporting System TOC Analyses

### 1. 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 the system requirements development, QAW is designed to work with another SEI process called the Architectural Tradeoff Analysis Methodology$^{SM}$ (ATAM$^{SM}$) to further improve the understanding of the system for potential contractors and software developers.

## H. SEI's Architectural Tradeoff Analysis Methodology$^{SM}$ (ATAM$^{SM}$)

The Software Engineering Institute's Architectural Trade-off Analysis Methodology$^{SM}$ (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 process 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, the 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 (2000, pp. 13–15). As depicted in Figure 2, 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.

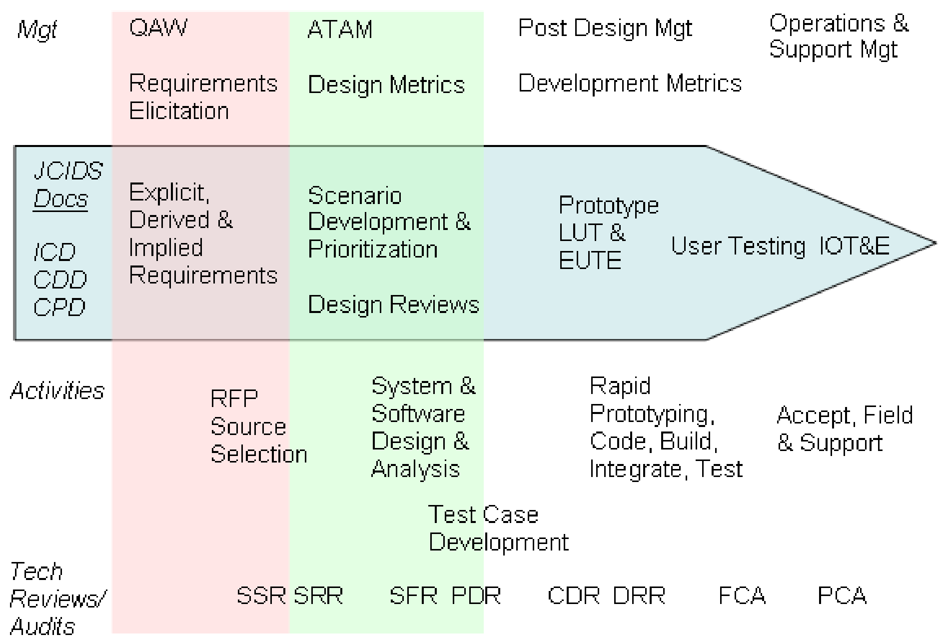


**Figure 2. QAW & ATAM$^{SM}$ Integration into Software Life Cycle Management**

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 2) 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 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 Software Engineering Institute 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 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 3 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 Key Performance Parameters (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.

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.

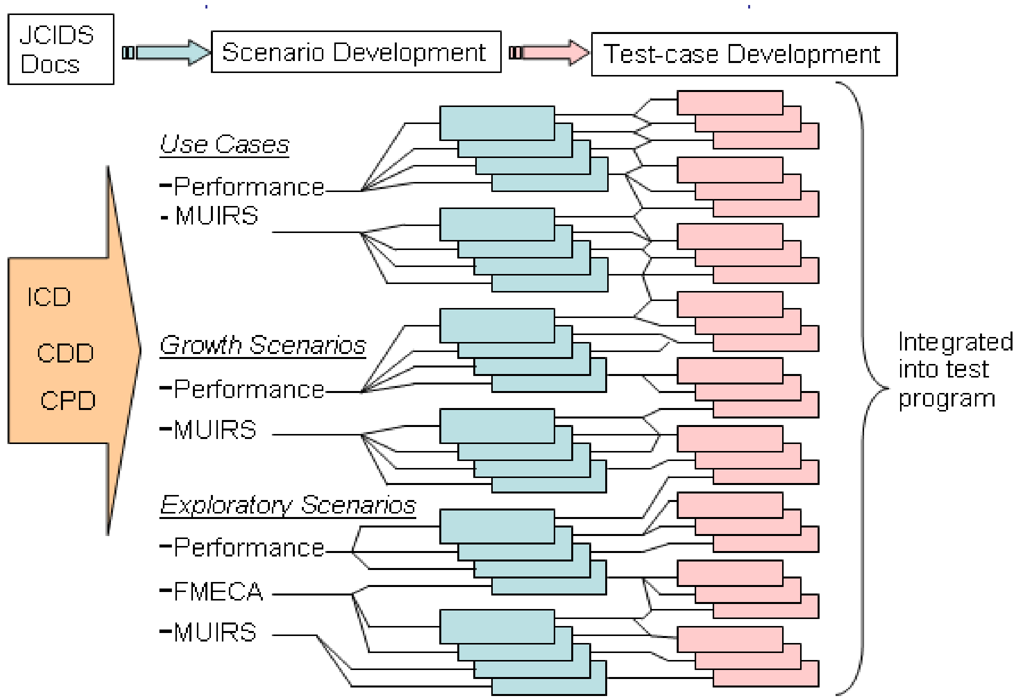


**Figure 3. Capabilities-Based ATAM$^{SM}$ Scenario Development**

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 the verification loop process by demonstrating that the final product produces the capability identified in the user requirements through operational testing.

Both 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.

## I. 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, 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, field service representatives (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. 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 business case analysis (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 life cycle cost.

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.

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), ubiquitous (nearly 30,000 units in 2010), and initial reliability numbers were lower than expected (as low as 1300 hours MTBF). Through a collaborative effort between the Program Manager, NAVSEA, and several commercial vendors, design and manufacturing improvements increased the MTBF to 40,000 to 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, May 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 field service representatives, 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.

# VII. Conclusions and Recommendations: Major Thrusts to Control TOC

Many of the TOC initiatives implemented since our last 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.

## A. Controls

Cost Estimates. The DoD has not yet demonstrated its ability to estimate program costs within reasonable confidence limits. Estimation of developmental costs are challenging at best and are 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 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℠ 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.

## B. Databases

Defense Acquisition Management Information Retrieval (DAMIR)—MDAP Systems Database. The DAMIR 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. DAMIR 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.

## C. 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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