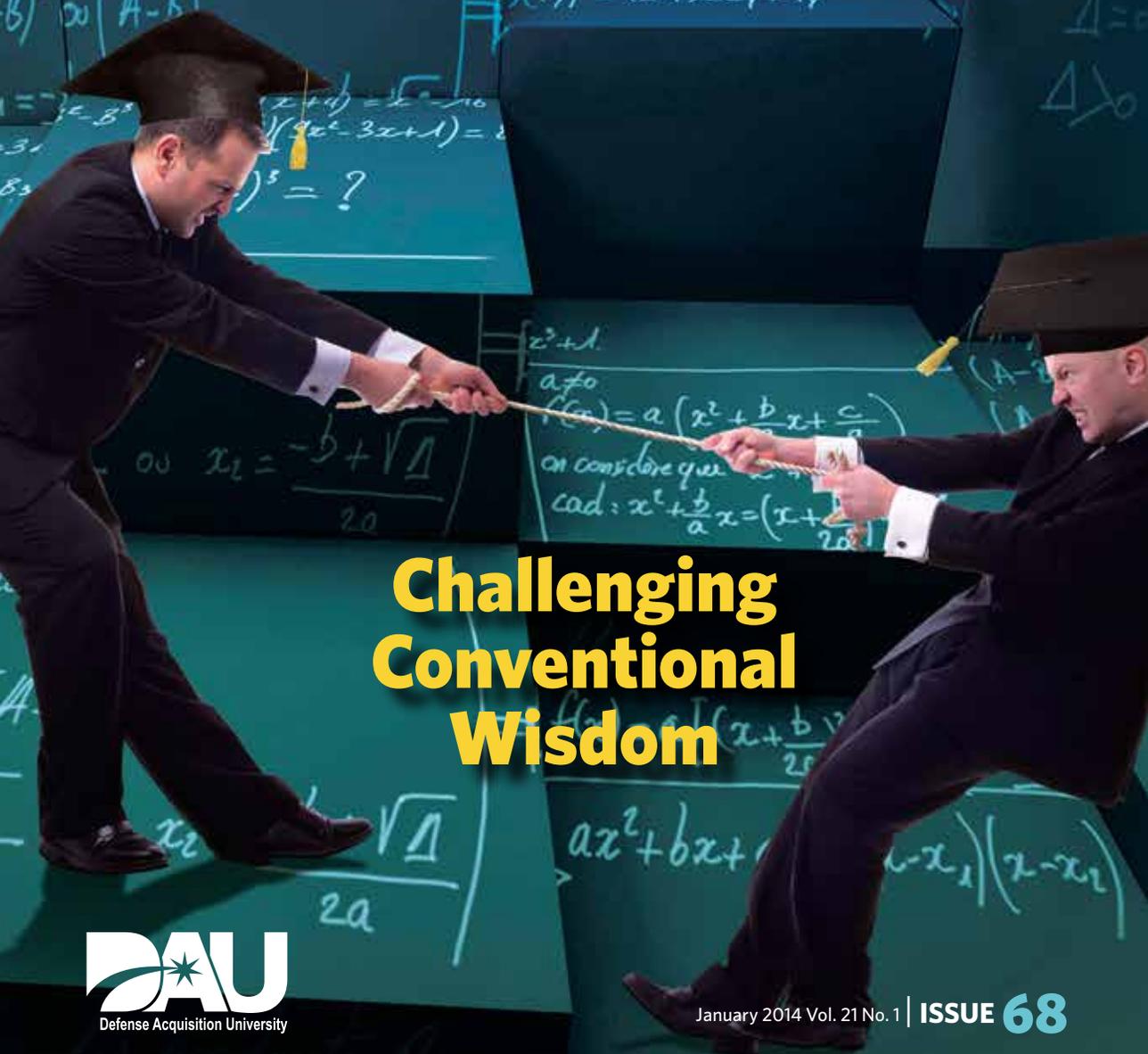




Defense Acquisition Research Journal

A Publication of the Defense Acquisition University



Challenging Conventional Wisdom

① *DoD Acquisition – To Compete or Not Compete: The Placebo of Competition*
William J. Levenson

② *Investigation into the Ratio of Operating and Support Costs to Life-Cycle Costs for DoD Weapon Systems*
Capt Gary Jones, USAF, Edward White,
Lt Col Erin T. Ryan, USAF, and
Lt Col Jonathan D. Ritschel, USAF

③ *Strengthening DoD Cyber Security with the Vulnerability Market*
Maj Bradley C. Panton, USAF, John M. Colombi,
Michael R. Grimaila, and Robert F. Mills

④ *A Conceptual Framework for Defense Acquisition Decision Makers: Giving the Schedule Its Due*
Chad Dacus and Col Stephen Hagel, USAF
(Ret.)

The Defense Acquisition Professional Reading List

John T. Kuehn, *“Agents of INNOVATION: The General Board and the Design of the Fleet That Defeated the Japanese Navy”*
Reviewed by Robert G. Keane

Article List

ARJ Extra



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Commercial markets abound with examples of competitive forces providing reduced costs and increased innovation. However, the defense market is materially different from commercial markets in many ways, and thus does not respond in the same way to competition. This analysis examines a series of outcomes in both competitive and sole-source acquisition programs, using a statistical model that builds on a game theory framework developed by Todd Harrison, Center for Strategic and Budgetary Assessment. The results show that the Department of Defense may actually incur increased costs from competition. Competition in defense acquisition may not reduce costs, but may—like a placebo—create a powerful perception of cost control.

Investigation into the Ratio of Operating and Support Costs to Life-Cycle Costs for DoD Weapon Systems

p. **442** *Capt Gary Jones, USAF, Edward White, Lt Col Erin T. Ryan, USAF, and Lt Col Jonathan D. Ritschel, USAF*

Recent legislation, such as the Weapon Systems Acquisition Reform Act of 2009, requires a renewed emphasis on understanding Operating and Support (O&S) costs. Conventional wisdom within the acquisition community suggests a 70:30 cost ratio with respect to O&S and acquisition of an average weapon system. Using 37 Air Force and Navy programs, the authors estimate the mean overall ratio of O&S costs to acquisition costs to be closer to 55:45, although many weapon systems displayed significant deviation from this 55 percent average. Contributing factors such as life expectancy and acquisition strategy (i.e., new system or modification) affect this variance. Their research advises against using a single “one-size-fits-all” O&S/acquisition cost ratio for all major DoD weapon systems.

Strengthening DoD Cyber Security with the Vulnerability Market

Maj Bradley C. Panton, USAF, John M. Colombi, Michael R. Grimaila, and Robert F. Mills

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Every year, the Department of Defense (DoD) upgrades its information technology systems, allows new applications to connect to DoD information networks, and reconfigures the enterprise to gain efficiencies. While these actions better support the warfighter and satisfy national security interests, they introduce new system vulnerabilities waiting to be exploited. Often, these vulnerabilities are discovered only after the system has already deployed, where costs to fix are much larger. This article recommends the DoD adopt an economic strategy called the vulnerability market, or the market for zero-day exploits, to enhance system Information Assurance. Through the mutual cooperation between industry and the military in securing information, the DoD optimizes security investments, secures critical information, and provides an effective and resilient warfighting capability.

A Conceptual Framework for Defense Acquisition Decision Makers: Giving the Schedule Its Due

Chad Dacus and Col Stephen Hagel, USAF (Ret.)

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Conceptual models based on economic and operations research principles can yield valuable insight into defense acquisition decisions. This article focuses on models that place varying degrees of emphasis on each objective of the defense acquisition system: *cost* (low cost), *schedule* (short cycle times), and *performance* (high system performance). The most appealing conceptual model is chosen, which the authors posit that, if adopted, would lead to shifts in priorities that could facilitate better outcomes, as empirical results suggest. Finally, several policy prescriptions implied by the model are briefly explored.

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From the Chairman and Executive Editor

The theme for this edition of *Defense Acquisition Research Journal* is “Challenging Conventional Wisdom,” for as the articles in this issue demonstrate, many of the most respected truisms in defense acquisition are not nearly so clear-cut as previously believed.

The first truism examined in this edition is that competition in the defense market should replicate the commercial market by reducing costs and increasing innovation. The article “DoD Acquisition—To Compete or Not Compete: The Placebo of Competition,” by William J. Levenson, builds upon prior research presented at the September 2012 Defense Acquisition University (DAU) Research Symposium, “The Limits of Competition in Defense Acquisition” (<http://www.dau.mil/research/pages/papers.aspx>). The author uses statistical modeling, within a game theory framework developed by Todd Harrison, to show that the DoD may actually incur increased costs from competition. This paper received the 2013 DAU Acquisition Excellence Award for Outstanding Acquisition Paper at the Eisenhower School, National Defense University.

A second truism is that the Operating and Support (O&S) costs account for about 70 percent of the total life-cycle costs of the average weapon system. In “Investigation into the Ratio of Operating and Support Costs to Life-Cycle Costs for DoD Weapon Systems,” by Capt Gary Jones, USAF, et al., that figure is shown to be closer to 55 percent of the life-cycle cost, though with substantial deviation around the mean. This finding has significant implications for the finance and budgeting of weapon systems programs.

A growing and pervasive realization in the world of information technology is that the current cyber security mechanisms such as defense-in-depth, penetration test tools, and cyber test ranges may prove insufficient in the face of rapidly evolving threats. Thus, Maj Bradley C.



Panton, USAF, and his coauthors, in their article “Strengthening DoD Cyber Security with the Vulnerability Market,” recommend the DoD adopt an economic strategy called the vulnerability market as a cooperative means between industry and the military to not only secure, but also optimize critical security investments.

Finally, the current emphasis on program costs as the primary means of optimizing the combination of cost, schedule, and performance is put under a microscope in “A Conceptual Framework for Defense Acquisition Decision Makers: Giving the Schedule Its Due” by Chad Dacus and Col Stephen Hagel, USAF (Ret.). They argue that a greater emphasis on meeting schedule will provide a more consistent set of outcomes for all three criteria.

The featured book in this issue’s Defense Acquisition Professional Reading List is John T. Kuehn’s (2008) *Agents of INNOVATION: The General Board and the Design of the Fleet That Defeated the Japanese Navy*, reviewed by Robert G. “Bob” Keane.

On a final note, I invite our readers to note the list of reviewers who have so graciously given their time and energy the past year to ensure that the *Defense Acquisition Research Journal* maintains the highest standards of editorial excellence that have made it the world’s premier journal of research on defense acquisition.



Dr. Larrie D. Ferreiro
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DAU Center for Defense Acquisition Research

Research Agenda 2014

The Defense Acquisition Research Agenda is intended to make researchers aware of the topics that are, or should be, of particular concern to the broader defense acquisition community throughout the government, academic, and industrial sectors. The purpose of conducting research in these areas is to provide solid, empirically based findings to create a broad body of knowledge that can inform the development of policies, procedures, and processes in defense acquisition, and to help shape the thought leadership for the acquisition community.

Each issue of the *Defense ARJ* will include a different selection of research topics from the overall agenda, which is at: <http://www.dau.mil/research/Pages/researchareas.aspx>.

Affordability and cost growth

- Define or bound “affordability” in the defense portfolio. What is it? How will we know if something is affordable or unaffordable?
- What means are there (or can be developed) to measure, manage, and control “affordability” at the program office level? At the industry level? How do we determine their effectiveness?
- What means are there (or can be developed) to measure, manage, and control “Should Cost” estimates at the Service, Component, program executive, program office, and industry levels? How do we determine their effectiveness?
- What means are there (or can be developed) to evaluate and compare incentives for achieving “Should Cost” at the Service, Component, program executive, program office, and industry levels?

- Recent acquisition studies have noted the vast number of programs and projects that do not make it successfully through the acquisition system and are subsequently cancelled. What would systematic root cause analyses reveal about the underlying reasons, whether and how these cancellations are detrimental, and what acquisition leaders might do to rectify problems?
- Do Joint programs—at the inter-Service and international levels—result in cost growth or cost savings compared with single-Service (or single-nation) acquisition? What are the specific mechanisms for cost savings or growth at each stage of acquisition? Do the data support “jointness” across the board, or only at specific stages of a program, e.g., only at research and development or only with specific aspects, e.g., critical systems or logistics?
- Can we compare systems with significantly increased capability developed in the commercial market to DoD-developed systems of similar characteristics?
- Is there a misalignment between industry and the government priorities that causes the cost of such systems to grow significantly faster than inflation?
- If so, can we identify why this misalignment arises? What relationship (if any) does it have to industry’s required focus on shareholder value and/or profit, versus the government’s charter to deliver specific capabilities for the least total ownership costs?

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Keywords: *Defense Industry, Game Theory, Bidding Strategy, Statistical Modeling*

DoD Acquisition—To Compete or Not Compete: *The Placebo of Competition*

 *William J. Levenson*

Commercial markets abound with examples of competitive forces providing reduced costs and increased innovation. However, the defense market is materially different from commercial markets in many ways, and thus does not respond in the same way to competition. This analysis examines a series of outcomes in both competitive and sole-source acquisition programs, using a statistical model that builds on a game theory framework developed by Todd Harrison, Center for Strategic and Budgetary Assessment. The results show that the Department of Defense may actually incur increased costs from competition. Competition in defense acquisition may not reduce costs, but may—like a placebo—create a powerful perception of cost control.

In the never-ending battle to control the costs of Major Defense Acquisition Programs (MDAPs) in the Department of Defense (DoD), the cry for competition can be heard throughout the U.S. Government like an incantation to conjure the invisible hand of free markets so aptly described by Adam Smith, the father of modern economics. Commercial markets abound with examples of competitive forces providing reduced costs and increased innovation. Deregulation and commercialization of telecommunication services, for example, broke up the AT&T monopoly and restored competition, resulting in the low-cost, innovative products and services now enjoyed on a global scale. Government officials and politicians point to endless examples of the powers of competition in commercial markets, such as the remarkable consumer electronics available today and the influence of Internet commerce that drives down prices. Can the DoD harness these competitive forces to control acquisition costs and provide innovative solutions for U.S. defense needs?

The market for the products and services sought by the DoD differs greatly from the free market of the commercial economy. Commercial markets enjoy a vast universe of customers, while in most cases the unique systems required by the DoD make the U.S. Government the sole customer and regulator. The companies of the military-industrial complex of the 1950s have consolidated and specialized over the past



two decades, strengthening oligopolies and creating monopolies, thereby limiting opportunities for competition. This article employs a simplified statistical model to examine various characteristics of competition in defense markets and to provide insight for acquisition professionals and policymakers. The results indicate that cost savings, when they occur, often come with adverse side effects on budget planning and industry health. Uncertainties in the competitive bid process can cause large cost variations, overwhelming the savings from competitive pressures on profit margins. Innovation introduced by competition can reduce costs, but innovation can be difficult to distinguish from overly optimistic cost estimates, particularly when sellers have to set prices before product development and production. Contrary to expectations, competition may actually increase costs relative to sole-source procurement.

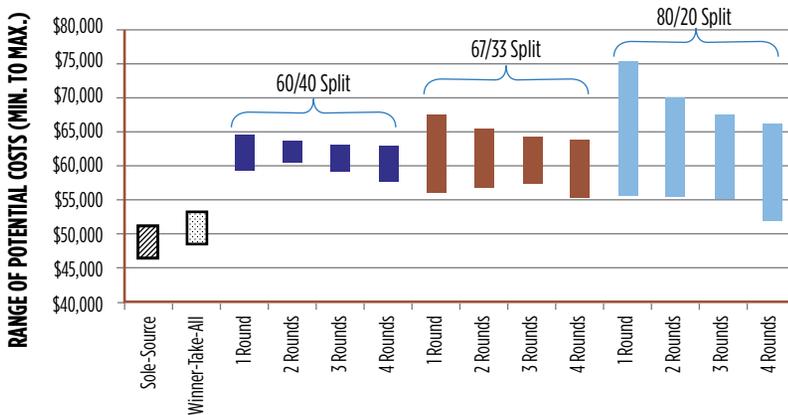
Background

The desire for competition has a long history in federal acquisition. In 1809, Congress passed the first law addressing the question, stating the preference for “formal advertising” for procurement contracts. Subsequent legislation periodically relaxed and strengthened requirements for competition in response to various wartime and peacetime demands. The Competition in Contracting Act (CICA) of 1984 laid the foundation for today’s regulations, requiring “full and open competition through the use of competitive procedures” (Manuel, 2011, p. 4). Subsequent legislation has amended CICA and allows for many alternatives to competition under specific conditions (Manuel, 2011). Most recently, in response to increased DoD acquisition costs and growing budget pressures, Under Secretary of Defense for Acquisition, Technology and Logistics Frank Kendall reemphasized competition to control and reduce cost (Kendall, 2012). Belying the recent emphasis on competition to mitigate cost challenges, a recent study implies that competition will often increase the cost of acquisition.

Todd Harrison of the Center for Strategic and Budgetary Assessment performed a game theory analysis of two equal competitors bidding on a hypothetical acquisition program (Harrison, 2012). He assumed each competitor had perfect knowledge of the development and production costs, and each could bid either a 10 percent profit, zero profit, or a 10 percent loss in any given round of competition (the analysis allowed for a loss in a round of bidding as a strategy to win future rounds, but recognized that a competitor would not accept a loss over the entire program).

Harrison’s analysis shows that sole-source procurement provides the lowest range of potential costs regardless of the number of rounds or the award split used in a competitive acquisition strategy (Figure 1). Competition produces higher costs in this analysis because each competitor incurs duplicative development costs, and neither competitor can realize the full cost benefits of a typical production learning curve. Harrison’s game theory model of competition examines the bidding behavior of two equal competitors, but it does not address characteristics that differentiate competitors or recognize imperfect knowledge about the costs of development and production. A statistical-modeling approach can explore these characteristics.

FIGURE 1. MULTIPLE ROUNDS OF COMPETITION

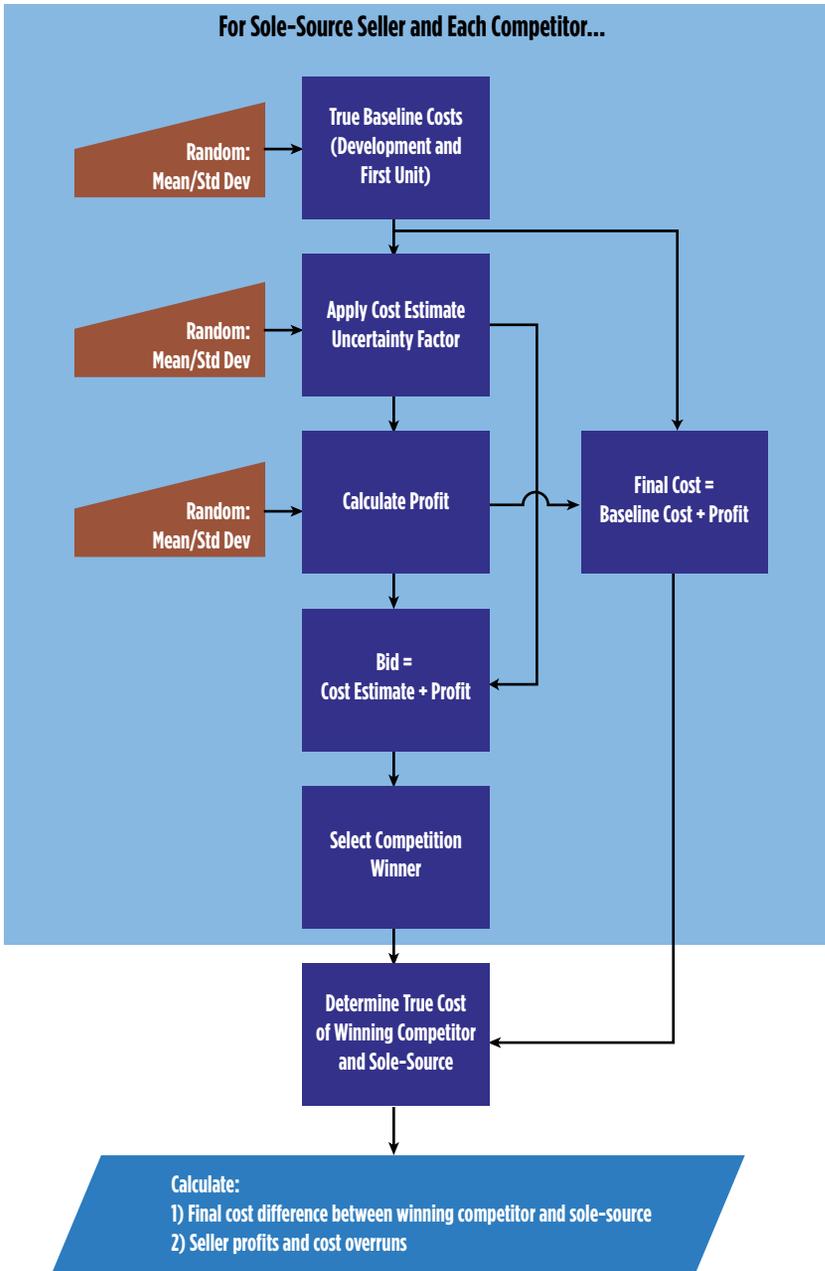


Source. (Harrison, 2012, p. 9)

Statistical Model and Analysis Methodology

To investigate how the outcomes of sole-source procurement compare to competitive procurement would require researchers to execute duplicate acquisition programs as both a competitive and sole-source procurement and compare the results. To gain meaningful data, researchers would have to conduct this experiment many times. Of course, such a real-world trial would be virtually impossible. Instead, this comparison can be made by using a statistical model of bidding and program execution, with comparison of the results of multiple trials in a Monte Carlo analysis (Figure 2).

FIGURE 2. FLOW CHART OF COMPETITION MODEL



The statistical model attempts to capture several key characteristics that affect the final price of an acquisition program, including profit sought by supplier, the accuracy of estimates used to produce supplier bids, innovations that reduce the true cost for one competitor, and the amount of prior experience each supplier has in developing and producing similar products. Whereas Harrison's analysis assumed the supplier bids reflect the true program cost, this approach evaluates the effects on the final program costs, which often vary substantially from initial proposals.

The analysis methodology starts with the same hypothetical acquisition program used by Harrison, which assumed a \$2,000 development phase, a 100-unit production run, and a \$1,000 cost for the first unit. The cost of subsequent units benefits from a learning curve defined as $C_n = C_F n^{\log_2 0.85}$, where C_n is the cost of the n th unit, and C_F is the cost of the first unit (for a \$1,000 first-unit cost and 100-unit purchase, the average cost becomes \$435). To evaluate the effects of competition, the model assumes that two competitors bid on the development and production phases, and the lowest bid wins. The final cost of the competition is then compared to that of sole-source procurement. In cases that examine the effects of random variables, the analysis uses random values for both the competitive and the sole-source procurement, compares final buyer cost for each, and repeats the process 1,000 times to obtain statistical data on the cost difference to the buyer, as well as on several other parameters.

Analysis Results

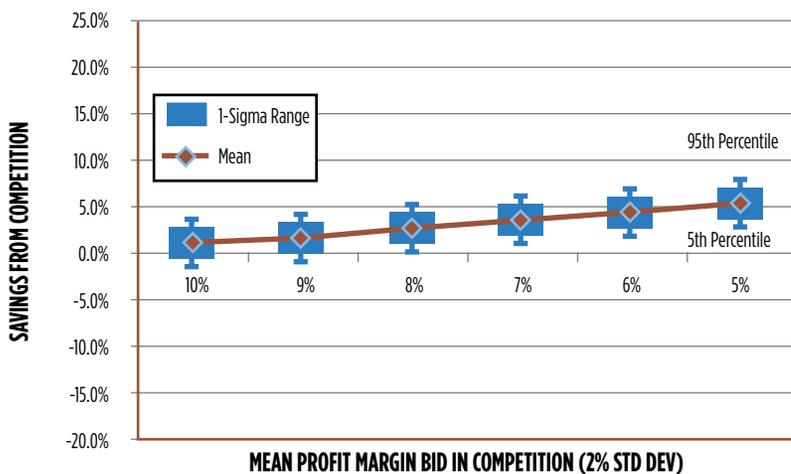
The following results illustrate the effects of each competition characteristic. Examining each effect independently provides insight that acquisition officials and policymakers can use to assess the competitive environment for a product, consider whether to emphasize competition, evaluate competitors and their proposals, and establish expectations for the results. The analysis begins with the most basic aspect of competition: the pressure on suppliers to trim profit margins to win a competition.

Case 1: Competitive Pressure on Profit Margin

To remain consistent with Harrison's results, the analysis of reduced profit margins assumes the sole-source supplier requires a profit of 10 percent, resulting in a total cost to the buyer of \$50,050. Since a sole-source provider feels no pressure to trim the profit margin, the analysis holds the 10 percent profit constant for this case. The competitors,

however, will feel pressure to lower their profit margin to win the competition. Business conditions for each competitor—such as weighted average cost of capital, manufacturing capacity, and the expectations of shareholders—will influence how much profit each competitor requires. The model will treat the profit margin contained in each competitor's bid as a random variable with a mean and standard deviation. Figure 3 shows the average, 1-sigma (one standard deviation) variation, and the range from 5th percentile to 95th percentile, for the savings the buyer can expect as the mean bid varies from 5 to 10 percent, assuming a bid standard deviation of 2 percent profit. Not surprisingly, sellers' reductions in acceptable profit margins lead directly to savings for the buyer. Note that the average saving exceeds the simple difference in mean profit margin between sole-source and competitive bidding because the competitive process selects the lower of the two bidders. Thus, for example, a mean bid profit margin of 7 percent saves the buyer not only the 3 percent difference between 7 percent and the sole-source bid of 10 percent, but an additional saving occurs by selecting the lowest of two bidders, resulting in an average 3.7 percent saving to the buyer. If more suppliers enter the competition, the saving will marginally improve.

FIGURE 3. EFFECT OF PROFIT MARGIN PRESSURES



Note. Competitive pressures can force sellers to reduce profit margins, resulting directly in buyer savings relative to sole-source procurement.

This somewhat obvious first case illustrates two characteristics of competition relative to sole-source procurement. First, competitive pressure on profit margins alone provides a relatively modest saving to the buyer. The defense industry generally has the lowest profit margins among its peers in other industries, ranging between 5 percent and 10 percent for the period from 1989 to 2006 (Arnold, Harmon, Tyson, Fasana, & Wait, 2009, p. 50). Starting at these low profit margins provides limited opportunity to shave margins further.

Second, a seller's willingness to reduce its profit margin significantly to win a competition may indicate a struggling business. For example, executives interviewed by the Space Industry Study Group at the Eisenhower School for National Security and Resource Strategy recently noted that each competition seems to have at least one *desperate bidder*, due to declining federal budgets. While these low bids promise savings for the government, acquisition officials should carefully consider whether the low bidder can survive unexpected cost increases and reliably deliver the final product.

Like Harrison's analysis, this first case assumes that the competitors have perfect knowledge of the development and production costs for the proposed product. Most MDAPs, however, do not enjoy perfect knowledge of these future costs.

Case 2: Bidding Accuracy

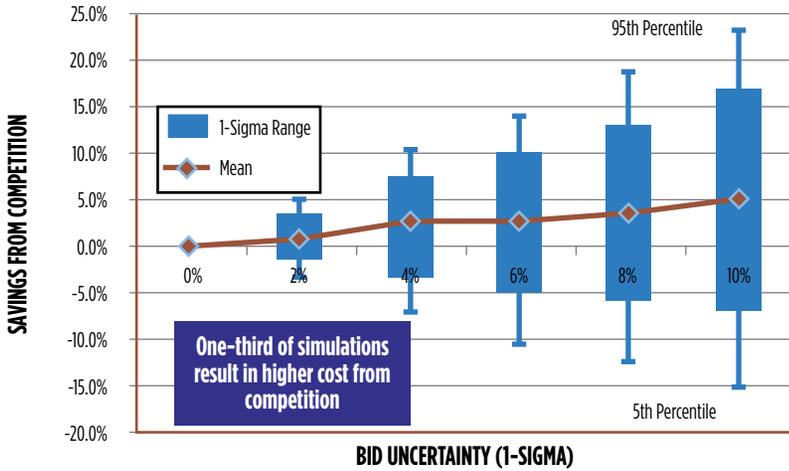
In addition to monopsonistic and oligopolistic conditions, the defense acquisition market differs from the commercial markets in another fundamental way. The defense industry faces significant uncertainty in its costs at the time it sets the price for its products. In a typical commercial market, a seller offers a product for sale after completing development and an initial production run. At that point, the seller understands its costs, can evaluate the demand, and can set the price and production rate to maximize profits and effectively compete against other sellers. In most MDAPs, the buyer asks the seller to set the price in advance. This analysis case will examine two effects of imperfect cost knowledge. First, the analysis assumes that both the sole-source provider and the two competitors have the same inaccuracy in assessing the future cost of the program. Then the analysis will evaluate the results if one competitor underestimates the true costs.

Case 2a: Equal bidding inaccuracy. To assess the effects of bidding inaccuracy on the outcomes of competition, the analysis assumes the true costs of development and production remain the same as Case 1, but that each seller has independent inaccuracy in estimating them. A random factor with a Gaussian distribution represented by its standard deviation (1-sigma) value will signify this uncertainty in the model. The bids of the sole-source provider and the two competitors will vary independently based on the same standard deviation.

This Case 2a scenario simulates a condition in which any seller will likely incur the same cost in the end, but be unable to estimate accurately the cost changes that might occur during the development and production learning curve. In this case, the contract type becomes relevant to the outcome. The analysis will evaluate both a Fixed Price (FP) and Cost Reimbursable (Cost-Plus, or CP) contract. For an FP contract, the buyer pays an agreed price regardless of the actual cost incurred by the seller, and therefore the seller could earn a profit higher or lower than the bid contains. For a CP contract, the buyer agrees to pay a fee, representing the seller's profit, based on a percentage of the initially estimated costs, and the buyer also pays the actual costs of development and production.

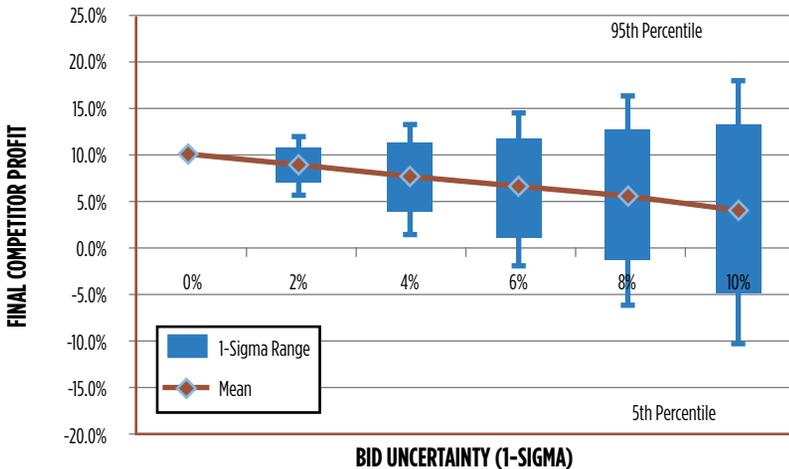
Figure 4 shows the cost savings that competition provides relative to sole-source procurement for an FP contract. The inaccuracy of the initial bid for an FP contract competition, on average, reduces the buyer's final cost relative to a sole-source award. The result has high variability; however, competition actually results in higher cost relative to sole-source procurement in about one-third of the simulations. In this case as in Case 1, the buyer benefits at the seller's expense, but since, by definition, the seller cannot predict its bid inaccuracies, the potential impact to the seller's profit (or loss) can be much greater. Figure 5 shows how inaccurate bidding affects the competitive seller's profits. While FP contracts place this risk on the seller, two issues could arise for acquisition programs: (a) if the seller incurs too much loss, it could become unable to complete the contract; and (b) if the seller incurs too much gain, it could draw the attention of regulators always on the lookout for excessive industry profits. For the sole-source seller, the average profit does not decline, but it has somewhat more variability. The competitive seller suffers more on average because the competition selects the bidder who underestimates the costs the most.

FIGURE 4. BID ACCURACY-FIXED PRICE CONTRACT



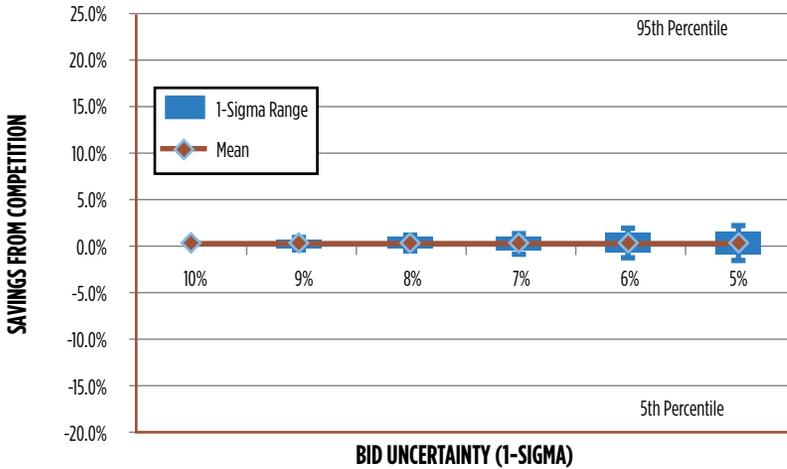
Note. As the inaccuracy of the initial bid increases for a Fixed Price contract, competition, on average, reduces the buyer’s final cost relative to a sole-source award; however, the result has high variability. Competition actually increases cost relative to sole source in about one-third of the simulations.

FIGURE 5. BID ACCURACY-FIXED PRICE CONTRACT



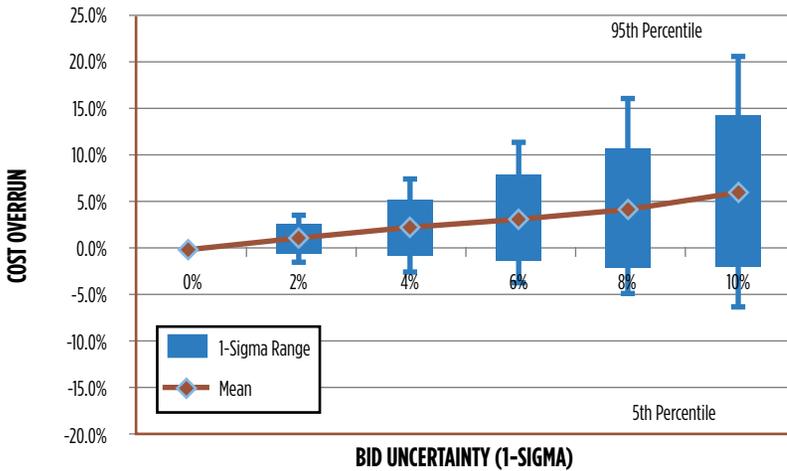
Note. Bid inaccuracy can severely impact seller profits on a Fixed Price contract.

FIGURE 6. BID ACCURACY-COST REIMBURSABLE CONTRACT



Note. Minimal savings from competition for a Cost Reimbursable contract: the initial bid only affects the fee paid to the seller as profit, so bidding accuracy influences the final cost only slightly.

FIGURE 7. BID ACCURACY-COST REIMBURSABLE CONTRACT



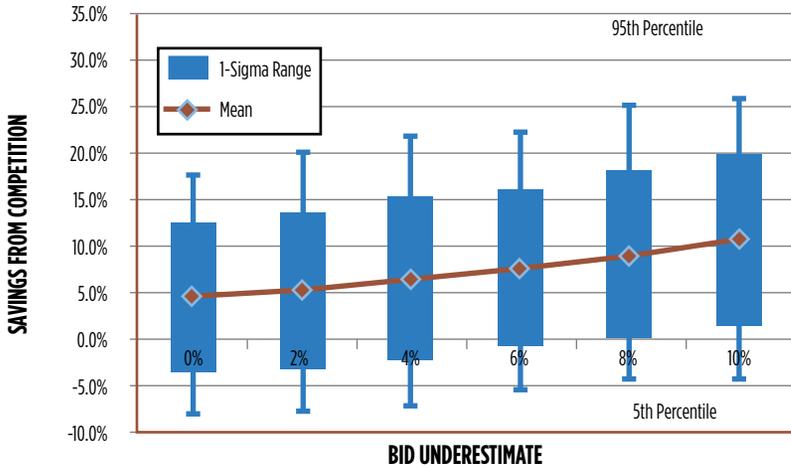
Note. Bid uncertainty leads to cost overruns on Cost Reimbursable contracts.

Figure 6 shows that bidding inaccuracy for a CP contract does not favor either sole-source or competitive procurement. In either case, the initial bid affects only the fee paid to the seller as profit, so bidding accuracy influences the final cost to the buyer only slightly. The effect for a CP contract reveals itself in the potential cost overruns relative to initial bids. Figure 7 shows the cost overrun statistics for the competitive seller in a CP contract. The average cost overrun increases for a competitive seller, but stays near zero for the sole-source seller because, like the effect on profit under an FP contract, the competition selects the seller that underestimates the cost the most. Therefore, competition for a CP contract will tend to increase the likelihood of cost overruns, but not significantly reduce the final cost to the buyer. In addition to random bidding inaccuracy, sellers may also have a bias toward underestimating development and production costs, which Case 2b examines.

Case 2b: One competitor underestimates costs. In Case 2a, the sole-source seller and both competitive sellers have uncertainty about the final costs, but on average their bids reflect the true cost. Often when forecasting cost, sellers will not only have inaccuracy, but a bias toward underestimation. Especially in the face of competition, a seller will tend to estimate costs optimistically. To represent this effect, the model can add a bias to the bids, while keeping the true costs of development and production the same as previous cases. Adding identical bias to the sole-source seller and both competitive sellers would merely shift the results of Case 2a. Instead, Case 2b assumes that one competitive bidder has less experience developing and producing the product than either the other competitor or the sole-source seller. For the less experienced seller, the analysis assumes a bidding inaccuracy of 10 percent (representing 1-sigma) and a bias toward underestimating the true cost. Meanwhile, both the sole-source seller and the other competitor will have a somewhat lower bidding inaccuracy of 5 percent without a bias.

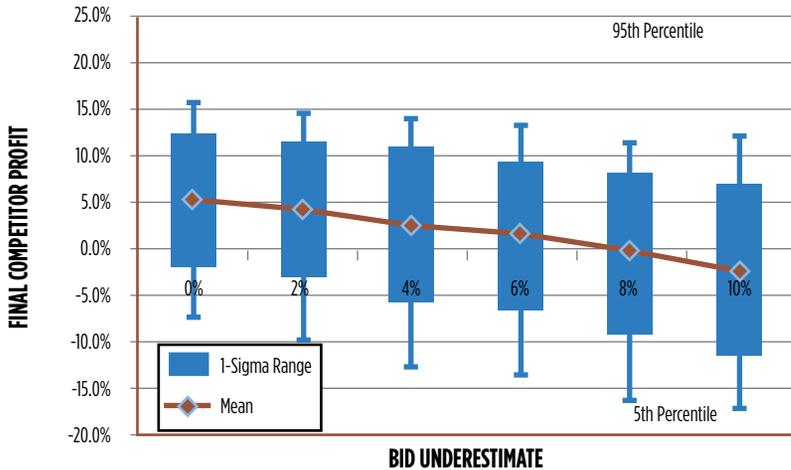
Figures 8 and 9 show the results for an FP contract as the bias varies from 0 to 10 percent. As with Case 2a, the buyer benefits from a lower cost at the expense of the seller's profit. An inexperienced competitor underestimating the final cost amplifies both effects. The competitive selection favors the inexperienced seller with the lower bid, creating more buyer savings relative to a sole-source seller, but increasing the concern that the seller will incur intolerably low profit, or even losses.

FIGURE 8. UNDERBID-FIXED PRICE CONTRACT



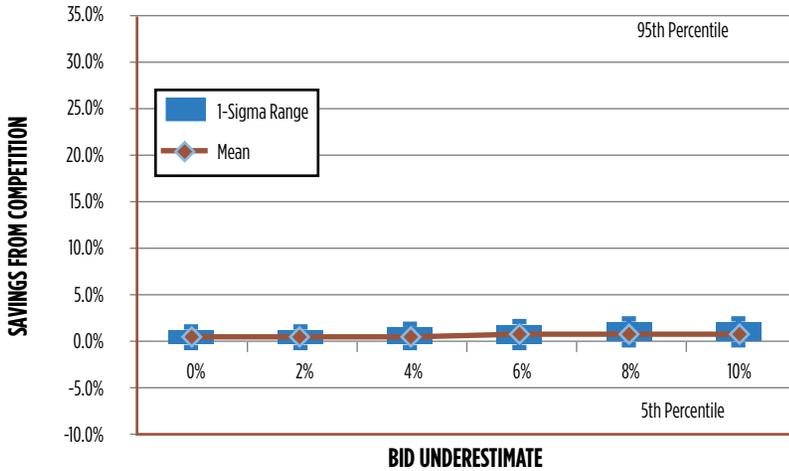
Note. A less experienced competitor will tend to have less accurate estimates and may underestimate final costs. As a competitor’s underestimate increases for a Fixed Price contract, the buyer enjoys a more favorable price than a more accurate bid from a sole-source seller.

FIGURE 9. UNDERBID-FIXED PRICE CONTRACT



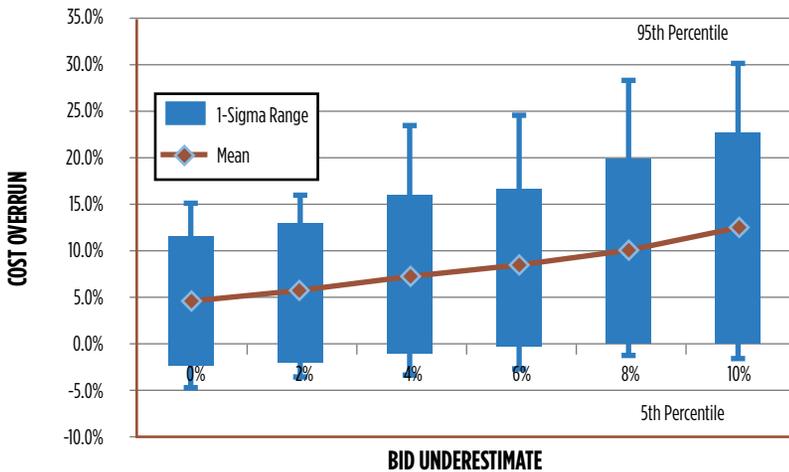
Note. A less experienced competitor will suffer reduced profits, or even losses, due to underestimated costs. Since competition will favor the lower bidder, competitive procurements will make seller losses more likely than sole-source procurements.

FIGURE 10. UNDERBID-COST REIMBURSABLE CONTRACT



Note. For a Cost Reimbursable contract, bid inaccuracy and bid underestimation provide little advantage for competition relative to sole-source procurement because the final price to the buyer includes any cost variation from the bids. Only the fee, or profit, paid to the seller varies—and only slightly.

FIGURE 11. UNDERBID-COST REIMBURSABLE CONTRACT



Note. Bid inaccuracy and bias toward underestimation can amplify cost overruns in Cost Reimbursable when comparing sole-source procurement to competitive procurement because competitive selection will favor the underestimated bid.

Figures 10 and 11 show the results for a CP contract. As with Case 2a, the effects of bid inaccuracy and bias in competitive procurement provide little savings to the buyer relative to sole-source procurement. Bid underestimation, however, has significant effects on cost overruns, which can threaten the program and disrupt future planning if not taken into account. Competitive procurement increases the effect relative to sole-source procurement because the competitive selection process favors the underestimated bid.

Cases 2a and 2b demonstrate that bid inaccuracy and bias can indeed lower the final cost to the buyer, but at the expense of the seller's profit on FP contracts, or of more likely cost overruns on CP contracts, both of which can put the entire program at risk. The Navy's A-12 acquisition program, which was cancelled in 1991, provides an example.

In 1984, a partnership between McDonnell Douglas and General Dynamics won the FP contract for the A-12 bomber with a bid of \$4.8 billion, substantially beating the \$5.9 billion bid of the partnership of Northrop and Grumman (Wilson & Carlson, 1995). Northrop and Grumman had prior experience with the key stealth technology required for the contract, while the winning bidder did not. Cost overruns and schedule delays began almost immediately after the contract was signed. Although it was an FP contract, the sellers could not absorb the cost increases and filed a Request for Equitable Adjustment for a price increase of \$1.47 billion, implying the losing bid of Northrop and Grumman more closely estimated the true costs. The DoD cancelled the program in 1991 due to these cost increases, spawning a lawsuit from the sellers alleging, in part, that the DoD had knowledge that the requirements were "unattainable" (Wilson & Carlson, 1995, p. W.10). The use of an FP contract with an underinformed competitor produced a contract price that seemed like a good deal at the time, but ultimately resulted in the cancellation of the program and spawned a lawsuit that continues today, two decades later.

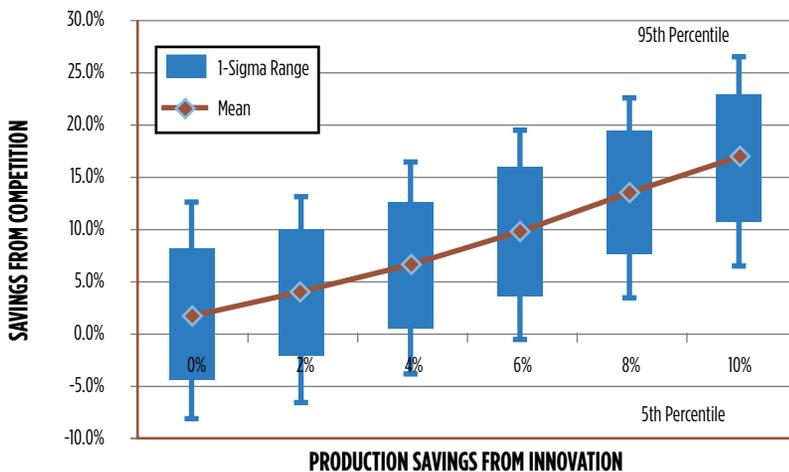
Thus far, the analysis has evaluated differences in competitor bidding characteristics while keeping the actual cost of development and production fixed. The next case examines the effects of competition where the sellers have differing design solutions or production processes that change the actual cost.

Case 3: Innovation

Innovation in design or production can create differences among sellers, resulting in true cost savings in the final product. Utilizing proven technology in a design, for example, might produce a less expensive product than a design that requires new technology development. Advanced manufacturing techniques or automated assembly could lower the production costs compared to existing manufacturing methods or manual assembly.

In Case 3, the analysis assumes that all of the sellers have a 5 percent standard deviation in the actual cost of their product and that one competitive seller has reduced the cost of production by up to 10 percent. Because innovation likely implies higher development costs, the analysis assumes that the seller with the lower production cost will also incur a 20 percent higher development cost, which as it turns out does not significantly affect the conclusions.

FIGURE 12. SAVINGS FROM COMPETITION AND INNOVATION



Note. Innovation in design or manufacturing can change the true cost. As the production savings of one competitive seller improve, the buyer benefits from competition relative to a sole-source seller without innovation.

Since all of the sellers in this case have accurate bid estimates (perfect knowledge of future costs), FP and CP contracts give the same results when comparing the cost of the competitive procurement to the sole-source procurement. Figure 12 shows the benefits that competitive

procurement provides over sole-source procurement when one competitor includes cost-saving innovations. Although the analysis assumes higher development costs, the savings during production and the competitive selection of the lowest cost seller overcome that disadvantage. Therefore, a buyer should favor competitive procurement over a sole-source procurement if any seller appears to offer innovative solutions that lower costs. The Evolved Expendable Launch Vehicle (EELV) program may provide an example.

Recently, the Air Force reinvigorated competition for space launch contracts under the EELV program (Leone, 2012). New entrants into this market, such as Space Technologies, Inc. (SpaceX), claim that they can provide launch services at lower costs than the current provider, United Launch Alliance, LLC. SpaceX expects its vertically integrated supply chain and a more efficient design will provide cost savings (Chaikin, 2012). Case 3 of this analysis indicates that the Air Force may reap true cost savings from this innovation-based competition. It remains unclear, however, whether this innovation can actually provide cost savings, or whether SpaceX has underestimated its cost as in Case 2b. While innovation may offer cost improvements, incumbent sellers in a defense market may have cost advantages over their competition due to their experience developing and producing similar products.

Case 4: Incumbent Advantages

In many defense markets, corporate consolidation has created oligopolies and monopolies, with a few companies competing for a limited number of defense programs. Corporate consolidation in many markets has also created strong incumbents who have much greater capabilities and experience producing their products than potential competitors. Two factors complicate the introduction of competition into a market with a strong incumbent. First, an incumbent's existing expertise and infrastructure provide a cost advantage over a new competitor. A new competitor may have to invest more in infrastructure and development to catch up.

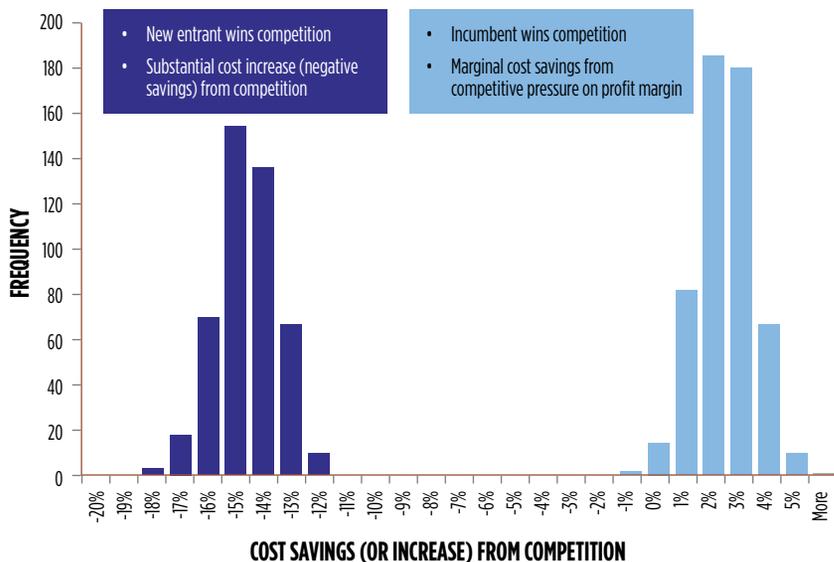
Second, incumbents will have a better ability to forecast the costs of a new product in their area of expertise. A new entrant, with less understanding of the challenges and complexities of a particular product, could easily underestimate the cost of development. In competitive procurement, these two factors can conspire to create the illusion of equal competitors. The incumbent will provide an accurate bid that

reflects its actual cost advantage, while the new entrant will likely have higher development costs and start higher on the production learning curve, but will underestimate the costs in its bid either out of ignorance or from competitive pressures. Both may decide to trim profit margins to better compete.

To represent this situation, the analysis for Case 4 assumes the following:

- The incumbent has a random bid inaccuracy of 5 percent (1-sigma) without a bias.
- The new entrant has a random bid inaccuracy of 10 percent (1-sigma) with an average underestimate of 15 percent.
- The incumbent starts lower on the production learning curve, making its production costs 15 percent lower than the new entrant.
- The new entrant has 20 percent higher development costs.
- The incumbent represents the sole-source seller, with no pressure to reduce profit margins from 10 percent.
- The incumbent and the new entrant compete and bid an 8 percent mean profit with a standard deviation of 1 percent profit.

Within these parameters, the model produces two families of potential outcomes for a CP contract, as shown in Figure 13. In cases where the incumbent wins the competition, the results reflect a slight (approximately 2 percent) cost savings relative to sole-source procurement, primarily due to the modeled competitive pressure to reduce profit margins. When the new entrant wins the competition, however, its cost disadvantages manifest themselves with substantially higher costs to the buyer relative to sole-source procurement from the incumbent. This illustrates the danger of forcing competition between a strong incumbent and a relatively inexperienced new entrant.

FIGURE 13. COST SAVINGS (OR INCREASE) FROM COMPETITION

Note. Histogram of outcomes from a competition for a Cost Reimbursable contract between an incumbent and a new entrant as compared to a sole-source procurement from the incumbent. When the incumbent wins the competition, competitive pressures on profit margin result in the slight cost savings relative to sole-source procurement. When the new entrant wins, its higher cost of development and production results in a substantial cost increase relative to a sole-source procurement.

The competition for the Future Imaging Architecture contract in 1998–99 provides an example of these Case 4 characteristics. To the surprise of many, the National Reconnaissance Office decided to open its next-generation imaging satellites to new competition, despite Lockheed Martin’s four-decade heritage as the sole provider of this technology. Boeing, looking to diversify its business, entered the competition and won, beating Lockheed Martin with a proposal determined to be cheaper and more innovative (Taubman, 2007).

Lockheed had a strong incumbent position, with more than \$30 billion invested by the government into its capabilities to produce imaging satellites. Boeing had little experience and vastly underestimated the cost, likely from a combination of ignorance and a desire to meet the government’s price targets. As Boeing realized development challenges, the subsequent cost growth ultimately caused the cancellation of the program at a loss of more than \$4 billion (Taubman, 2007).

Summary

This study analyzed four aspects of competition relevant to the DoD's effort to control and reduce the cost of MDAPs: Case 1, Competitive Pressure on Profit Margin; Case 2, Bidding Accuracy; Case 3, Innovation; and Case 4, Incumbent Advantages. The results call into question the justification of promoting competition on the basis of cost, and offer acquisition officials and policymakers insights into the outcomes they can expect from competition:

- Competition may pressure sellers to trim profit margins, but the defense industry already operates with low margins relative to its peers. Cost variation from other characteristics of competitive procurement, such as bidding uncertainty, overwhelms the modest cost reduction available from profit margins. When weighing competitive procurement against sole-source procurement, DoD acquisition officials should look beyond mere pricing pressures for benefits and risks.
- Unlike commercial markets, markets for MDAPs usually require sellers to set prices before they know the development and production costs. DoD acquisition officials should consider the potential inaccuracy of cost estimates when selecting contract type and recognize that competition increases the likelihood and severity of seller losses or cost overruns that could threaten program completion.
 - For FP contracts, inaccuracies in cost predictions have a more powerful and unpredictable influence on cost outcomes than the competitive pressures on profit margins, resulting in more cost than sole-source procurement in one-third of the cases. Savings to the buyer come at the expense of seller profits, which could threaten the ability of the seller to complete the program as profits diminish or losses increase.
 - Inaccuracies in cost predictions for CP contracts have little effect on final cost to the buyer, but can significantly increase cost overruns, threatening completion of the program and complicating future planning.

- Innovation in design or production offers the best rationale to promote competition over sole-source procurement to reduce costs to the buyer. Competitors that offer cost savings through more efficient design or advanced production processes can directly influence the final cost to the buyer. DoD acquisition officials face the challenge, however, of distinguishing between truly innovative solutions and the seller's overly optimistic cost estimates.
- Incumbent sellers may enjoy a significant advantage over new competitors entering the market. A new entrant's optimistic cost estimates, however, can win a competition against the accurate estimates of a lower cost incumbent, resulting in dramatically higher final costs to the buyer relative to sole-source procurement from the incumbent. When promoting competition against a strong incumbent, DoD acquisition officials must consider whether a new entrant offers innovation that can realistically overcome the cost advantage enjoyed by the incumbent.



Conclusions

Kendall (2012), in his memorandum entitled “Better Buying Power 2.0,” reemphasized competition to control and reduce costs. This study and a prior analysis of competition cast doubt on cost as a rationale for promoting competition in defense acquisition.

Harrison (2012) concluded that maintaining competition during a DoD acquisition will likely increase the total cost to the government. The higher costs in Harrison’s study result from redundant development and infrastructure costs and the inability of multiple competitors to benefit fully from the cost savings of production learning curves.

This study expanded on Harrison’s work by evaluating the effects of competitor differences and imperfect knowledge of development and production costs. While competition can pressure sellers to win business by trimming their profit margins, the already low profit margins in the defense industry limit this cost improvement to just a few percent relative to the cost of sole-source procurement.

Unlike commercial markets, where sellers typically set prices after completing product development and initial production, sellers in the defense acquisition market usually set their prices in advance of development and production. The inaccuracies and underestimation of these costs in a competition may appear to provide an initial cost benefit for an FP contract, but competitive selection of the lowest cost seller increases the chances of unsustainably low profits (or even losses) for the seller, threatening program completion and supplier health. Bid inaccuracy in a competition for a CP contract does not significantly affect the final cost to the government, but does amplify the chances of cost overruns relative to sole-source procurement, increasing planning challenges and threatening program viability.

Only when one or more competitors offer innovations that truly reduce the costs of development and production does the government substantially benefit from competition over sole-source procurement without the adverse side effects of cost overruns. Distinguishing between true innovation and optimistic cost estimating, however, can pose a challenge for DoD acquisition officials.

In defense markets with a strong incumbent that enjoys advantages of experience and expertise, forcing competition from less experienced new entrants can produce costly final outcomes. Incumbents will likely produce more accurate estimates reflecting their true cost advantages, while a new entrant out of ignorance or competitive pressure could significantly underestimate the effort required and produce a bid that appears to beat the incumbent. Unless the new entrant offers innovation that overcomes the incumbent's advantage, the cost of the competition could greatly exceed sole-source procurement from the incumbent.

Certainly, justification for promoting competition in DoD acquisition goes well beyond cost control. Competition promotes fairness and impedes collusion by treating all sellers equally. It reassures the citizenry that the government spends public funds effectively and fairly. Competition in DoD acquisition maintains consistency with the fundamentals of capitalism that drive the U.S. economy, and it can incentivize innovation in the defense industry to provide improved capabilities and lower costs to the DoD.

These and many other reasons can justify promoting competition, but the analysis herein and by Harrison make cost savings from competition an uncertain claim. The DoD may actually incur increased costs from competition, which—like a placebo—creates a powerful perception of cost control.

Author Biography

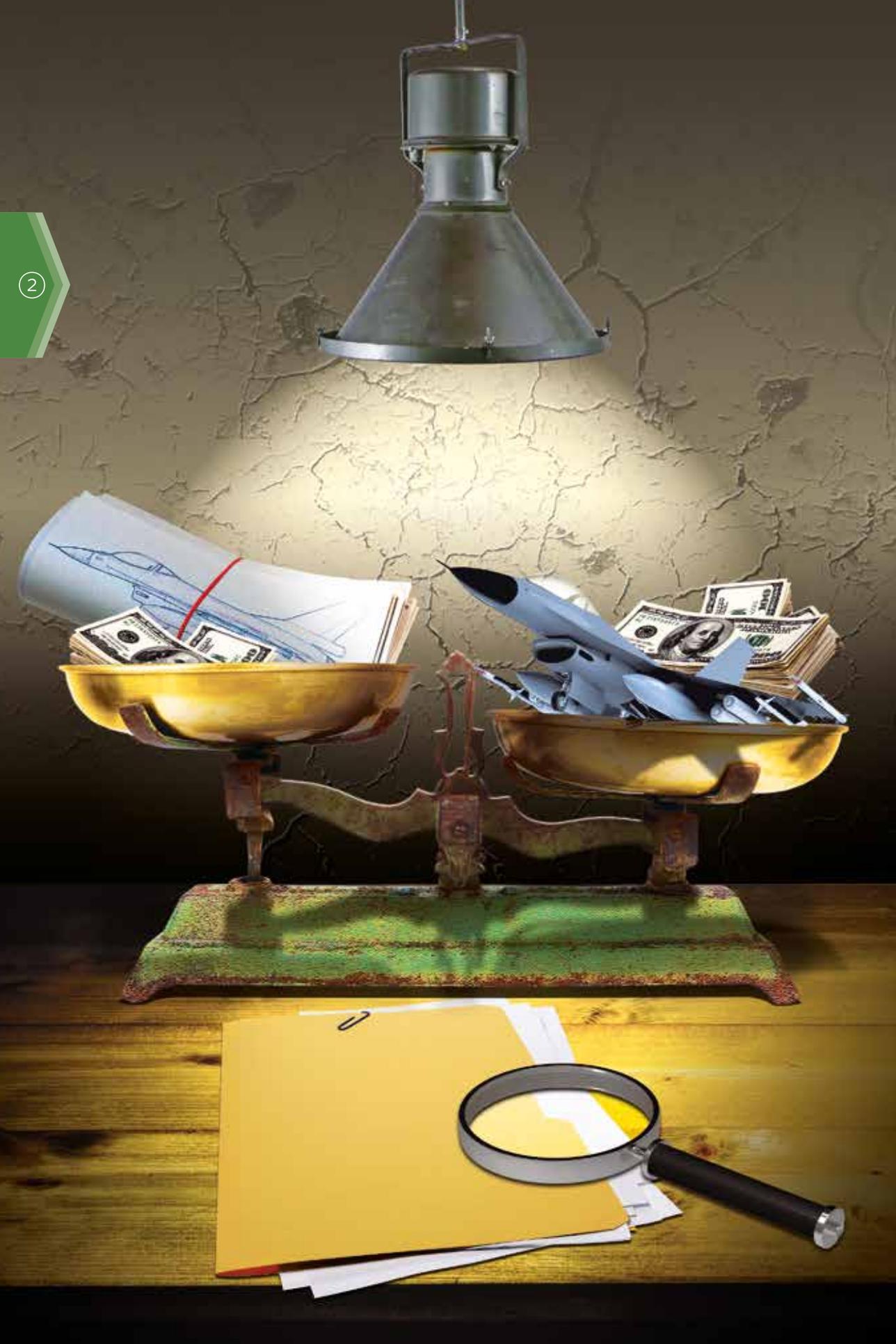


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Keywords: *Operating and Support (O&S), Life-Cycle Cost, Cost Analysis Improvement Group (CAIG), Cost Assessment and Program Evaluation (CAPE), Systems Acquisition*

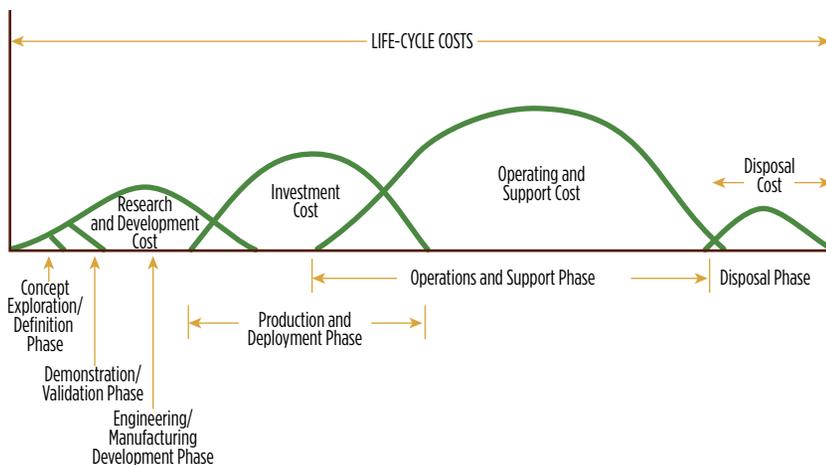
Investigation into the Ratio of Operating and Support Costs to Life-Cycle Costs for DoD Weapon Systems

 *Capt Gary Jones, USAF, Edward White, Lt Col Erin T. Ryan, USAF, and Lt Col Jonathan D. Ritschel, USAF*

Recent legislation, such as the Weapon Systems Acquisition Reform Act of 2009, requires a renewed emphasis on understanding operating and support (O&S) costs. Conventional wisdom within the acquisition community suggests a 70:30 cost ratio with respect to O&S and acquisition of an average weapon system. Using 37 Air Force and Navy programs, the authors estimate the mean overall ratio of O&S costs to acquisition costs to be closer to 55:45, although many weapon systems displayed significant deviation from this 55 percent average. Contributing factors such as life expectancy and acquisition strategy (i.e., new system or modification) affect this variance. Their research advises against using a single “one-size-fits-all” O&S/acquisition cost ratio for all major DoD weapon systems.

The Weapon Systems Acquisition Reform Act of 2009 and tightening Department of Defense (DoD) budgets have brought increased scrutiny to the life-cycle cost of major weapon systems acquisition. In a significant paradigm change, operating and support (O&S) costs are no longer relegated to the background for major acquisition decisions. For example, the DoD's 2013 budget plan considered mothballing the Block 30 variant of the Global Hawk to save money due to O&S costs, arguing that the venerable U-2 aircraft could meet theater commanders' needs for reconnaissance at less cost. As a result, it is imperative that we have an accurate understanding of the relative costs to operate and support DoD weapon systems.

FIGURE 1. NOTIONAL LIFE-CYCLE COSTS FOR A DOD WEAPON SYSTEM



Note. Figure 1 is illustrative versus quantitative. Adapted from *Operating and Support Cost-Estimating Guide*, published by the Office of the Secretary of Defense, Cost Analysis Improvement Group, 1992.

The cost profile of a typical DoD weapon system is shown in Figure 1 (Office of the Secretary of Defense Cost Analysis Improvement Group [OSD CAIG], 1992). The graph shows the four phases of a program's cost over its lifetime: research and development (R&D), procurement, O&S, and disposal, with O&S considered the most expensive of the four phases. The conventional wisdom of this 70:30 or "golden ratio" of O&S to acquisition cost (assuming negligible disposal cost) is that such a pattern holds for a majority of weapon systems. Therefore, Figure 1 has permeated

the DoD literature and acquisition schoolhouse training material. As a result, many levels of acquisition leadership reinforce the idea to managers and analysts that a cost ratio exists among the various stages of a weapon system's life, namely 70 percent for O&S and 30 percent toward acquisition (Carter, 2011).

Several studies by the Government Accountability Office (GAO) cite this 70:30 ratio or display charts to reflect this pattern (General Accounting Office, 2000a, 2000b; GAO, 2010, 2012). This research looks to determine the origins and accuracy of this ratio using historical O&S cost data. If actual O&S data do *not* support this ratio, then the veracity of this rule is called into question and might have significant implications in portfolio analysis and affordability analysis decisions that affect the broader DoD budget.

Terms and Definitions

Throughout this article, we define O&S costs in the same manner as the OSD CAIG (2007), now the Cost Assessment and Program Evaluation (CAPE) system's O&S cost:

Consists of sustainment costs incurred from the initial system deployment through the end of system operations. Includes all costs of operating, maintaining, and supporting a fielded system. Specifically, this consists of the costs (organic and contractor) of personnel, equipment, supplies, software, and services associated with operating, modifying, maintaining, supplying, training, and supporting a system in the DoD inventory. (p. 2-2)

For the definition of life-cycle cost (LCC), we turn to the *Defense Acquisition Guidebook* (DAG). The DAG, published by the Defense Acquisition University (DAU, 2012), defines LCC as follows:

For a defense acquisition program, life-cycle cost consists of R&D costs, investment costs, operating and support costs, and disposal costs over the entire life cycle. These costs include not only the direct costs of the acquisition program, but also indirect costs that would be logically attributed to the program. In this way, all costs that are logically attributed to the program are included, regardless of funding source or management control. (p. 7)

When dealing with the life of a weapon system, we discuss its service life and its life expectancy. According to the DAU online glossary, the service life describes the period of time “from first inception of the weapon until final phase-out” (DAU, 2012). Realistically, some costs incurred in the very early stages of a program, such as those before Milestone A, may not be fully captured due to the immaturity of the technology or divergence from some original concept. According to the 1992 and 2007 versions of the OSD CAIG (CAPE) *Operating and Support Cost-Estimating Guides*, life expectancy should include the phase-in period, a period of steady-state operations, and a phase-out or decommissioning period (OSD CAIG, 1992; 2007). The draft 2012 OSD CAPE *Operating and Support Cost-Estimating Guide* wasn’t as clear, though it stated that “[t]he O&S estimate should extend over the full life expectancy of the system,” alluding to the idea that life expectancy only pertains to the O&S phase. As we show in the next section, these terms appear to be used interchangeably even though they are clearly defined to be different in scope.

We make one last distinction before highlighting various studies that discussed acquisition cost to O&S cost ratio. In performing financial analyses, analysts and researchers need to account for inflation when comparing fiscal events that happened in different time periods. The Base Year (BY), or Constant Year, describes past and future costs as they would appear in a certain year of reference. Then Year (TY), or Current Year, describes costs as they would appear when costs are incurred or when purchases are made, usually taking into account the effects of inflation over time. In this research, we assume BY forms the basis for analysis in the literature reviewed, unless specifically noted.

Historical Research

To understand the origins of the 70:30 ratio, we conducted a literature search. What was remarkable about this review is how little empirical research appears to have been conducted on this topic, and how a recurring, authoritative set of assertions continues to propagate without independent evaluation or confirmation.

Two studies from the 1970s examined O&S cost ratios with respect to life-cycle costing. Fiorello (1975) states that the costs of ownership, “...in general make up over 50 percent of the LCC of aircraft weapon systems” (p. 5). Unfortunately, Fiorello provides no information on the

derivation of this percentage. In October 1977, the Comptroller General of the United States gave a report to the U.S. Senate Committee on Appropriations about O&S costs of new systems compared to the systems they are replacing (General Accounting Office, 1977). In Appendix IV, Part 2, this report shows the most recent cost estimate for a fleet of 800 F-18s, and shows that 42.2 percent of this fleet's LCC can be attributed to O&S costs. This information was based on an estimate that used the actual performance and logistics of the F-14 as an analogy to the F-18, and used an estimated life span of 15 years.

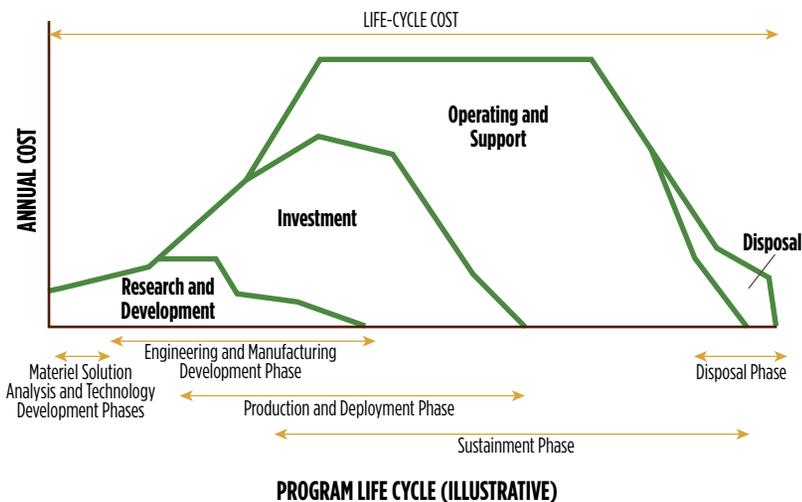
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In 1981, the Comptroller General of the United States delivered a report to Congress on logistics planning for the M1 tank (General Accounting Office, 1981). The report was aimed at convincing Congress that more funding should be spent on R&D and initial procurement to reduce the O&S costs, arguing “the costs of operating and supporting a system, such as the M1, may be 70 to 90 percent of the system's life-cycle cost” (p. 18). Like previous studies, the authors do not elaborate or indicate the source of this ratio information.

With the release of the *Operating and Support Cost-Estimating Guide* in 1992, OSD CAIG gave more official guidance regarding O&S cost estimates (OSD CAIG, 1992). This guide does not designate any particular ratio of O&S costs to acquisition costs, but does portray the customary program cost pattern during the various acquisition phases. Figure 1 originated within this 1992 guide, and many training materials have reproduced or mimicked this graph. Since 1992, the OSD CAIG has issued one other *Operating and Support Cost-Estimating Guide* (2007) and had intended to officially release another in 2012. We reviewed

the 2012 draft version, but the OSD CAPE *Operating and Support Cost-Estimating Guide* delayed final publication due to the impending release of the revised DoD 5000.4-M-1, *Cost and Software Data Reporting (CSDR) Manual (2007)*, to incorporate any policy changes therein. Figure 2, which first appears in the 2007 and also the 2012 draft OSD CAPE O&S Guide illustrates the slight change to Figure 1 from 1992. Neither of these versions of the guide includes any further information on cost ratios.

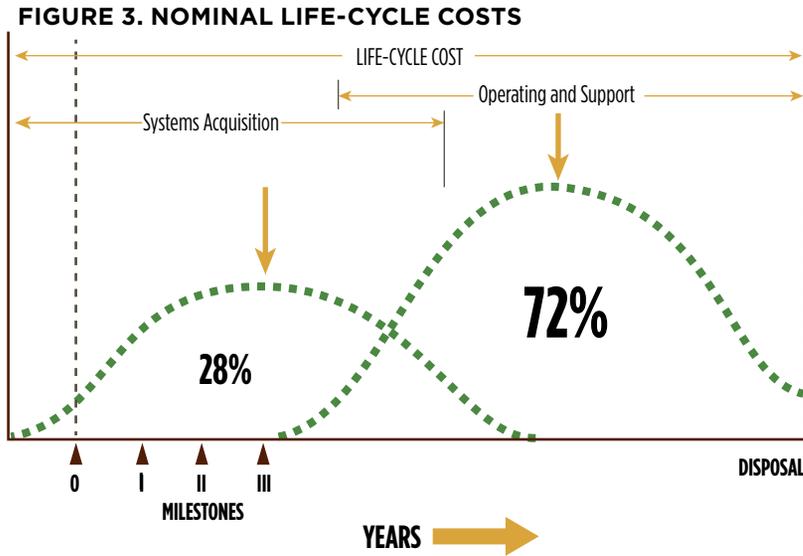
FIGURE 2. ILLUSTRATIVE SYSTEM LIFE CYCLE



Note. This figure depicts the ratio as nominal. Adapted from *Operating and Support Cost-Estimating Guide*, published by the Office of the Secretary of Defense, Cost Analysis Improvement Group, 1992.

In 1997, the Defense Systems Management College (DSMC) published its *Acquisition Logistics Guide*, in which it illustrates “the dominant role that logistics plays in system life-cycle cost” (DSMC, 1997), as portrayed in Figure 3. This is the first time a ratio with this level of specificity is provided (72 percent of life-cycle costs attributed to O&S). Unfortunately, the guide provides no details on how the percentages were obtained or derived. Figure 3 is replicated in four other sources: (a) a 2000 General Accounting Office report titled *Air Force Operating and Support Cost Reductions Need Higher Priority* (General Accounting Office, 2000a); (b) a 2003 General Accounting Office report on reducing Total Ownership Costs through setting requirements (General Accounting Office, 2003); (c) the American Institute of Aeronautics and Astronautics’ *Management of Defense Acquisition Projects* (Rendon,

Snider, & Allen, 2008); and (d) an acquisition research paper published by the Naval Postgraduate School entitled, *Total Ownership Cost—Tools and Discipline* (Naegle & Boudreau, 2011).



Note. Adapted from Figure 13-1 of *Acquisition Logistics Guide* (3rd ed.), Defense Systems Management College, 1997, p. 13-6.

In 1999, the Institute for Defense Analyses (IDA) produced a seemingly influential document that covered a presentation by a panel of representatives from the OSD, Naval Center for Cost Analysis, Air Force Cost Analysis Agency, and the U.S. Army Cost and Economic Analysis Center during the 32nd Annual DoD Cost Analysis Symposium (IDA, 1999). In this document, weapon system types are split out and presented in terms of their R&D, procurement, and O&S costs, where the information is available. Table 1 summarizes the information presented, which is cited in the Life-Cycle Cost article from the DAU's ACQuipedia Web site (Life-Cycle Cost, 2008).

For most system types, the percentages reflect what was considered at the time to be "typical" percentages of life-cycle costs. The exceptions were in the Rotary Wing Aircraft category, where the percentages came from the Comanche estimate in the 1997 Selected Acquisition Report (SAR), and the Missiles and Surface Vehicles categories, which did not specifically state what the percentages represent. However, we assumed them to be "typical" since no other discussion led us to believe

otherwise. The only two categories that come close to, or meet exactly, the 70:30 ratio are the Ships and Automated Information Systems (AIS) categories. The data from Table 1 appear to be the source for the *GAO Cost-Estimating and Assessment Guide* (GAO, 2009), and DAU's course material on BCF 106, Introduction to Cost Analysis (DAU, 2009).

TABLE 1. COST RATIOS BY WEAPON SYSTEM TYPE

System Type	R&D	Investment	O&S/Disposal
Space	18%	66%	16%
Fixed-Wing Aircraft	20%	39%	41%
Rotary-Wing Aircraft	15%	52%	33%
Missiles	27%	33%	39%
Electronics	22%	43%	35%
Ships ^a	1%	31%	68%
Surface Vehicles	9%	37%	54%
AIS ^b		30%	70%

Note. Data represent point estimates, without accompanying statistical data. No further information was obtainable. Adapted from *Status of DoD's Capability to Estimate the Costs of Weapon Systems: 1999 Update*, published by the Institute for Defense Analyses, 1999.

^aMost ship design costs are included in production cost of lead ship of a class. ^bAvailable data preclude split of pre-O&S costs into R&D and Investment categories.

For the past 15 years or so, the GAO consistently cites or mentions this 70:30 ratio of acquisition cost to O&S cost (General Accounting Office, 2000a). Specifically:

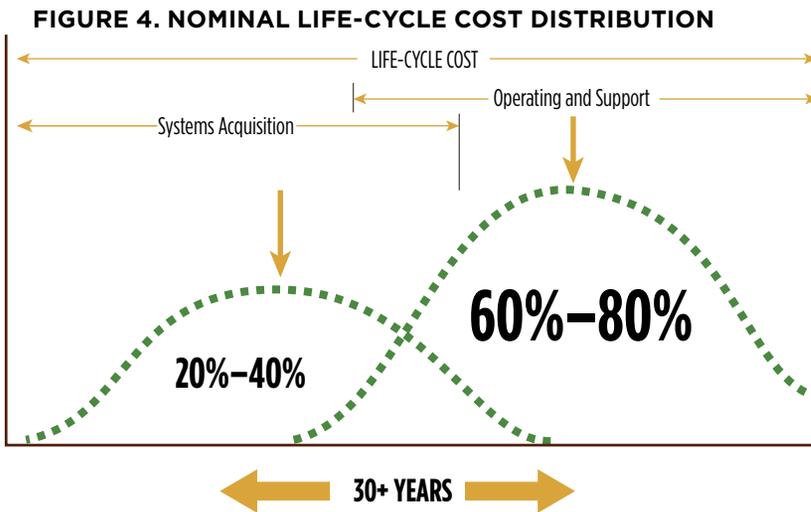
...operating and support costs include those for fuel, repair parts, maintenance, and contract services, as well as the costs of all civilian and military personnel associated with a weapon system. History indicates that these costs can account for about 70 percent of a system's total life-cycle costs. (p. 3)

With respect to the Army (General Accounting Office, 2000b):

While some attention has been given to the cost of operating and supporting a weapon system after it is fielded, responsibility for these functions after systems are fielded generally shifts to other Army agencies such as maintenance depots, software support facilities, and operating bases. DoD has long identified this division of responsibility as a key cause of higher weapon system

operating and support costs, which are generally estimated to account for about 60 to 70 percent of a system's total life-cycle costs. (p. 7)

GAO is not the only recent source to focus on this particular ratio value. In an article in the *Defense AT&L* magazine on designing systems for supportability, Dallosta and Simcik (2012) state that, "...total ownership costs incurred during the operations and support phase may constitute 65 percent to 80 percent of total life-cycle cost." Figure 4 accompanies this quote within their article, but once again, no information is provided on how that figure was derived or percentages allocated.



Note. Adapted from *Designing for Supportability: Driving Reliability, Availability, and Maintainability In While Driving Costs Out*, by P. M. Dallosta and T. A. & Simcik, 2012, pp. 34-38.

The history of O&S cost ratios, as presented in the reports and studies discussed in this article and summarized in Table 2, often show the plausibility of 70 percent of a total weapon system's LCC representing O&S costs, especially in the more recent reports. In addition, relatively few of the O&S statistics cited in the Table 2 literature review appear to be grounded in historical O&S data. Instead, we find they are based on estimates of how long a weapon system will last and how costly it is to repair, replace, sustain, maintain, or operate. By extracting actual O&S cost data and accounting for the increased length of current weapon systems, serious researchers can readily determine what this true percentage should be.

TABLE 2. SUMMARY OF FINDINGS FROM LITERATURE REVIEW

Source	O&S Portion of LCC
Fiorello, M., <i>Getting "Real" Data for Life-Cycle Costing</i> , 1975	50%
General Accounting Office, <i>O&S Costs of New Weapon Systems Compared with Their Predecessors</i> , 1977	42.2%
General Accounting Office, <i>Logistics Planning for the M1 Tank</i> , 1981	70-90%
OSD CAIG, <i>O&S Cost-Estimating Guide</i> , 1992	78%, 84%
DSMC, <i>Acquisition Logistics Guide</i> , 1997	60-80%, 72%
IDA, <i>Status of DoD's Capability to Estimate the Costs of Weapon Systems: 1999 Update</i> , 1999	Varies by Type
General Accounting Office, <i>Higher Priority Needed for Army O&S Cost Reduction Efforts</i> , 2000	60-70%
DoD, <i>Weapon Systems Acquisition Reform Act of 2009</i>	60-75%
General Accounting Office, <i>Cost Estimating and Assessment Guide: Best Practices for Developing and Managing Capital Program Costs</i> , 2009	Varies by Type
General Accounting Office, <i>Littoral Combat Ship: Actions Needed to Improve Operating Cost Estimates and Mitigate Risks in Implementing New Concepts</i> , 2010	70%
General Accounting Office, <i>Improvements Needed to Enhance Oversight of Estimated Long-Term Costs for Operating and Supporting Major Weapon Systems</i> , 2012	70%
Dallosta & Simcik, <i>Designing for Supportability: Driving Reliability, Availability, and Maintainability In While Driving Costs Out</i> , 2012	65-80%

Analysis and Results

To collect actual O&S expenditures, we utilized the Naval Visibility and Management of Operating and Support Costs (VAMOSOC) system for the Navy, and the Air Force Total Operations Cost (AFTOC) system for the Air Force. We excluded Army programs from the analysis because the Army's Operating and Support Management Information System is currently unable to allocate major cost elements (including personnel and fuel) to individual systems. Acquisition costs were collected from SARs in the Defense Acquisition Management Information Retrieval system. The analysis was limited to Acquisition Category I (ACAT I) programs. [Note. These are programs that exceed \$365 million (BY 2000) in Research, Development, Test, & Evaluation (RDT&E) funding or \$2.19 billion (BY 2000) in Procurement funding, or have been designated by Congress or the DoD as an ACAT I program due to high visibility or interest.] Generally, costs associated with necessary additions or changes for each system were included in the SARs, mostly under the Military Construction appropriation. Infrastructure costs were not necessary for many systems since some new and many modification programs do not require new facilities or structures.

The data were screened using inclusion criteria for the research database. Each program had to have fielded operational units and have a stable period of O&S costs. This stability provided some assurance that the program was past the initial ramp-up in fielding and was able to produce a realistic estimate of recurring annual costs. Therefore, each program needed to have produced at least 10 percent of the planned procurement quantities. Early in production, contractors may run into difficulties that could change the production schedule or increase costs due to factors unknown when production commences. Until these issues are resolved, the acquisition is likely to have a greater risk of increasing significantly.

The final database consisted of 37 programs with operational data from 1989 through 2010. Table 3 lists all the programs analyzed, organized by the lead Service component. We grouped these programs into eight different categories: Missiles, Cargo/Tanker Aircraft, Fighter Aircraft, Helicopters, Ships, Electronic Equipment, Unmanned Aerial Vehicles, and Tilt-Rotor Aircraft. We determined these categories by similarities or unique capabilities from other weapon systems; for example, the tilt-rotor aircraft, which is a combination of helicopter and cargo aircraft.

TABLE 3. FINAL DATABASE-LIST OF PROGRAMS ANALYZED

Ships	Service	Cargo/Tanker	Service
AOE 6	Navy	C-130J	Air Force
CVN 68 (By 1974/1975)	Navy	C-17A (BY 1996)	Air Force
CVN 68 (By 1976)	Navy	E-2C	Navy
DDG 51	Navy	JSTARS (BY 1998)	Air Force/Army
LHD 1	Navy	KC-135R	Air Force
LPD 17	Navy		
MHC 51	Navy	Missiles	Service
SSGN	Navy	AMRAAM	Air Force/Navy
SSN 21	Navy	JASSM	Air Force/Navy
SSN 774	Navy	AIM-9X	Navy/Air Force
STRATEGIC SEALIFT	Navy	JSOW (AGM-154)	Navy/Air Force
T-AKE	Navy	Helicopters	Service
T-AO 187	Navy	C/MH-53E	Navy
		MH-60R	Navy
		(BY 2006)	
		MH-60S	Navy
Fighters	Service		
F-16 C/D	Air Force	UVA	Service
F-22 (BY 2005)	Air Force	GLOBAL HAWK	Air Force
JPATS (BY 2002)	Air Force/Navy	PREDATOR	Air Force
AV-8B REMAN	Navy		
EA-18G	Navy	Electronic Equipment	Service
F/A-18 E/F	Navy	NESP	Navy
F-14D	Navy		
T-45TS (BY 1995)	Navy		
Tilt-Rotor	Service		
V-22 (BY 2005)	Navy		

From the information in the VAMOSC and AFTOC systems, we calculated an actual Annual Unitized O&S Cost (AUC) per program. This metric describes the cost to operate and sustain one unit (individual plane, ship, etc.) per year. Generally speaking, the AUC is calculated by dividing the total annual O&S cost for a system by the number of units operational in the year. [Note. For a more complete description of the AUC methodology, see Ryan, Jacques, Colombi, & Schubert (2012).] We approximated the total O&S cost of a particular program by multiplying the AUC by the number of units procured by the life expectancy of the system. It is important to note that some costs that can be logically attributable to programs, such as the maintenance of simulators and training devices, may or may not be included properly in the VAMOSC and AFTOC systems. This uncertainty has the potential for understating O&S costs.

TABLE 4. SUMMARY OF DIFFERENCES IN LIFE EXPECTANCY FROM VARIOUS VERSIONS OF THE OSD CAIG O&S COST-ESTIMATING GUIDE

	1992	2007	2012 (draft)
Cargo	25	25	30-40
Bomber	25	25	30-40
Tanker	25	25	30-40
Fighter	20	20	20-30
Helicopter	20	20	20-30
Small Missiles	15	15	10-20
Large Missiles	20	15	10-20
Electronic Equipment	10	10	10-30
Ships	20-40	20-40	20-40
Ground Combat Vehicles	20	20	20
Unmanned Aerial Vehicles	N/A	N/A	15-25

Table 4 shows how the life expectancies have changed over the years. As illustrated, life expectancy has increased for most systems, most notably for the Cargo/Bomber/Tanker and Electronic Equipment categories. Since one of the unknowns in this analysis is the expected life of each program, we used the draft 2012 OSD CAPE *Operating and Support Cost-Estimating Guide*, coupled with program-specific information

found in SARs, to develop specific platform service life ranges. Table 5 shows these life expectancy ranges. From these estimates, we chose the highest and lowest expectancies to use as an upper and lower bound.

TABLE 5. LIFE EXPECTANCIES FOR VARIOUS WEAPON SYSTEMS

	High (yrs)	Low (Yrs)		High (yrs)	Low (Yrs)
Ships			Cargo/Tanker		
AOE 6	40	20	C-130J	50	25
CVN 68 (BY 1974/1975)	50	20	C-17A (BY 1996)	40	25
CVN 68 (BY 1976)	50	20	E-2C	40	20
DDG 51	40	20	JSTARS (BY 1998)	40	25
LHD 1	40	20	KC-135R	40	25
LPD 17	40	20	Missiles		
MHC 51	40	20	AMRAAM	40	10
SSGN	40	20	JASSM	20	10
SSN 21	40	20	AIM-9X	33	10
SSN 774	40	20	JSOW (AGM-154)	30	10
STRATEGIC SEALIFT	40	20	Helicopters		
T-AKE	40	20	C/MH-53E	30	20
T-AO 187	40	20	MH-60R (BY 2006)	30	20
Fighters			MH-60S	35	20
F-16 C/D	30	20	UVA		
F-22 (BY 2005)	30	20	GLOBAL HAWK	34	15
JPATS (BY 2002)	30	20	PREDATOR	25	15
AV-8B REMAN	30	20	Electronic Equipment		
EA-18G	30	20	NESP	30	10
F/A-18 E/F	30	20	Tilt-Rotor		
F-14D	30	20	V-22 (BY 2005)	43	30
T-45TS (BY 1995)	30	20			

Before performing any calculations, we standardized the annual cost data to Fiscal Year (FY) 2010 using OSD inflation indices. Once normalized to FY 2010, the costs per year were de-escalated back to the base year of the program. For certain programs that reported more than one baseline year due to changes or milestones in the program, for example, the V-22 Osprey, we used the most recent SAR report. Multiplying the actual AUC by the highest (or lowest) life expectancy for a program and by the number of units to be procured (as given by the last or most recent SAR) resulted in our estimate of O&S costs. To calculate the ratio of O&S to LCC, we divided the O&S cost estimate by the total of the O&S cost estimate and the acquisition actual cost. Table 6 provides the summary statistics for all weapon systems studied.

TABLE 6. SUMMARY STATISTICS FOR ALL PROGRAMS

	Mean	Median	Standard Deviation
High	55.92%	62.57%	22.74%
Low	43.85%	48.33%	21.96%
Average	49.88%	54.09%	23.02%

For all programs as a whole, we estimate an approximate range of 44–56 percent (mean) or 48–63 percent (median) for the proportion of life-cycle costs attributable to O&S. The “high” end of the range (using the upper estimate of life expectancy) went from 4.91 percent (Joint Standoff Weapon, or JSOW) to 88.79 percent (KC-135R), with a standard deviation of 22.48 percent. The “low” end (using the lower estimate of life expectancy) started at 1.69 percent (JSOW) and went through 83.19 percent (KC-135R), with a standard deviation of 21.56 percent. The large standard deviation associated with this overall range highlights vast differences among the weapon systems in terms of O&S costs and emphasizes the need to further reduce the set of programs into different types.

In Table 7, we segregate the weapon systems into eight categories, and then for the Ship and Cargo/Tanker groups we performed two additional analyses. The Ships category includes 13 ships, three of which consisted of submarines. Of these three, two fell outside two standard deviations from the mean—the SSN 21 and the SSN 774. The SSN 21 O&S proportion was estimated to fall within 11.65 percent and 20.87 percent, and the SSN 774 was estimated to fall between 12.65 percent and 22.46

percent. Because these relatively low O&S percentages affected the mean value for the whole group, we reran the Ship group without the submarines and presented that information as well.

TABLE 7. SUMMARY OF O&S COST PERCENTAGES BY TYPE OF SYSTEM

Platform	Mean	Median	Standard Deviation
Ships	48.21%	51.12%	18.14%
Ships – No Submarines	53.26%	53.12%	13.13%
Fighter Aircraft	52.99%	51.46%	15.65%
Cargo/Tanker Aircraft	65.15%	61.73%	13.98%
Cargo/Tanker – No KC-135R	59.94%	59.55%	9.68%
Missiles	8.35%	6.56%	7.51%
Helicopters	70.73%	70.13%	5.70%
Unmanned Aerial Vehicles	71.56%	71.56%	9.39%
Electronic Equipment	15.53%	15.53%	9.60%
Tilt Rotor Aircraft	65.03%	65.03%	5.77%

For the Cargo/Tanker group, five airframes were included in this category—four Air Force and one Navy. One program stood out as anomalous in this group—the KC-135R. Overall, the ratios for this category were 59.19 percent–71.11 percent (mean); and 54.20 percent–70.30 percent (median). The KC-135R range was 83.19–88.79. Although the upper estimate for the KC-135 fell within two standard deviations of the mean and median, the estimate for the low end exceeded two standard deviations above both measures. As with the Ship category, we removed this outlier from the group and reran the analysis. Lastly, although we did determine a range of the expected O&S proportion of LCC for electronic systems, we cannot in good faith determine this range to be representative for other electronic systems given we only had one data point in this category.

Since the work performed on this database seemed to show a possible connection between high O&S proportions and variant/modification programs, an additional analysis was performed on all newly developed systems. This is presumably due to the fact that the initial acquisition

cost of a plane, for instance, is included in the “new” estimate, but not included in the “modification” estimate since the aircraft has already been purchased. The resulting list included 22 systems. The ranges for O&S proportions for this group were 35.09 percent–47.00 percent (mean); and 36.97 percent–53.98 percent (median). The decreases in proportions from the larger group of systems, including variant and modification programs, seem to lend some credence to the notion that new systems will have more life-cycle costs devoted to acquisition than to sustainment. Table 8 summarizes the results.

TABLE 8. SUMMARY STATISTICS FOR NEW PROGRAMS

	Mean	Median	Standard Deviation
High	47.00%	53.98%	23.60%
Low	35.09%	36.97%	21.27%
Average	41.04%	45.84%	22.99%



Discussion and Conclusions

2

To make informed decisions regarding the maintenance and lifetime cost of our nation's weapon systems, leaders and portfolio managers need to have the right information at the right time. The DoD has accumulated valuable information about its sustainment costs through systems like AFTOC and VAMOSC. By tapping into this historical information, analysts and decision makers can better understand what portion of a weapon system's LCC can be attributed to acquiring the weapon system and what portion can be attributed to operating and supporting it.

The notion of O&S costs being 70 percent of LCC has been circulating around the DoD acquisition community for more than 35 years, and has repeatedly been emphasized in several recent GAO reports. The origin of this 70:30 ratio comes from an amalgamation of *estimates* of the O&S weapon systems' costs given by program offices or other official sources, such as SARs. However, by analyzing the *actual* sustainment costs in VAMOSC and AFTOC, the 70 percent O&S to 30 percent Acquisition cost ratio for a "typical" DoD weapon system appears not to be valid. Our data suggest that O&S costs are quite varied, with a mean of 55 percent.

Not only does the conventional wisdom regarding this fundamental LCC ratio appear to be incorrect, but the tendency to reduce the life-cycle costs of all DoD weapon systems down to a single ratio with respect to acquisition cost is impractical and imprudent. Although the average percentage of O&S costs observed fell around 50–55 percent of LCC, we noticed significant deviations from this percentage. Not only did individual weapon system's ratios vary from this percentage, but also entire categories of systems. Both of these observations suggest a peanut butter spread of one ratio of acquisition to sustainment is too simplistic. The differences within certain categories or subcategories, such as Ships and Submarines, illustrate the need to further distill these groups into more meaningful and homogeneous types of systems before assigning a typical O&S/Acquisition cost ratio.

Another interesting item to come out of this research was the variable nature of life expectancies itself. As shown earlier in Table 4, many weapon systems categories have experienced an increase in their recommended life expectancies over the past two decades. Fighter platforms expected to be operational for 15 years, e.g., the F-15, are still around almost 30 years later. A look at the actual useful lives as well as the

expected lives of our weapon systems has shown that not only are we capable of sustaining our weapon systems far beyond their intended lives, but we are able to extend the capabilities of existing naval vessels and airframes through modification. This can have a profound impact on the costs to sustain these systems for a longer duration. As these systems continue to age, additional research should be conducted to monitor actual O&S costs.

By illustrating the variability of life-cycle proportions among weapon systems categories, we have shown a more realistic picture of what program analysts and portfolio managers can expect in terms of sustainment costs. Although beyond the scope of our work, perhaps future studies can drill down to speculate or reason why different sorts of systems appear to have such different cost ratios. This research has begun to open a window into the real effects of acquisition strategy on life-cycle costs. In the face of looming budget cuts over the next decade, leaders across the DoD and Congress are struggling to make tough decisions regarding our nation's arsenal. Only with a full understanding of how our acquisition decisions affect our long-term sustainment costs can we make the right decisions on what capabilities are needed, how we will acquire those capabilities, and how we will maintain those capabilities.



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Keywords: *DoD, Acquisition, Vulnerability Market, Reverse Auction, Metric*

Strengthening DoD Cyber Security with the Vulnerability Market

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Every year, the Department of Defense (DoD) upgrades its information technology systems, allows new applications to connect to DoD information networks, and reconfigures the enterprise to gain efficiencies. While these actions better support the warfighter and satisfy national security interests, they introduce new system vulnerabilities waiting to be exploited. Often, these vulnerabilities are discovered only after the system has already deployed, where costs to fix are much larger. This article recommends the DoD adopt an economic strategy called the vulnerability market, or the market for zero-day exploits, to enhance system Information Assurance. Through the mutual cooperation between industry and the military in securing information, the DoD optimizes security investments, secures critical information, and provides an effective and resilient warfighting capability.



To save money, increase automation, and facilitate information sharing, the Department of Defense (DoD) is increasingly acquiring new information system(s), or IS. These new systems are more complex, interconnected, and interdependent than older systems in the DoD inventory. With these new capabilities comes a negative externality; the more complex a system is, the more difficult it is to secure. Faced with this reality, the United States is making a significant investment in cyber security. In the years between 2004 and 2009, the annual federal cyber security investment grew from \$4.2 billion to \$7.3 billion (a 58 percent increase). The augmented investment in cyber security focuses on establishing a front-line defense to prevent intrusions, integrating intelligence into cyber security, and shaping the future environment by enhancing research, development, and education. One gaping hole in this strategy is a focus on acquiring systems that are secure by design. This article is an analysis of that gap and investigates whether the integration of a vulnerability market (VM), or the market for zero-day exploits, increases overall DoD cyber security and lowers the total cost of ownership for acquired systems.

The Prevalence of Vulnerabilities

Historically in the DoD, as budgets get tighter, IS aggregate. This phenomenon occurs primarily to offset the expense of maintaining a large workforce by automating much of the work accomplished by individuals. These systems also aggregate because of technological advances that reduce their physical footprint and required operations and maintenance (e.g., virtualization). As a consequence of aggregation, an increase in the number of automated processes drives an increase in the quantity and complexity of IS. Unfortunately, as the number, complexity, and size of systems increase, the prevalence of flaws also increases.

A common measure of the complexity of a system is calculated by enumerating the amount of software lines of code (SLOC). In 2010, a RAND study noted large code bases typically indicate a rate of one defect for every thousand lines of code (Landree, 2010). By applying this defect rate to two widely utilized operating systems—Windows Vista and Debian Linux—there would be approximately 50,000 defects in the Microsoft Windows Vista Operating System, and 200,000 defects in Debian Linux (Marchenko & Abrahamsson, 2007). Applying this defect rate to the Navy DD(X)'s 10 million SLOC, there may be as many as

10,000 defects. While only a fraction of these defects would allow access to the IS and lead to unauthorized system control, an entirely defect-free IS is realistically impossible to achieve.

DoD's Information Security Efforts

In response to the enormity and potential consequences of a state-sponsored or independent hacker exploiting critical system vulnerabilities, the DoD relies on a concept called “Defense-in-Depth.” Defense-in-Depth is the DoD approach to distributing system-wide exploitation risk across multiple levels of information security. The levels integrated in this shared-risk environment, according to Department of Defense Directive (DoDD) 8500.01E, are: “people, technology, and operations; the layering of IA [information assurance] solutions within and among IT [information technology] assets; and, the selection of IA solutions” (DoD, 2002). Stated simply, by applying information security tools across multiple boundaries of the DoD enterprise, exploiting a vulnerability at the interior of the network is increasingly difficult.

In the cyberspace domain, exploiting a system can be categorized as targeted or indiscriminate. Indiscriminate attacks are those not focused at a particular entity; rather, they seek to exploit security vulnerabilities across many systems. These attacks are often thwarted by several layers of the DoD enterprise network security as the level of system fingerprinting and malware complexity is limited and easily recognized. On the other hand, a targeted attack is executed by a highly skilled individual(s) who seek to attack a specific system. Because the target is specific, the attacker will become an expert on its network architecture, hardware and software components, and intrusion safeguards.

As layers of network defense increase, attack sophistication grows as well. According to an October 2011 report released by the U.S. Government Accountability Office (GAO), 20 federal agencies reported an increase in the amount of targeted and indiscriminate cyber attacks against critical assets. In fact, these agencies (one of which was DoD) reported a 25 percent increase in the number of reported intrusions from 2009 to 2010 (GAO, 2011). Unlike a medieval castle where an enemy can defeat a single layer of defense without compromising the entire castle, cyber security is defeated if a single available attack vector is successfully identified and exploited.



In November of 2007, the DoD established the *DoD Information Assurance Certification and Accreditation Process (DIACAP)* policy, captured in Department of Defense Instruction (DoDI) 8510.01 (DoD, 2007). The purpose of DIACAP is to provide a risk management process for IA and detail IS certification and accreditation requirements throughout a system's life cycle. It provides a step-by-step process to assure DoD systems are protected and defended "by ensuring their availability, integrity, authentication, confidentiality, and nonrepudiation" (DoD, 2002). DIACAP was created out of necessity as the former policy, DITSCAP (DoD Information Technology Security Certification and Accreditation Process), was ill-equipped to handle information systems in the net-centric environment. Improving upon DITSCAP, DIACAP established standardized IA controls, a schedule to review an individual system's IA status, and testable metrics to measure security effectiveness. Although this is seen as an improvement over DITSCAP, DIACAP has flaws.

DIACAP measures security effectiveness according to a prescribed timeline (every 1 to 2 years). Should a new vulnerability be discovered, verification of a security patch installation could then take months before the next IA inspection. Furthermore, the IA controls monitor known system vulnerabilities and do not take into account threat monitoring, incident detection, or incident response. DIACAP is a risk mitigation process that is more reactive than proactive when it comes to system vulnerabilities. It works well for new IS acquisitions as they are tested against the latest vulnerability database with the latest tools. As systems mature, DIACAP becomes less effective as threat monitoring takes a back seat to operations. Currently, efforts are underway to revise how the DoD handles certification and accreditation of its systems. These efforts are resulting in a revision of the DoDI 8500.02 series, which will mandate the use of the DoD Information Assurance Risk Management Framework (DIARMF). While DIARMF addresses many shortcomings, it will be years before the process is fully implemented.

Penetration testing, or authorized hacking, is designed to evaluate the vulnerability of a system to indiscriminate and targeted cyber attacks. The goal of penetration testers is to obtain unauthorized privileges by exploiting flaws in system design or implementation (Chairman of the Joint Chiefs of Staff Instruction [CJCSI] 6510.01, 2011). Other incidents that penetration testing detects include denial of service, malware

infection, and malicious code. Unfortunately, penetration testing can never prove a system is void of vulnerabilities. Penetration testing only identifies the presence of known vulnerabilities.

Following the fielding decision for new information systems, organizations schedule periodic red and blue team penetration exercises to test system security. These tests prove effective across the entire DoD network; however, team manpower makes it difficult to assess the majority of systems. In an effort to offset the manpower shortfall, the DoD is embarking on the development of several “cyber test ranges” to simulate real-world conditions in a controlled environment. Two such environments in development are known as the DoD Information Assurance Range and the National Cyber Range.

The assemblage of the DoD defense-in-depth strategy—DIACAP framework, penetration test tools, and cyber test ranges—represents the government’s dedication to identify known system vulnerabilities. Even with these monumental fiscal and personnel investments, the DoD remains incapable of measuring the security of a system with a meaningful metric.

Vulnerability Markets

Prior to 1997, the Federal Acquisition Regulation (FAR) prohibited use of auctions to establish contracts between the government and supplier. Language in the FAR specifically prohibited auction techniques that indicate to an offeror a cost that it must meet to obtain further consideration; advise an offeror of its price standing relative to another offeror; and otherwise furnish information about other offerors’ prices (General Services Administration [GSA], 2005, pt. 15.610[e][2]). In 1997, the FAR was rewritten, and the Office of Management and Budget (OMB) removed the ban on government involvement in auctions. Ever since, DoD has taken advantage of the e-commerce auction marketplace to procure a variety of supplies. Some examples of DoD auction procurements include:

- Navy procuring aircraft and ship parts;
- Army purchasing IBM ThinkPads, saving 40 percent off the GSA price;

- Army purchasing spare parts for the Patriot Missile system; and
- Air Force acquiring computer equipment, saving 27 percent.

Additionally, the OMB reported that the Environmental Protection Agency conducted 94 reverse auctions in 2007 and saved almost 14 percent from the government estimate (OMB, 2008). In tight fiscal times, where saving money is the lifeblood of any program, the savings achieved by using online auctions are hard to ignore. Although these auctions have only been employed for the procurement of physical items, the model is applicable toward purchasing software security vulnerabilities in the cyber domain.

Vulnerability Market Examples

The VM emerged as a way for security researchers and hackers to disclose vulnerabilities for financial gain. In the past decade, three VM models surfaced, which form the majority of vulnerability events: the bug challenge, the bug bounty, and the bug auction.

Bug Challenge

In a bug challenge, the simplest of the VM models, a vendor offers a reward for reporting vulnerabilities related to a particular product. Unlike the other two models described in this section, the bug challenge is administered directly by the vendor and has no intermediary acting as a clearinghouse. This model has a couple of major flaws. First of all, prizes for a vulnerability are not market-driven and may not accurately reflect its actual value (Schwalb, 2007). As finding vulnerabilities involves a significant investment, researchers could sell their finds on the black market for a much higher price. Secondly, bug challenges are often by invitation-only, where the researchers are placed on contract and required to sign nondisclosure agreements. By restricting the researchers, the vendors have the ability to keep any vulnerabilities secret and subsequently refuse to patch the products.

For 3 weeks in 2000, the Secure Digital Music Initiative (SDMI) conducted a public bug challenge aimed at breaking SDMI watermarking technologies. The challenge was invitation-only and offered a cash prize for any team that could win any of the six challenges posed. The ultimate goal was to identify an authentic copy of the audio file to combat online

music piracy. This event was sanctioned by the music recording industry and required all participants to sign a nondisclosure agreement prior to accessing SDMI data files (Craver, 2001).

Bug Bounty

Differing from a bug challenge, a bug bounty is conducted by a vendor seeking to pay researchers to identify malicious code used to infiltrate their systems. The goal of this market model is for a vendor to flush out an undetected vulnerability currently being exploited by hackers. Placing a bounty on vulnerabilities is, by nature, a reactive countermeasure to unsecure software. Recognizing the benefit of this model, the company that developed the popular Web browser Mozilla instituted the Mozilla Security Bug Bounty. Starting in 2004, the Bug Bounty sought to reward individuals who reported *critical* security bugs (The Mozilla Foundation, n.d.). Since December of 2010, Mozilla has paid out a total of \$104,000 for 64 qualifying bugs.

Bug Auction

A bug auction utilizes auction theory to conduct a VM. Conducted in an online environment, sellers of vulnerabilities attempt to maximize profit while buyers attempt to minimize cost. In bug auctions, two models are commonly used: the English and Dutch auctions, described in Table 1.

TABLE 1. DESCRIPTION OF COMMON AUCTION TYPES

Auction Type	Bidding / Offer Process	Description
English (Traditional)	Bids increase	This is the typical auction in which a single seller of a single item (or lot of items) receives increasing bids from prospective buyers. The auction ends at a predetermined time, and the item goes to the highest bidder for the highest bid price.
Dutch (Reverse)	Offers decrease	The exact opposite of the English auction. A single buyer of a single item (or lot of items) receives decreasing offers from prospective sellers. The auction ends at a predetermined time, and the item is purchased from lowest offerer for the lowest price.

Note. Adapted from "Auctions in Defense Acquisition: Theory and Experimental Evidence," by B. Linster and D. Mullin, *Acquisition Review Quarterly*, Summer 2002, p. 214.

In contrast to the widely used English auction, Dutch (Reverse) auctions are less frequently utilized. Reverse auctions, consisting of one buyer and multiple sellers, are occurring more frequently in government material acquisitions. While not yet applied to information security, several federal agencies recognize the financial benefit of market competition between suppliers. Several cases of successful reverse auctions are detailed in Table 2.

TABLE 2. HISTORIC SAVINGS FROM COMMERCIAL AND GOVERNMENT REVERSE AUCTIONS

Procuring Activity	Item Procured	Cost Savings	% Savings
State of Pennsylvania	Aluminum	\$170,000	9%
United Technologies	Circuit Boards	\$32,000,000	53%
Owens Corning	Packing Materials	\$7,000,000	7%
U.S. Navy (NAVCIP)	Ejection Seat Components	\$933,000	28%
U.S. Air Force	Computers	\$88,000	27%
DESC	Natural Gas	\$972,000	22%
U.S. Army CECOM	Transformers	\$195,000	53%

Note. Adapted from CLC031: *Reverse Auctioning* [Online course module], published by the Defense Acquisition University, 2012. NAVCIP = Naval Inventory Control Point; DESC = Defense Energy Support Center; CECOM = Communications-Electronics Command.

Reverse auctions may benefit DoD information security in three ways. First, reverse auctions enhance cyber security through early identification of vulnerabilities. Second, the auctions leverage the skills and knowledge of private security researchers in the private sector. Third, when compared to an expected loss, executing an auction costs far less than remediating an attack.

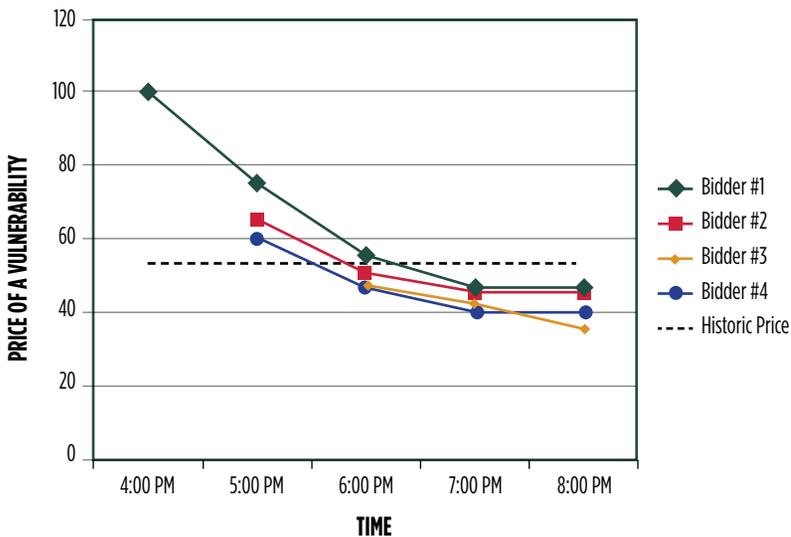
Based on these advantages, this article concentrates on developing a reverse auction model to be used by the DoD prior to full system deployment.

Applying Reverse Auctions

While traditional auctions aim to increase bids on an item for sale, reverse auctions strive for the opposite: to drive prices down. In reverse auctions, buyers initiate the auction rather than the seller. The buyers identify a product or service they want to buy and the starting price at which they are willing to compensate the sellers. Once the auction

window is opened, the bidders (e.g., the sellers) compete to offer the products or services at the lowest cost possible while still retaining a profit. This concept takes advantage of free market competition to lower prices for the buyer (Figure 1).

FIGURE 1. REVERSE AUCTION—PRICE DRIVEN DOWN OVER TIME

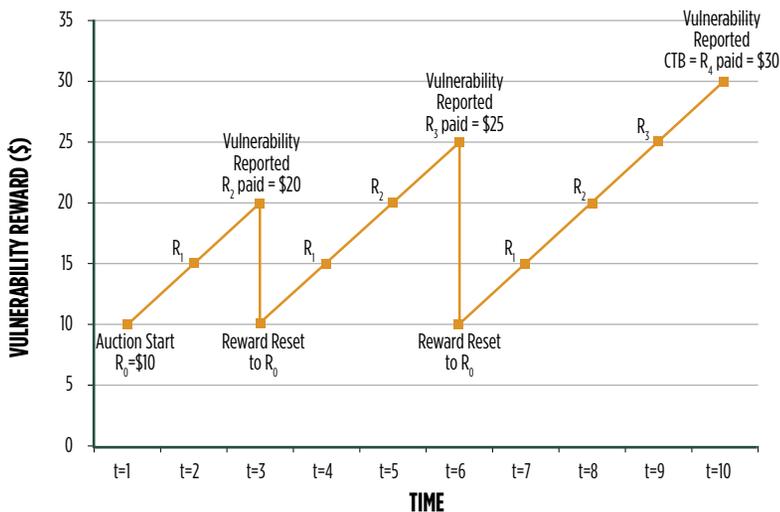


The purpose of using a reverse auction to discover vulnerabilities is twofold. The first objective is to identify possible security issues associated with a software product. By offering cash incentives, vulnerability discovery rates increase based upon the number of researchers attracted to the competition. The greater the number of researchers, the more likely a vulnerability will be found. The second objective is that the vulnerability auction has the potential to provide a meaningful metric that would describe the relative security of a product.

Using a variant of the reverse auction model will allow the government to use auctions for the procurement of software vulnerabilities. The government (aka the buyer) would initiate a reverse auction within an identified pool of software researchers (aka the sellers). The government would identify and provide access to a system it believes to be secure. The government's certainty of system security is articulated as an initial monetary valuation, expressed as the variable R_0 . The objective of the researcher participating in the auction is to disprove the government's

assertion. If after a predetermined amount of time a researcher does not report a vulnerability to the government, the reward value increments from R_0 to R_1 . In the Figure 2 example, the reward first increments from $R_0 = \$10$ to $R_1 = \$15$. This incremental increase repeats until a vulnerability is reported or until the prearranged auction window closes. R_n represents the amount (\$) of reward at increment “n.” If a researcher reports a software vulnerability, the government would pay the current value of R_n dollars. The Figure 2 example shows vulnerabilities reported at R_2 and R_3 where a researcher is paid \$20 and \$25, respectively. At the auction’s conclusion, the last value of the reward (R_4), equates to the security of the system. This final value, or the Cost-To-Break (CTB) metric, is the amount of money it costs an individual to discover and report a vulnerability.

FIGURE 2. REVERSE AUCTION-REWARD OVER TIME, UP TO COST TO BREAK (CTB)



Applying VM Concept to DoD Information Systems Acquisition

For the DoD VM to be successful, it is imperative that a substantial set of qualified software researchers participate. As arduous as it is to discover software vulnerabilities, the researchers must perceive an adequate level of compensation for their efforts. Compensation to incentivize participation can take many forms in the VM.

Financial gain is the most common type of incentive offered in commercial VMs. In March 2012, *Forbes* published a price list that enumerates the financial value an open market vulnerability possesses (Table 3). The value of these vulnerabilities is a function of a free-market economy and the forces of supply and demand. While the vulnerability may not be worth the cost to the vendor, potential consumers of vulnerabilities may perceive the cost offsets their risk and any potential costs of using the vulnerability.

TABLE 3. PRICE LIST FOR SOFTWARE VULNERABILITIES

Application	Vulnerability Price List
Adobe Reader	\$5,000 - \$30,000
MAC OSX	\$20,000 - \$50,000
Android	\$30,000 - \$60,000
Flash or Java Browser Plug-ins	\$40,000 - \$100,000
Microsoft Word	\$50,000 - \$100,000
Windows	\$60,000 - \$120,000
Firefox or Safari	\$60,000 - \$150,000
Chrome or Internet Explorer	\$80,000 - \$200,000
iOS	\$100,000 - \$250,000

Note. Adapted from “Shopping for Zero-Days: A Price List For Hackers’ Secret Software Exploits,” by A. Greenberg, 2012, *Forbes*.

To establish a financial reward, the DoD must provide additional reassurances in the form of nonattribution and anonymity to the researchers. Nonattribution and anonymity have a value unto themselves. By offering a safe and nonattribution environment, security researchers are welcome to hack a government system without threat of being prosecuted under state and federal law. These reassurances, coupled with a financial reward, must counterbalance the price of a vulnerability on the open market.

In the world of vulnerability discovery, a major motivation amongst researchers is their reputation. In the hacker community, an individual’s reputation ranges from the lowest revered status of “script kiddie” to the highest “elite” status. John Arquilla, a professor of defense analysis at the U.S. Naval Postgraduate School in Monterey, California, recently estimated that only around 100 “elite” hackers are in the world today (Carroll, 2012). By leveraging reputational exclusivity and the egos of

security researchers, the DoD could incentivize individuals to participate. A researcher's reputation may be elevated based upon the number of vulnerabilities or new attack vectors discovered. A heightened reputation will enhance the researcher's status in the hacker community and could also result in job and consulting offers within industry.

Altruism, in the cyber security environment, is also a powerful motivator. It is so powerful, in fact, that the term "white hat" hacker was developed specifically for the altruistic security movement. The term white hat describes a hacker ethically opposed to the abuse of IT and concerned with improving overall security to benefit society. Traditionally identified as specialists in penetration testing or vulnerability investigation, white hats use their expertise to protect computer health and improve system security. After discovering a vulnerability, white hats will either contact the vendor directly to force a patch or disclose the vulnerability to a third party like the United States Computer Emergency Readiness Team. These incentives, with cash rewards resulting from a DoD-sponsored VM, have the propensity to increase software vulnerability discovery rates and software security.

Cost to Break

Complete product security is almost impossible to measure. Metrics, such as SLOC, can describe complexity of the system, but fail to describe overall security. The number of vulnerabilities patched over a given amount of time is also a useful metric that is quantifiable and easily understood. Moreover, a company can advocate the amount of effort (in dollars and time) spent securing a product. The failure of this metric is that a hacker only needs a single undiscovered vulnerability to exploit the system. To provide a meaningful way of measuring the security of a system, the DoD requires a metric that is quantifiable, easily understood, dynamic, and supports IT acquisition milestones for decision makers.

The traditional definition of a system's CTB is the cost that an attacker will incur in compromising the system. These costs may include money, research time, risk of being caught, etc. Because many of these costs truly vary amongst individuals, calculating this view of the CTB metric is unfeasible. Rather than attempting a CTB metric focused on the individual, this article proposes using the VM to evaluate the security of the system by using a large sample population of security researchers.

Using a VM to calculate the CTB of a system was originally proposed by Dr. Stuart Schechter of Harvard University. In Dr. Schechter's model, the CTB is the result of the market price to discover system defects governed by the presence of competition amongst researchers (Schechter, 2002). Otherwise stated, the market-focused CTB is a product of a vulnerability auction where an IT producer offers a cash prize to free-market researchers to break their system. This strategy of paying researchers to break their systems is used frequently today; however, it is not tracked as a true metric. For example, since 2007 the CanSecWest security conference has hosted the annual Pwn2Own bug challenge, which rewards researchers for hacking into some of the most popular computer applications. During the 2013 Pwn2Own challenge, researchers were awarded \$480,000 for cracking applications developed by Microsoft, Google, Adobe, Mozilla, and Oracle. Even more impressive, Google claimed theirs was the most secure operating system on the market by offering \$110,000 for a browser or system-level compromise delivered via a Web page. At the end of the conference, the entire Google prize pot of \$3.14 million remained intact (Thomson, 2013).

The inability of researchers attending the conference to crack the application effectively placed the CTB metric for the Google Chrome OS at \$110,000. Accordingly, this metric could be used by Google to compare its security to other operating systems (e.g., Windows, Linux). This ability to compare applications is the real value of the CTB metric; the vendor is now able to highlight the security of its product relative to its competitors. For a discerning consumer concerned with product security, the CTB may influence the decision to purchase one product versus another.





The CTB metric may play a role in the DoD as well. Prior to awarding a contract to a specific vendor, the DoD establishes a source selection strategy or acquisition plan that outlines all evaluation factors affecting contract award. Should software security be an evaluation factor in the selection, the CTB would be invaluable in the comparison of multiple vendors. The hope would be that the DoD acquires secure software systems prior to contract award. Additionally, use of the CTB metric could be included in the Joint Capabilities Integration and Development System requirements process. By requiring that an IS must meet specified thresholds, the contractor and government ensure the IS is secure prior to deployment.

Application of a VM leads to several benefits. First of all, a VM provides an additional round of development and operational testing. Second, the VM increases analysis prior to fielding. Increased scrutiny and additional researchers also increase the vulnerability disclosure rate and result in reducing the total cost of ownership. Third, by wide use of the VM to enumerate the CTB metric, the government will be able to compare and discern multiple systems.

Conclusions and Recommendations

Perfect information security will never be achieved. Whether vulnerabilities are due to mistakes by the software developer, a vendor's unwillingness to fix flaws, or an error by the user, the outcome is the same—valuable information is susceptible to attack. In the information age, industry understands the issues of software vulnerability prevalence as much as the DoD. In the past decade, dozens of VMs have sprung into existence based upon the perceived need to enlist nonorganic researchers to report application vulnerabilities. The responsibility for securing data does not lie solely with the vendor or with the product consumer. True information security and management of the risk of unauthorized disclosure is the responsibility of the entire community.

Because a government online reverse auction market for the purpose of identifying software vulnerabilities has never been applied to a DoD IS acquisition, concerns arise that this concept is legally and economically unfeasible. Legally, federal statute permits and encourages the use of online marketplaces (GSA, 2005, pts. 1.102, 4.5) for systems acquisition. Furthermore, precedent in the commercial and government sectors is established. As reported by the *Washington Post*, the National Security

Agency (NSA) allegedly spent more than \$25 million in 2012 to procure vulnerabilities (Fung, 2013). With respect to security concerns, the National Institute of Standards and Technology encourages acquiring systems that are “secure by design” rather than those that are “secure by obscurity.” While obscurity and controlling open visibility into systems design might delay potential adversaries, hidden vulnerabilities may ultimately be exploited to their advantage. Security by design does not rely on hiding vulnerabilities. Instead, vulnerabilities are eliminated by secure software design principles. In cases where a critical system must be controlled and disseminated to trusted individuals, entry into the VM is governed through the enforcement of appropriate clearance requirements.

Economically, each IS vulnerability has the probabilistic potential to cost the DoD immense resources. Although calculating the consequences of using a system with unknown vulnerabilities is difficult to quantify, discovery of a vulnerability prior to use in an operational environment is more cost-effective than remediating it postdeployment. Decreasing the probability and increasing the discovery rate of system vulnerabilities are the primary goals of the proposed VM model for DoD-acquired systems. Not only will the discovery of an unknown vulnerability effectively reduce the probability of a successful attack, life-cycle operations and maintenance costs are also reduced. Addition of a VM to the development phases within DoD acquisition results in a proactive approach to information security and mission assurance.

Use of this auction model will create a meaningful and easily understandable metric to ensure the DoD acquires systems with built-in security. This CTB metric has the propensity to reform the defense industrial base as well as conform to information security requirements as dictated by the warfighter. Through the mutual cooperation between industry and the military in securing information, the DoD will optimize security investments, secure critical information, and provide an effective and resilient warfighting capability.

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Keywords: *Acquisition, Operations Research, Cost, Schedule, Performance, Analytic Models*

A Conceptual Framework for Defense Acquisition Decision Makers: *Giving the Schedule Its Due*

 *Chad Dacus and Col Stephen Hagel, USAF (Ret.)*

Conceptual models based on economic and operations research principles can yield valuable insight into defense acquisition decisions. This article focuses on models that place varying degrees of emphasis on each objective of the defense acquisition system: *cost* (low cost), *schedule* (short cycle times), and *performance* (high system performance). The most appealing conceptual model is chosen, which the authors posit that, if adopted, would lead to shifts in priorities that could facilitate better outcomes, as empirical results suggest. Finally, several policy prescriptions implied by the model are briefly explored.

Principles from microeconomic theory and operations research can provide insight into acquisition decisions to produce military capabilities in an environment of scarce resources. To begin a discussion of the analytic models involved, it helps to identify desired outcomes. In the acquisition literature, *cost* (low cost), *schedule* (short cycle times), and *performance* (high system performance) are generally regarded as primary objectives in fielding new systems (Department of Defense [DoD], 2006). This article focuses on conceptual models involving these three goals that place varying degrees of emphasis on each objective. The most appealing conceptual model is chosen, which we posit that, if adopted, could clearly lead to badly needed shifts in priorities. Empirical results bolster the proposition that changing priorities could lead to better outcomes. Finally, we discuss several policy changes implied by the chosen model.

In pursuing a defense acquisition, the immediate question becomes what combination of cost, schedule, and performance can or should be considered optimal? If the only guidance provided to analysts is to do their best to minimize cost and time to field while maximizing performance, then making tradeoffs will rely on professional military judgment at best or become arbitrary at worst. The basis for decision making can be unclear and result in disputes, and the acquisition professional may lose sight of the overall objective. Therefore, the goal of this article is to develop a new way of characterizing the acquisition problem that will help decision makers make more informed tradeoffs.

The Efficient Frontier of Defense Acquisition

Each defense acquisition program can be judged by how much input (time and money) is consumed to produce the desired military output (performance or capability). This uncontroversial statement of defense acquisition system objectives reveals how this incredibly complex system reduces to a relatively simple problem involving production economics. To put it in mathematical terms, a system's performance can be expressed hypothetically as a function of the independent variables time and money, as described in the following associated interactions.

$$\text{Performance} = f(\text{time, money})$$

FIGURE 1. NOTIONAL PERFORMANCE ISOQUANTS

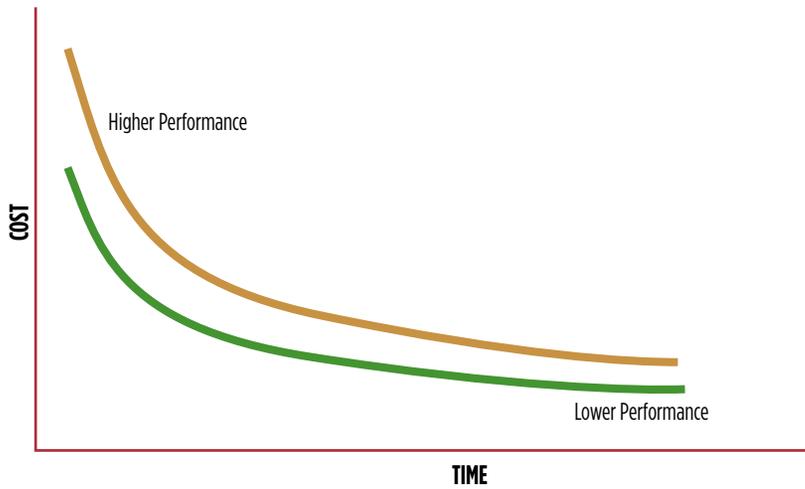
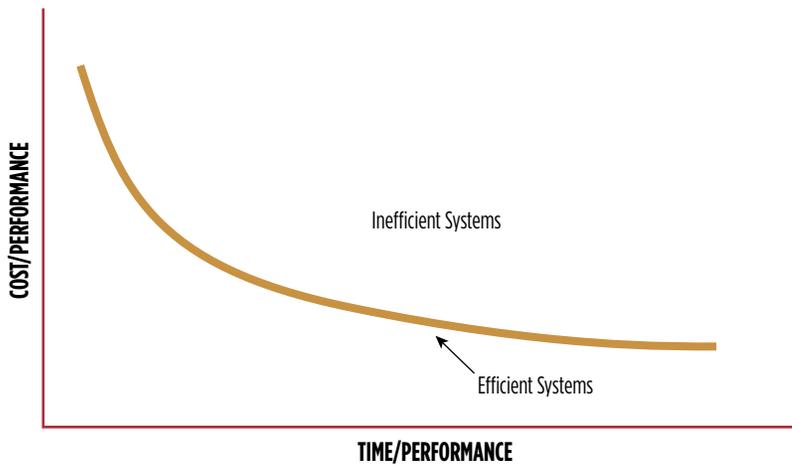


FIGURE 2. THE DEFENSE ACQUISITION EFFICIENT FRONTIER



Using this function, performance can be plotted as a function of either time or money in a standard Cartesian graph. Another way to visualize this function is to hold performance constant while varying time and money. All of the combinations of time and money result in the same performance makeup of what is called a performance isoquant. Figure 1 illustrates this concept with two notional performance isoquants. If cost



and time are then divided by performance and graphed in the same manner, it becomes clear that increases in either cost/performance or time/performance are undesirable. The efficient frontier of cost, schedule, and performance represents optimal outcomes under the current system. The curve in Figure 2 illustrates the efficient frontier, and points above the line are considered inefficient.

The goal of defense acquisition system managers and practitioners would be to choose to develop and produce systems that occupy the efficient frontier. Although reaching the efficient frontier may, in practice, be extremely challenging, improvements toward that end are constantly sought. As such, a commonly occurring issue arises when one considers how a hypothetically inefficient program should be improved to reach efficiency—should costs be cut, time-to-launch condensed, and/or performance enhanced? In other words, how should marginal resources be allocated?

If the system is allowed to function with limited oversight, how might the actors behave and what are the implications of their decisions? What might be a better way to state the acquisition problem to develop a commonsense approach to the question of how to make tradeoffs between cost, schedule, and performance? Finally, do empirical results tend to support or refute the recommended model, and what sort of actions can be taken to make the current defense acquisition system more consistent with the chosen conceptual model?



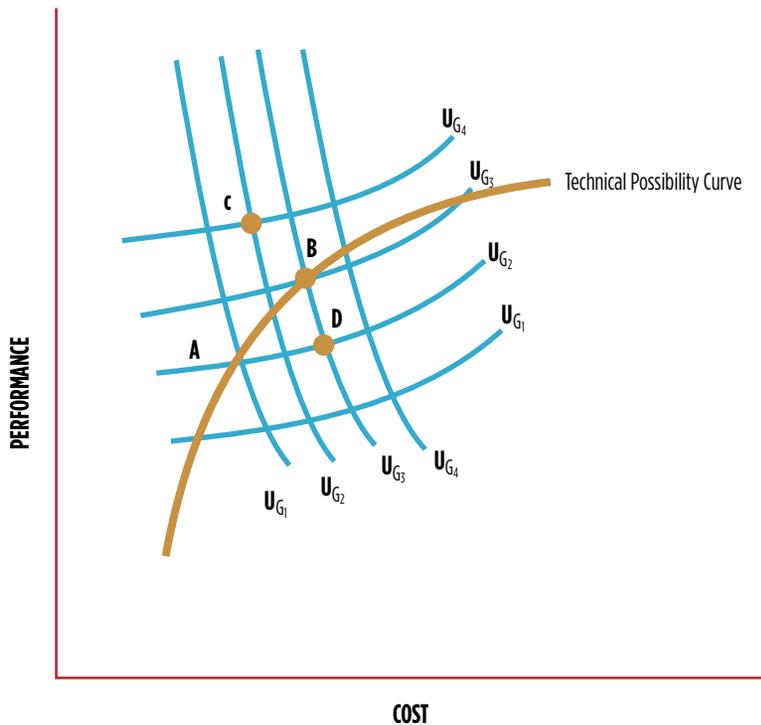
Economic Incentives of Defense Contractors and the Defense Department

Edmund Conrow (1995) developed an excellent microeconomic framework to investigate the incentives of buyers and sellers in the defense acquisition system. His most important insight is that while government and contractors have objectives that can and often do conflict, negative outcomes associated with aligned government and contractor incentives are quite likely to occur—and have occurred in the past. To avoid similar outcomes in the future, mitigating incentives or controls must be put in place.

The government and contractors' preferences can be discussed in terms of cost, schedule, and performance. Clearly, the government prefers low cost, shorter cycle times, and high performance. Meanwhile, contractors' preferences are more nuanced. In the absence of a fixed-price contract, contractors generally prefer rising system costs to strengthen their own bottom lines. However, this preference is not absolute because spiraling costs can result in negative reviews on the Contractor Performance Assessment Reporting system. Developing higher performing systems improves a contractor's future market position by keeping it on the cutting edge of technology. Finally, extended schedules imply a longer relationship with a government client that may offer future system development opportunities, though this inclination can backfire when taken too far, as with preferring high system costs. As depicted in Conrow (1995), this can be illustrated graphically using government and contractor indifference curves sketched in cost-performance space.

Figure 3 provides a visual representation of the indifference curves inspired by Conrow (1995). The government's utility curves are labeled U_{G_i} where increasing i indicates increasing utility. For the government, utility clearly increases from right to left and bottom to top. Meanwhile, contractor utility indifference curves are labeled analogously by U_{C_i} . The technical possibilities curve represents what performance levels are possible at each cost and intersects both sets of indifference curves at two places, A and B . These are feasible and efficient choices for cost and performance. Meanwhile, point C is infeasible due to lack of adequate technology, while point D is inefficient and, thus, inferior to points A and B . Of the two feasible and efficient points, point B dominates because it offers both government and contractor a higher level of utility.

FIGURE 3. GOVERNMENT AND CONTRACTOR COST AND PERFORMANCE ISO-SCHEDULE CURVES WITH TECHNICAL POSSIBILITY CURVE



This economic analysis reveals that, in the absence of strong cost control, the program office and contractor will tacitly conspire to increase performance at the expense of cost. That is, the program office and the supplier can agree on performance, but they cannot agree on either cost or schedule. Therefore, the natural inclination is to maximize performance and see how much cost and schedule can be massaged. This insight from economic theory reinforces the beliefs of defense experts. Indeed, since program managers and executive officers clearly benefit from managing larger and more complex programs, some claim that the budget and schedule objectives are not as important in the eyes of important decision makers. Laws like Nunn-McCurdy are intended to mitigate this tendency to let costs and schedule spiral out of control. However, some argue that Nunn-McCurdy has failed in its stated goal because it only requires congressional notification of a breach (Ewing, 2011). Often, Congress is already aware of the program’s struggles and does not react to the breach. Further steps need to be taken to effectively

discipline the system. A new way to look at the objectives of developing and fielding a system might help clarify what needs to be done, and is the focus of this article's final section.

A Constrained Optimization Approach

Reconciling the competing objectives of the defense acquisition system has proven to be quite challenging. While optimization and tradespace tools are useful, senior leaders bear primary responsibility for communicating DoD acquisition strategy through their statements and actions. A notional optimization problem specification can be helpful in framing a strategy in a manner that is internally consistent, and such that the goals (referred to as the objective function in operations research) and constraints reinforce one another.

In the language of operations research, any proposed system must not exceed a maximum budgeted cost; take too long to field and, thus, sacrifice military utility; or fall below minimum performance standards. In mathematical terms:

$$\text{Cost} \leq C$$

$$\text{Time} \leq t$$

$$\text{Performance} \geq P$$

As in the previous section, these constraints, taken in isolation, do not offer any rationale for making tradeoffs. For instance, what should be done if the system's development schedule slides to the right—should costs be increased by allowing more overtime or hiring more staff, or should performance goals be sacrificed to tighten the schedule? Adoption of a decision rule can help facilitate such decisions. Even the adoption of a heuristic decision rule can enlighten analysts and prove useful in promoting the goals of the acquisition system. That is, even though this conceptual model is admittedly a greatly simplified representation of an extraordinarily complex system, it still yields valuable insights to those in defense acquisition leadership positions. Indeed, the models discussed throughout this article assume decision makers possess more information than is ever available in practice, so much is left to professional judgment, particularly regarding unforeseen cost and schedule risks.

This set of constraints suggests a constrained optimization problem specification could be useful in framing the discussion. Standard operations research principles dictate that three different system specifications are possible. The potential explanatory power of each will be judged by the implications arising when the specification is translated into English.

Budget Specification Model

Minimize *Cost*

subject to *Performance* $\geq P$

Time $\leq t$

The Budget Specification Model can be considered as an attempt at obtaining defense “on the cheap.” Its appeal is intuitive, particularly in today’s budgetary environment of increasing fiscal constraints, but this specification can be removed from consideration because the cost uncertainty associated with it would severely disrupt the planning, programming, budgeting, and execution process. Budgets must be specified precisely, and including the program budget as a constraint is the only feasible way to proceed.

Capabilities-Based Specification Model

Maximize *Performance*

subject to *Cost* $\leq C$

Time $\leq t$

The Capabilities-Based Specification Model formalizes the undisciplined incentive structure outlined in the previous section. Of the three approaches, this model is the most vulnerable to requirements creep. While this specification will almost certainly lead to the highest performing systems, it will leave the DoD vulnerable to former Secretary of Defense Robert Gates’ critique of “running up the score” (Thompson & Karon, 2009). Furthermore, the two constraints often seem to be somewhat negotiable. Timelines are lengthened to lower short-term costs and expenditure becomes important, seemingly, only when Nunn-McCurdy

limits are in danger of being breached. As previously mentioned, even a Nunn-McCurdy breach often fails to motivate change. In other words, the constraints are not binding, leading to an undisciplined system. If this specification is chosen, the focus must be on disciplining the system through enforcement of the constraints and ending requirements creep, for example. With primary emphasis on maximizing capability, there will always be a strong tendency to extend timelines to get that last bit of performance.

Threat Specification Model

Minimize *Time*

subject to *Performance* $\geq P$

Cost $\leq C$

The Threat Specification Model best reflects the thinking behind amendments to the Federal Acquisition Regulation for needs of “unusual and compelling urgency” (General Services Administration, 2005). The naming of the threat specification arises from the idealized case: when a threat is imminent and a near-term response is required. This sort of rapid acquisition authority is designed to meet immediate warfighter needs. Some experts have advocated a similar system be adopted for all acquisition. In the words of retired Air Force Lieutenant General David Deptula, “...we need to be able to operate much quicker and inside our adversary’s decision rate” (Hoffman, 2010).

This problem specification has intuitively appealing implications—and it is not susceptible to Secretary Gates’ “runnin’-up-the-score” criticism. Using time as the objective function will, in most cases, reinforce the cost constraint somewhat because simplifying the acquisition process will undoubtedly reduce costs. In any case, in nonemergency acquisition, this objective function and its associated constraints are in harmony to a greater extent than the capabilities-based specification. The primacy of performance in the capabilities-based specification naturally leads to higher costs and longer cycle times, while enhanced focus on reducing cycle times should not cause overall costs to rise to the same degree as long as the concept is not taken too far. The DoD’s

Better Buying Power 2.0 initiative (Kendall, 2012) makes the mutually reinforcing nature of reducing both cycle times and cost explicit during the development phase:

This initiative will assess the root causes of long product cycle time, particularly long development cycles, with the goal of significantly reducing the amount of time, and therefore cost, it takes to bring a product from concept to fielding. (pp. 5-6)

Furthermore, the capability constraint is unlikely to be violated, or the system is likely to be cancelled due to inadequate military utility. Because of the objective function's primacy, requirements creep should not be as ubiquitous. Therefore, this approach should have the added benefit of being easiest to discipline.

An immediate critique of the Threat Specification Model is the possibility of being stuck with less capable systems for many years. If the acquisition cycle is shortened, this criticism is blunted somewhat because our armed forces do not have to be impaired as long with less capability, but it still remains troubling. The most plausible solution is a hybrid framework that follows this decision rule, but retains some of the virtues of the existing system. While the chosen model does not advocate for a single-minded focus on the schedule, program managers should avoid roadblocks that might stymie a program in the absence of overwhelming cost or performance benefits.

Empirical Results

While the recommended theoretical framework may be intuitively appealing, the more important question is whether any empirical evidence exists to support the hypothesis that an enhanced focus on schedule will improve acquisition outcomes more generally. Since the available historical data are merely observational, obviously there will be no perfect test. However, the results of a few statistical tests offer some hope of improving acquisition outcomes through adopting a different mindset.

A potentially contentious argument made in advancing the merits of the Threat Specification Model described in the previous section, was that an enhanced focus on the schedule would also pay dividends by helping to avoid unpleasant cost outcomes. This proposition can be examined

by determining whether schedule problems precede or occur simultaneously with cost overruns. If schedule slippages occur first, this suggests that, in some cases, cost overruns could be prevented by first ensuring a program can meet its schedule. Of the 54 programs listed as incurring Nunn-McCurdy cost breaches on the Defense Acquisition Management Information Retrieval system from December 1997 to June 2012, 38 (or 70.4 percent) experienced Acquisition Program Baseline schedule breaches in a previous Selected Acquisition Report. If the timing of the breaches is determined by chance, schedule breaches should take place before cost breaches about 50 percent of the time. If we consider these programs to be representative of all programs, this proposition can easily be tested statistically using a simple exact binomial test. Carrying out such a test reveals that the observed results would be very unlikely to occur due to chance ($p\text{-value} < 0.001$), so the unavoidable conclusion that schedule slippages more often precede cost breaches than the converse is true. If the same proposition is tested while allowing for simultaneous breaches, the results are even more conclusive—43 of 54 schedule breaches occurred before or simultaneously with cost breaches ($p\text{-value} < 1.0 \times 10^{-5}$). These test results are presented in Table 1. *Such outcomes strongly suggest that schedule problems precede cost breaches. Therefore, preventing the schedule breach could eliminate the cost breach too.*

TABLE 1. TIMING OF ACQUISITION PROGRAM BASELINE SCHEDULE BREACHES VS. NUNN-MCCURDY COST BREACHES

Criteria	Frequency
Schedule Breach First	70.4%*
Schedule Breach First/Same Time	79.6%*

* - $p\text{-value} < 0.01$, $n = 54$

The next question that arises is whether focusing on schedule can also benefit performance outcomes. This is much more difficult to test since performance goals must clearly be met within a certain time-frame—making the two goals virtually indistinguishable. The key here is to reverse the direction of causation and set performance goals that are realistically within reach with existing technology or imminent scientific advancement. That is, it is important to avoid reaching for unrealistic technological advances to achieve higher performance goals. This proposition has been supported empirically through analysis of Selected Acquisition Reports and Defense Acquisition Executive Summaries (Dacus, 2012). Before DoD acquisition Milestone B, each

critical technology element of a program is assessed to determine how far along the discovery process each element has progressed. Low technology readiness levels, which describe the maturity of these critical technology elements, have been linked to larger cost overruns and more pronounced schedule slippage. If two simple decision rules that require minimum individual and system-wide technology readiness levels before a development effort is allowed to become a program of record are enforced, cost and schedule outcomes are improved dramatically, with mean differences in outcomes that are statistically significant (Table 2). *These results provide strong evidence that setting more realistic performance goals can lead to substantial improvements in cost and schedule performance. Therefore, performance goals should be set with the schedule very much in mind.*

TABLE 2. APPLICATION OF THE MINIMUM TECHNOLOGY READINESS LEVELS DECISION RULE

Quantity of Interest	No Violation	Violation
Mean Months Behind Schedule**	7.7 mos.	31.2 mos.
Mean Percentage Cost Overrun*	3.2%	35.5%

* p -value < 0.05, ** p -value < 0.01, $n = 50$.

Note. Adapted from "Improving Acquisition Outcomes Through Simple System Technology Readiness Metrics," by C. Dacus, 2012, *Defense Acquisition Research Journal*, 19(4), p. 453.

Some Policy Recommendations

The Threat Conceptual Model (also referred to as the Threat Specification Model) lends itself to interpretation through various policy recommendations. Some of these recommendations and a discussion of their implications follow. These examples capture the spirit of the Threat Conceptual Model, but do not represent an attempt to catalog all of its implications. Creative implementation of the values inherent in the model may lead to unanticipated benefits. With that caveat in mind, schedules could be shortened by focusing on stability, by avoiding technology overreach, by keeping systems as simple as possible, and by initiating fewer programs.

Insist on Stability

Continual change, whether in the requirements themselves or in available program funding, leads to extended schedules and should be minimized to emphasize meeting the program schedule. Requirements instability can stem from a desire to improve performance above what was originally envisioned, but consistently engaging in requirements creep conflicts with the proposed mindset. According to those surveyed for the 2006 Defense Acquisition Performance Assessment Report, requirements instability was the most commonly identified reason for cost growth and schedule extensions (Kadish, 2006). According to a 2008 Government Accountability Office report, *Defense Acquisitions: Assessments of Selected Weapon Programs*, cost increases for programs with no requirements changes after system development were significantly lower (72 percent vice 11 percent). Further, according to a 2011 GAO study, requirements changes added 5 months to delays already being experienced (GAO, 2011). Intuitively, this makes sense; changing direction after the program is underway is likely to increase the time to field and raise costs.

According to those surveyed for the 2006 Defense Acquisition Performance Assessment Report, requirements instability was the most commonly identified reason for cost growth and schedule extensions (Kadish, 2006).

Just as adding requirements tends to cause a later delivery of promised capability, so does a slip in a program's budget. This often stems from a desire to reduce costs in the short run or from shifting priorities. Of course, some budget changes may be unavoidable due to congressional action, but the Services must make a commitment to the schedule and exercise discipline when possible to avoid disrupting the program. If requirements are to be achievable, there must be the financial resources to pay for them. As it stands, every year programs are forced to rejustify themselves to virtually every funding authority within the program's funding hierarchy. During that process, Congress may decide to adjust the procurement quantity, as it did with the C-17 when additional numbers were added to the planned buy, creating some second- and

third-order effects to other programs. More often, Congress decides to cut the number of program units, as was the case with the F-22. Unfortunately, reduced quantity increases the per-unit cost because the sunk development costs are allocated across fewer units (Deloitte, 2009).

Shifting requirements and budget instability often work together to lengthen programs. Deloitte (2009) noted that:

...most programs are funded and launched while there is still significant uncertainty about everything from systems and technologies to integration, interoperability, and supply chain requirements. This lack of certainty and knowledge makes it difficult or impossible to make informed funding decisions, which often leads to cost overruns and schedule delays. (p. 12)

The DoD begins programs with too many unknowns leading to longer cycles, greater costs, and more oversight.

Avoid Technology Overreach

Study after study notes that the DoD reaches for capabilities that are too far off—pushing for “exquisite” solutions as former Secretary of Defense Gates called them. These capabilities are often technology-driven and far beyond current reach. The GAO reports too many programs enter into one phase or another without mature technologies (GAO, 2011). As mentioned earlier in the Empirical Results section, immature technology at both the subsystem and system levels leads to delayed delivery of a promised capability to the warfighter, and to budget-busting cost overruns. The longer the program runs, the greater the temptation to add to it the latest technology or some other requirement, placing the program in what Spinney called a “death spiral development” (Fallow, 2002). A more disciplined approach to selecting the right technologies for a proposed system will enable program managers to have more effective control over schedules and, therefore, cost (Ward, 2010).

Keep It Simple

Complexity is also a factor that drives long acquisition cycles to push for increased performance at the expense of the schedule. It might be prudent to look at less complex systems that are not “silver bullet systems” capable of being all things to all users, but instead incorporate “ready-for-prime-time” technology. For example, the F-22 was jokingly referred to as the E/F/A/B/C/K-22 to indicate the DoD was counting on

one aircraft to meet all its needs. Clearly the DoD does not have to defeat the adversary with a single system and should make its acquisition decisions with simplicity in mind.

Complexity is the antithesis of affordable, on-time systems. Dan Ward, in particular, has been writing on this topic for some time (Ward, 2012). As discussed in Department of Defense Instruction (DoDI) 5000.02 and the Better Buying Power initiatives promulgated by Under Secretary of Defense for Acquisition, Technology and Logistics Frank Kendall, a proven successful approach has been taking programs in bite-sized increments, shooting for the “80 percent solution” with evolutionary systems to follow. It may be far better to take a less capable, mature system now and build up to the full capability through evolutionary or block development. The F-16 is a notable example of incremental development, taking the “best” that could be made quickly for a reasonable cost, but adjusting to new technologies and adapting for the current challenges and operational experience (Quadrennial Defense Review Independent Panel, 2010). This reinforces the need to set realistic goals to meet the schedule.

Starting more programs than the Service can afford creates inefficiencies by lengthening programs. Inevitably, more programs will be competing for the same limited funds, thereby creating a slow, vicious death spiral cycle due to sparse budgets

Initiate Fewer Programs

Although DoDI 5000.02 stipulates full funding as an entrance requirement for a development effort’s individual phases, the DoD starts more programs than it can hope to fund through full production (Chaplain, 2011). This practice creates a myriad of problems—it lengthens acquisition cycles, creates pressure to underestimate costs, and eventually leads to quantity cuts that can precipitate a program’s death spiral. This results from the DoD and the Services pursuing perceived higher performance through a more robust portfolio of capabilities. However, more often than not, this impulse is driven by a lack

of clear priorities on which capabilities or systems should be developed. Indeed, the need for better prioritization has been tacitly acknowledged through the recent revamping of the Joint Capabilities Integration and Development System. A consistent and analytically based prioritization of systems that can close the maximum number of capability gaps could encourage a reduction of the chaotic competition that plagues the defense acquisition system right now. For example, the DoD could adopt an algorithm similar to one RAND developed for prioritizing systems early in the acquisition cycle (Chow, Silberglitt, & Hiromoto, 2009).

Starting more programs than the Service can afford creates inefficiencies by lengthening programs. Inevitably, more programs will be competing for the same limited funds, thereby creating a slow, vicious death spiral cycle due to sparse budgets. Eventually, the DoD needs to admit some of the future systems are just not going to happen without huge infusions of cash, which seems unlikely. Banking on sufficient funds to cover all programs through full production places other systems in jeopardy, and while the investments may not be wasted completely, the money could be better spent elsewhere to produce on-time programs.

Conclusions

Previous research has failed to develop a theoretical framework from which to analyze tradeoffs within the acquisition system. Although the acquisition community has produced many potentially useful observations and recommendations since the early 1990s, this gap in the literature has arguably marginalized efforts to implement worthwhile policy changes. By making it seem as if the recommended policy changes were not motivated by any single overarching guiding principle, the impetus for a paradigm shift was weakened, and piecemeal changes and stalls were the result. This research effort seeks to unite many of the previous recommendations under a single theoretical rubric.

While this article has taken on a distinctly mathematical tone, the primary objective has been to develop an internally consistent framework for the *values* DoD leaders should communicate to the acquisition community. That is, the complexity of the defense acquisition system precludes resolution of priorities through a simple mathematical programming problem, but the insight gained through the inherent

prioritization represented in the model allows for clarity of purpose. For the *process* to be disciplined, senior leaders must transmit *unambiguous* values through their statements and *actions*.

In keeping with this framework, the popular DoD convention of focusing primarily on costs should be eschewed, and more attention should be paid to meeting the schedule. Empirical results have demonstrated that cost performance is likely to improve through adoption of a new mindset, and the more realistic expectations concerning a system's performance that are implied by this conceptual model will undoubtedly improve both cost and schedule outcomes.

Author Biographies



Dr. Chad Dacus is a defense analyst-economist at the Air Force Research Institute (AFRI). Before joining the AFRI staff, he worked for the Center for Naval Analyses (CNA) as both a field representative at U.S. Fleet Forces Command and as a research analyst at CNA headquarters. Dr. Dacus holds a PhD in Economics from Rice University and an MS in Statistics from Texas A&M University.

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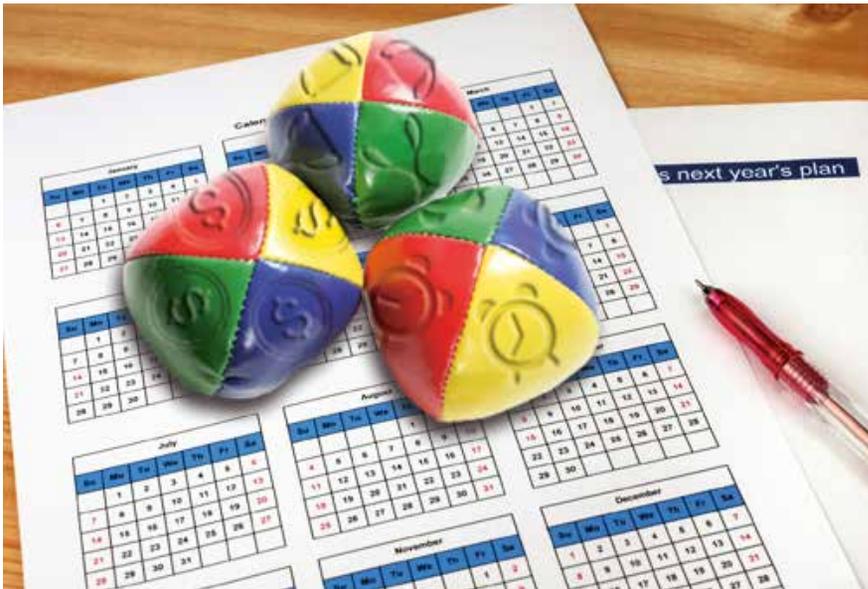
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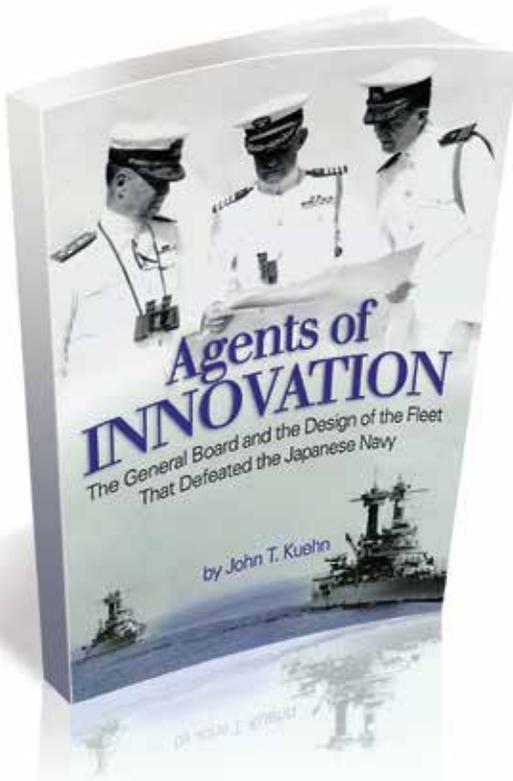
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Featured Book

Agents of INNOVATION: The General Board and the Design of the Fleet That Defeated the Japanese Navy

Author(s):

John T. Kuehn

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Hardcover, 296 pages

Reviewed by:

Robert G. "Bob" Keane

Mr. Keane is currently the President of Ship Design USA, Inc.

Review:

Innovation during the period between World Wars I and II? How could that be? The Nation could little afford to build new warships. Treaties limited the number, type, and size of capital warships as well as fortifications in the Western Pacific. Yet, the Navy knew it had to implement new, emerging technologies such as naval aviation and undersea warfare. Navy leaders recognized they had to look for innovative ways to overcome the decreasing strength of their fleet relative to Japan's. As Professor John Kuehn emphasizes, this multidimensional threat drastically altered the way the Navy viewed the application of sea power. The simple premise of this brilliant book is "the U.S. Navy's contributions to victory in the Pacific...can be understood only by studying how the General Board...constructed the 'treaty navy' during the period between the wars."

The General Board was established as an advisory body by the Secretary of the Navy in 1901. Its members were senior- and mid-level officers with proven experience and promise. The Board hastened collaboration between the Naval War College, the Bureaus (now the Systems Commands), and the Chief of Naval Operations. It held iterative deliberations concerning naval warfare strategies, new technologies and systems, and the structure and size of the U. S. Navy Fleet. The Board collaborated closely with the Bureau of Construction and Repair (BuC&R)—now the Naval Sea Systems Command (NAVSEA)—tasking BuC&R to conduct extensive ship design studies to determine the size and structure of an affordable fleet. Although the Board's official role was advisory, its actual influence was much greater. It had the final word on ship design decisions, including critical operational requirements and costs. Professor Kuehn provides a captivating description of how the Navy was transformed from a battleship-centric Fleet to an efficient treaty Fleet, designed to operate at extreme distances without available bases, that by 1937 also included aircraft carriers, cruisers, destroyers, submarines, and new types of logistics support ships.

All defense acquisition professionals should study this exceptional book, which describes the elements and processes for successful acquisition outcomes. Professor Kuehn stresses the General Board's collaborative process demonstrates that innovation can occur in the face of constraints. MIT's Eric von Hippel, who has done pioneering research in new product innovation, emphasizes that one of the most important steps to innovative concept development and cutting concept development time and cost is for lead users—users like senior Fleet operators at the leading edge of products—to assess their own needs and create the design concept that satisfies their own needs. His research validates

what Professor Kuehn discovered: that there are very few—maybe even no—conditions under which properly equipped users engaged in open innovation cannot outdo closed, manufacturer-based innovators. This same “open innovation” process was also followed by successor boards such as the Ship Characteristics Improvement Board (SCIB) during the build-up to a 600-ship Fleet in the 1980s and 1990s. Unfortunately, the SCIB was abolished around 2000 and has not been reconstituted. The Performance Assessment and Root Cause Analysis (PARCA) Office within the Department of Defense Office of the Under Secretary of Defense for Acquisition, Technology and Logistics, recently highlighted the root causes for major defense acquisition programs with critical cost growth as part of the Nunn-McCurdy breach certification process. PARCA emphasized that unrealistic estimates are generally caused by the invalidity of major assumptions *not* methodological errors. This has led to what PARCA referred to as “framing assumptions” early in an acquisition program, which put the program on an initial path for success or failure. The common incorrect framing assumption made by acquisition programs with critical cost growth was the “Design is mature.” In his book, Professor Kuehn has captured how the General Board managed technical risks to ensure a mature design before entering into a shipbuilding contract. Again, this is a must read for you “back-to-the-future” types.

Mr. Robert G. “Bob” Keane is currently the President of Ship Design USA, Inc. Prior to starting his own consulting firm, he worked at the Naval Sea Systems Command for 35 years. He was a member of the Senior Executive Service for 21 years and rose to the senior executive leadership positions of Chief Naval Architect of the Navy and the Navy’s Chief of Ship Design.

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We would like to express our appreciation to all of the subject matter experts who volunteered to participate in the *Defense Acquisition Research Journal* peer review process. The assistance of these individuals provided impartial evaluation of the articles published during the 2013 print year. We would also like to acknowledge those referees who wished to remain anonymous. Your continued support is greatly appreciated, and we look forward to working with many of you again in print year 2014.

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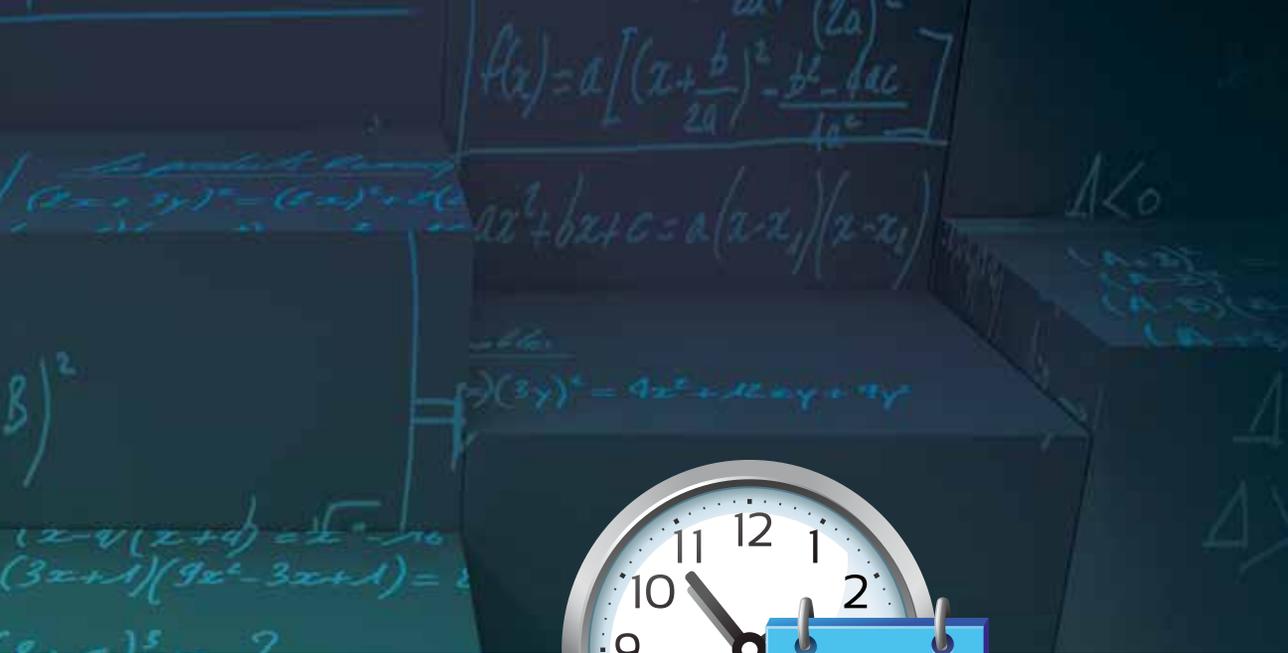
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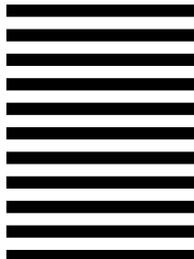


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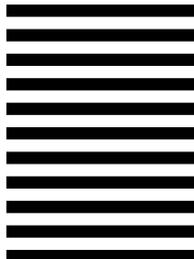


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