PAPERS

Best Project Management and Systems Engineering Practices in the Preacquisition Phase for Federal Intelligence and Defense Agencies

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ABSTRACT

The analysis of several government defense and intelligence agency large-scale acquisition programs that experienced significant cost and schedule growth shows that several critical factors need to be addressed in the preacquisition phase of the acquisition cycle. These include overzealous advocacy, technology readiness levels, life-cycle cost, schedule details, requirements maturity, acquisition and contract strategy, program office personnel tenure and experience, risk management, systems engineering, and trade studies. The results of this study—which incorporated data from industry responses, government and industry executive interviews, numerous studies, and reports—indicate that early preacquisition activities executed in a rigorous fashion can significantly reduce the risk of cost and schedule growth. In this paper, the root causes of the cost and schedule growth are discussed as well as techniques and alternatives to improve program performance.

KEYWORDS: acquisition practices; project management; systems engineering; federal government

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INTRODUCTION

The motivation of this study was to ascertain the causes of cost and schedule growth on major programs by the Department of Defense (DOD) and Intelligence Community (IC). What this study found was that one of the golden axioms of program management remains true—namely, that most unsuccessful programs fail at the beginning. The principal causes of growth on these large-scale programs can be traced to several causes related to overzealous advocacy, immature technology, lack of corporate technology roadmaps, requirements instability, ineffective acquisition strategy, unrealistic program baselines, inadequate systems engineering, and workforce issues.

This study was undertaken as part of a continual effort to improve the organizational acquisition processes. One specific area that will certainly help stem the tide of cost growth on future government developments is to develop a more rigorous preacquisition phase. Preacquisition represents the activities and deliverables that occur prior to the program entering the execution phase. These activities take place prior to the Program Initiation or milestone B according to the current DOD (2003) acquisition framework as shown in Figure 1. At this milestone, the Milestone Decision Authority (MDA) makes the decision to enter or not enter the acquisition phase. Although the DOD and IC have taken steps to improve acquisition cycle review gates and processes, much of the cycle remains tailorable, subject only to the criteria imposed by the MDA.

The value of this study is to add to the existing knowledge base of best acquisition practices in the federal defense and intelligence communities. The study results have identified specific recommendations that can be implemented by program managers on their programs. The recommendations presented in this paper for successful large-scale acquisition have been proven to be effective for large-scale systems such as weapons, vehicles, missiles, ships, satellites, and airplanes. These recommendations can also be applied to large-scale government IT projects as well because they too suffer from poor upfront planning (Government Accountability Office [GAO], 2006a) and similar best practices have also been observed in the IT project management literature (Murray, 2002).

Methodology

The methodology for this study encompassed evaluating information from four primary sources: (1) responses from six requests for information (RFIs) by industry; (2) more than 30 acquisition reports, documents, and studies; (3) interviews with 42 government and industry senior executives and

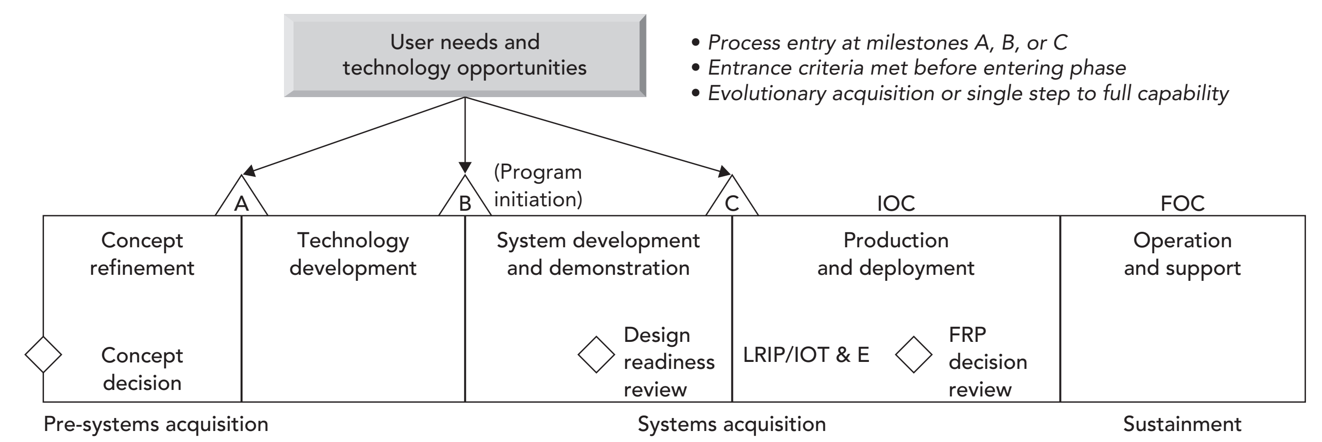

Figure 1: Defense acquisition management framework (DOD, 2003).

program managers; and (4) interviews with three national laboratories and two think tank organizations. A block diagram is presented in Figure 2 that details the process. Once the complete set of data was assembled, it was organized, assimilated, and reviewed for common themes. Best preacquisition practices for the federal defense and intelligence communities were then developed from the common themes.

The industry RFI responses were collected from several corporate partners with deep understanding and expertise in the acquisition arena. These RFI responses have been treated as confidential and proprietary. Many of the reports, studies, and documents, such as GAO reports, are open to public dissemination. Some of the data collected from IC and DOD programs is classified and proprietary and was treated as such. The government and industry executive interviews as well as the interviews with think tanks and laboratories were handled as confidential and proprietary.

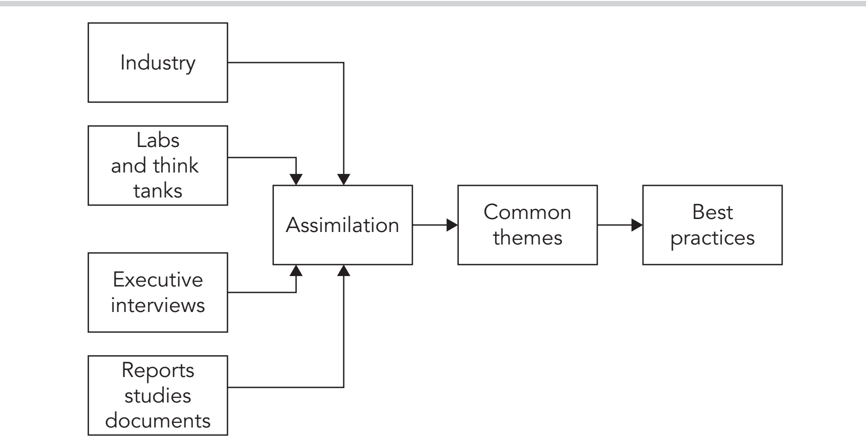

Figure 2: Process flow for this study.

Findings

The findings of this study are listed here within by section. Each section describes a specific study result, which includes overzealous advocacy, immature technology, lack of corporate technology roadmaps, requirements instability, ineffective acquisition strategy, unrealistic program baselines, inadequate systems engineering, and workforce issues.

Overzealous Advocacy

Although overzealous advocacy is difficult to quantify, its impact is discussed in almost all the data sources as one of the principal causes of cost and schedule growth. Advocacy by itself is neither good nor bad; however, it can have a positive or negative influence on program success. From a positive standpoint, advocacy can help initiate a program and can ensure consistent support throughout the program's life cycle. On the other hand, overzealous advocacy can lead to overly optimistic cost, schedule, and inflated performance estimates and, in the worst cases, suppression of bad news. This negative brand of advocacy exercised prior to the program initiation milestone has resulted in unrealistic program cost, schedule, and technical baselines, ultimately leading to cost and schedule growth for many DOD and IC programs. The root causes of negative advocacy can be traced to several root causes: the desire of an agency or contractor to gain positive political light, the desire of a federal agency to insert a budget wedge into congressional language for a program, or at times personal gain to achieve a promotion.

For example, a March 2007 *Washington Post* article by Merle (2007) on a Navy combat ship program that is close to $100M over budget per vessel describes how the program suffered from "excess optimism" and states that the contract structure did not encourage either the government or contractor to determine a realistic cost. Additional evidence derived from the study interviews and responses points to short government program manager tenure, which leads to a lack of accountability and, ultimately, overzealous advocacy. At many DOD and IC organizations, the data cites frequent senior management turnover as an issue that leads to a culture where it is "hard to establish accountability" and "no ownership of the program." In many cases, the program champion initially sells the program to Congress at certain cost, schedule, and performance baseline. Soon after the program is awarded, the program champion is reassigned or transferred to another position. Subsequently, the next program manager inherits an oversold program. One suggested solution is to enforce program manager tenures of five to six years versus the two to three years, which are typical of most government acquisition organizations. Industry can also play a part and fuel overzealous advocacy if a low bid is submitted to the government for a large acquisition in order to capture the contract. Further complicating the issue is that industry also fears providing the government bad news, as one response indicates "the prime contractor should not have to fear retribution for bearing bad news." Thus, overzealous advocacy exists on both the government and contractor sides.

One technique to counteract the powerful advocacy forces that underestimate cost, schedule, and performance and muffle bad news is to develop a comprehensive stakeholder communication plan early preacquisition phase. As the 2002 Booz Allen Hamilton report (2002; hereafter BAH) on large-scale systems growth recommends, large-scale acquisition organizations must develop communication practices that emphasize consistent reporting methods to ensure timely, relevant, and accurate financial, schedule, and technical reporting on all programs. For example, a GAO (2007a) report recommends increasing transparency into a program by developing a firm cost, schedule, and performance baseline for those elements considered far enough along to be in system development and demonstration, and report against that baseline. Moreover, the Defense Science Board report (DOD, 2003; hereafter DSB) recommends requiring credible cost assessments prior to program initiation to counterbalance advocacy. To further bolster this recommendation, many of the responses, interviews, and reports cite a "need for open communication between Government and contractors to discuss issues as they arise." And finally, if such a plan exists, this would allow decision makers to "re-examine decisions as new information is disclosed."

As previously stated, the case study data indicate that many programs move into the execution phase too early due to overzealous advocacy. This is one of the cognitive traps that a 2006 *Harvard Business Review* article by Bazerman and Chugh call "bounded awareness." Bounded awareness prevents people from seeing, seeking, using, or sharing highly relevant information during the decision-making process. The most worrisome aspect of this trap is when decision makers are motivated to favor a particular outcome. When organizations rush into the execution phase before all the facts are in, they create hypotheses and seek to confirm them rather than questioning them. Bazerman and Chugh (2006) suggested a technique to generate contradictory evidence is to assign a "devil's inquisitor" role to a member of the group. The "devil's inquisitor" will ask questions instead of arguing an alternate point of view and pushes people to look for additional evidence outside of their bounded awareness. Specifically, the DSB (2003) cited examples where programs fixated on a technical solution and architecture well before all alternatives had been explored.

In summary, the study data show that in order to counteract overzealous advocacy, a communication plan should be developed and delivered prior to program initiation that lists all the stakeholders and describes the process, form, and method of how decision makers will be supplied with timely information. This plan will allow decision makers to interpret early warning signs of a major problem and expeditiously address it, such as a significant cost, schedule, or performance issue. In addition, agencies should consider incorporating either internal or external reviews of their programs and assigning a "devil's inquisitor" to promote critical thinking prior to making a decision.

Immature Technology

When a program chooses to extend technology invention into the acquisition phase, there is a very high risk of experiencing technical maturity issues. These unexpected technical issues, which have systematic effects throughout the entire program, can require significant money and time to mature. Many of these technology issues can be traced to the collective desire of government and contractor program proponents to push state-of-the-art technology. The result has been program cost and schedule growth for many programs and cancellation for some.

The effects of initiating a large-scale acquisition with immature technology have been addressed in several reports. Recently, a GAO study (2006b) on selected major weapons programs reviewed 54 DOD programs and performed an analysis of the cost growth as a function of technology maturity at key milestones. Results from the report are shown in Figure 3 and show that only 10% of the assessed programs demonstrated mature technologies at the development start. By the time of their design review, only 43% had reached critical technology maturity, and by the time of production only 67%—that, is one-third did not achieve critical technology

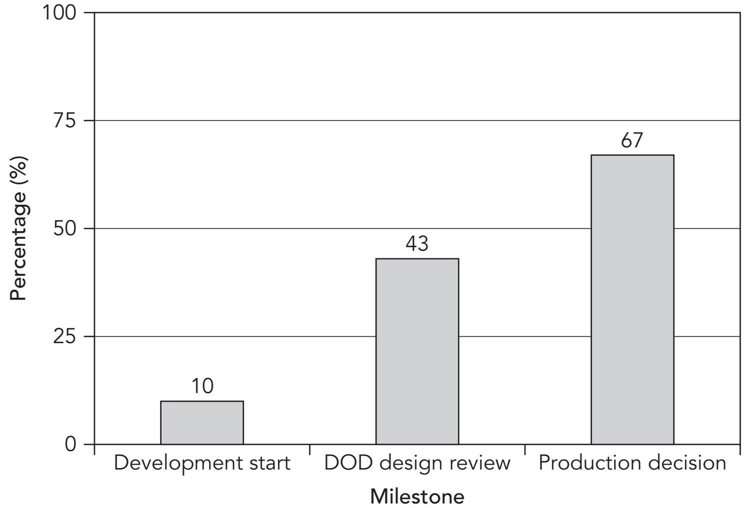

Figure 3: Percentage of programs that achieved critical technology maturity levels at key milestones from GAO (2006b).

maturity by production. The data illustrate that once a program is behind on technology development, it stays behind.

The ramifications of the data in Figure 3 are shown in Figure 4. Following through on this data, the GAO study found that programs with mature technology at key milestones had average cost overruns of 4.8%, while programs with immature technology had average cost overruns of 34.9%. This data clearly show technology immaturity can lead to cost growth.

In order to determine the maturity of a technology, a Technology Readiness Level (TRL) scale was developed by the National Aeronautics and Space Administration (NASA) and DOD to assess the maturity level of a technology prior to incorporation of the technology into a system or subsystem. Table 1 shows the NASA (Mankins, 1995) and DOD (2005) definitions of TRLs. Many of the responses and interviews suggest that technologies be matured to a "TRL of 4–5" or "TRL 6–7" before proceeding to large-scale acquisition, which is at the program initiation milestone. One advantage is that there is "a huge economic force multiplier in making the up-front investment to ensure that the technology is mature prior to acquisition." Furthermore, the responses and interviews both explicitly state that new state-of-the-art hardware less than TRL 4 and validated in parallel with program execution usually resulted in compromised mission success. And finally, another response states that all stakeholders must "communicate and agree on TRL for each new technology early in program."

One example of how technology immaturity contributes to rising costs is currently illustrated in the NPOESS satellite program where only 1 of the 14 critical technologies was mature at the production decision in 2002 August (GAO, 2006b). By 2006, the unit costs increased by 34%, triggering a Nunn-McCurdy breach and congressional review in January 2006. In addition, the first NPOESS large-scale launch slipped 17 months and could result in a gap in large-scale coverage of at least three years. Another example is the F-22A air superiority fighter that has increased by 188.7% per unit. Two of its technologies, the integrated avionics and stealth, did not mature until several years after the development was started. On the Army's Future Combat System (FCS), none of the program's critical technologies are fully mature, and only 18 are nearing full maturity (GAO, 2006b). This program is currently suffering a 54.4% per unit cost increase with the last procurement scheduled for 2012.

The data from this study support the view that the government does not fully review technologies prior to beginning an acquisition. As one response states: "the government pushes state of the art in technology, operates with unstable requirements, and doesn't adequately develop technology before using it." Other responses from programs that suffered cost growth state

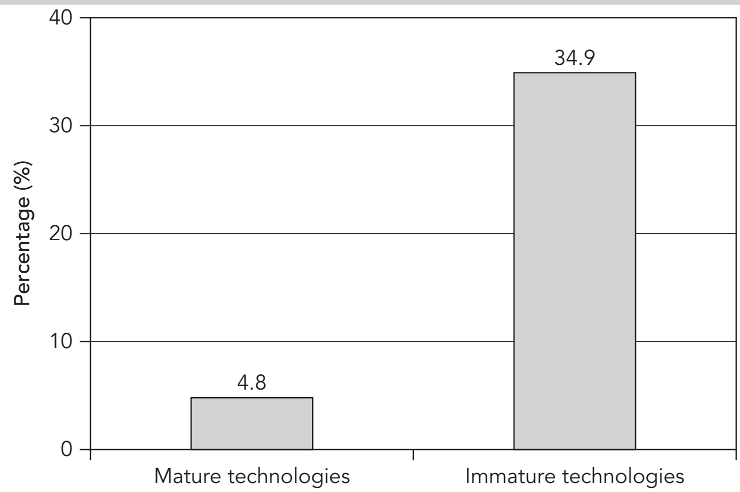

Figure 4: Average program research, development, test, and evaluation cost growth from first full estimate from GAO (2006b).

TRL	Description
1	Basic principles observed and reported
2	Technology concept and/or application formulated
3	Analytical and experimental critical function and/or characteristic proof of concept
4	Component and/or breadboard validation in laboratory environment
5	Component and/or breadboard validation in relevant environment
6	System/subsystem model or prototype demonstration in relevant environment
7	System prototype demonstration in operational environment
8	Actual system completed and "flight qualified" through test and demonstration
9	Actual system "flight proven" through successful operations

Table 1: TRL levels and descriptions from NASA and DOD.

that the "common thread between the programs is that they counted on technology that had not been adequately developed prior to ATP." Conversely, the same contractor states that a successfully managed program "implemented mature technology in its upgrades program."

In many of the cases previously discussed, programs were initiated without sufficient technology assessments, resulting in cost and schedule growth and in the worst cases, failures discovered in operations. Many of these cost overruns could have been alleviated if rigorous technology assessments were completed prior to program execution to ensure that the technologies were sufficiently matured to a high TRL level prior to acquisition. Most of the data indicates that a TRL 6 to be the best level for insertion in an acquisition.

Lack of Corporate Technology Roadmaps

Another area directly related to the technology immaturity issue is the fact that many government organizations have no corporate investment strategy that links technology development in the R&D directorates to the operational directorates. Studies by the GAO (2006b, 2006c) and BAH (2002) supported the idea that government acquisition organizations should develop an overall investment strategy for their large-scale programs. The existence of a corporate investment strategy will enable an organization to align efforts and mature selected technologies to the appropriate TRL level for insertion into an acquisition program. For example, one GAO (2006d) study reported on improving DOD technology transition processes recognized that successful industry practices center on a strong strategic planning function that defines critical investment priorities, and a structured process that defines the path toward a technology's transition to product development. Also, the technology transition is supported internally by technology transition agreements that hold the corporate research labs accountable for what they must deliver.

Much of the study data echoes similar sentiments in that DOD and IC agencies need "an evolutionary plan to evolve capabilities with future technologies commensurate with risk." When the government buys one unit per purchase, it does not buy down technology risk. Study responses and interviews that support the development of roadmaps state that the government's "desire for transformational capabilities, increased competition environment, and tight budgets lead to inadequate program baselines. Establishing the program baseline discipline is not easy as it requires a comprehensive strategic business plan vetted through senior leadership." Adequate support for the industrial base requires the government develop a "forward-looking plan with systematic purchases identified to allow industrial base retention planning." The interviews and responses recommend that industry and government "fund technology development through qualification prior to incorporation into an operational development program." This implies maturing technology to high TRL levels such as TRL 8 prior to program initiation.

The study data show that a lack of corporate technology roadmaps with well-defined technology maturation and insertion dates continues to impede the maturation of technology for insertion into large-scale systems. This state of affairs will continue to hinder the maturation of technology for large-scale systems until a corporate investment strategy is developed and adhered to by each DOD and IC agency, which in turn will help stem the tide of cost and schedule growth in DOD and IC acquisition programs.

Requirements Instability

Within the DOD and IC, it is commonly understood that the addition or modification of requirements almost always leads to cost and schedule growth—but nonetheless this practice continues. There are several causes that have led to this current state of affairs even though the net effect of this requirements instability continues to lead to significant cost and schedule growth on many major developments.

Large-scale developments have become more critical to meeting national security needs and the number of users continues to increase. This diverse array of government officials and organizations often demand new or increased capabilities to satisfy their unmet needs, which inevitably results in new or modified requirements. One study source noted that the "larger user community involvement in defining interfaces and requirements drive us to new technologies and use of large systems of systems." In many cases these new or modified requirements stretch the technology challenges, which result in cost and schedule expansion. Further exacerbating requirements stability issues, recent DOD and IC programs have adopted approaches to satisfy all requirements by acquiring large, complex systems that stretch the technology and engineering challenges to extreme limits.

A recent *Washington Post* article by Capaccio (2007) reported on the new presidential helicopter program, which has increased in cost by 34% for system design and construction of helicopters and stated that the Navy and contractor "didn't seem to be on the same page in terms of what the requirements were and what exactly the contractor was required to deliver." The DSB report (DOD, 2003) identified requirements growth as a primary driver of cost increases and schedule delays. Specifically, the report found that the failure to control requirements growth during the development implementation stage contributed significantly to cost increases on several large-scale programs. Nowinski and Kohler (2006) described the "tyranny of the requirements process" and that the requirements for the nation's first photographic large-scale system CORONA was to "do the best you can in the shortest possible time." Moreover, the requirements for the follow-on system to CORONA were outlined in a one-page memo from the Director of Central Intelligence (DCI) to the Director of the NRO—that system was delivered in five years. And finally, the document for the nation's first near-real-time digital imaging large scale was a one-and-a-half-page memo from the United States Intelligence Board—the system was delivered in five years. According to Nowinski and Kohler (2006), these successful government programs were driven by urgent mission needs established at the national level and garnered broad support from the executive and congressional branches.

An example of a program that has suffered requirements growth has been the Space-Based Infrared System High (SBIRS-High) large-scale program. Throughout this program, the DOD continued to allow new requirements to be added well into the acquisition phase for the program, culminating with 18 Key Performance Parameters (KPPs). The DOD (2003) panel members suggest that four to five KPPs per program as a rule of thumb are sufficient. Currently, the SBIRS-High program is suffering from a 315% cost increase relative to the original 1996 estimate primarily attributed to not adequately defining the requirements up front and not controlling additional requirements growth (DOD, 2003). Figure 5 illustrates how requirements changes have directly impacted the cost growth for the SBIRS-High program. In short, Figure 5 shows that requirements added more than $1B to the cost of the program.

Another example shown in Figure 6 is the Advanced Extremely High Frequency (AEHF) communication satellite program, which experienced dramatic cost growth $1.08B from May 2000 to November 2001 (DOD, 2003). The cost growth was attributed to two factors: (1) a cost growth of $0.36B (20%) to implement the same requirements used to define the May 2000 budget and (2) a cost growth of $0.72B (over 40%) to fund new requirements. This case study illustrates the direct relationship between requirements and cost growth. In summary, these two examples provide evidence that unstable requirements can lead to significant cost growth.

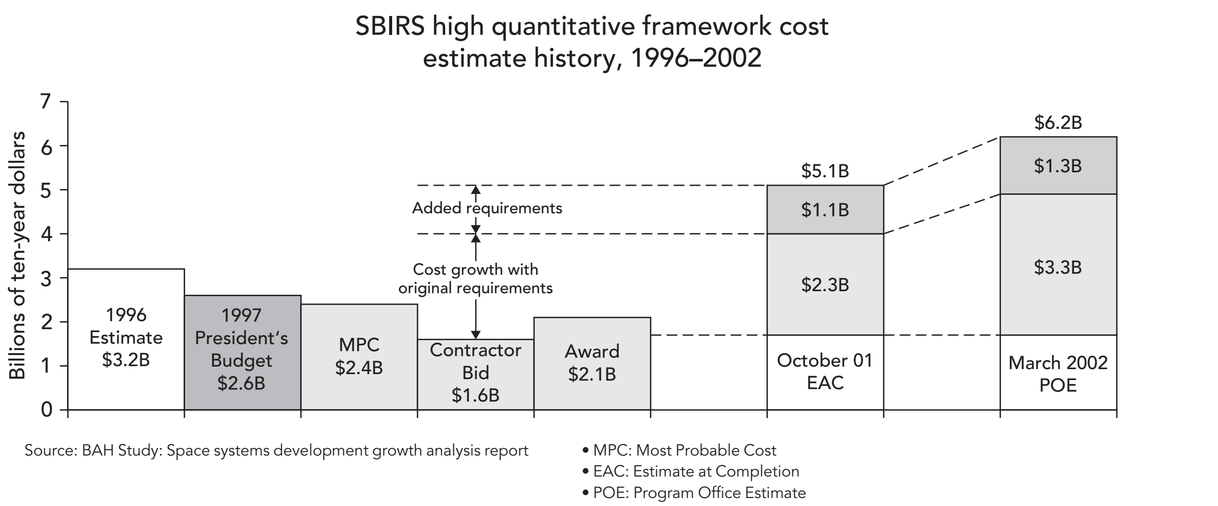

Figure 5: SBIRS-High cost growth due to requirements instability.

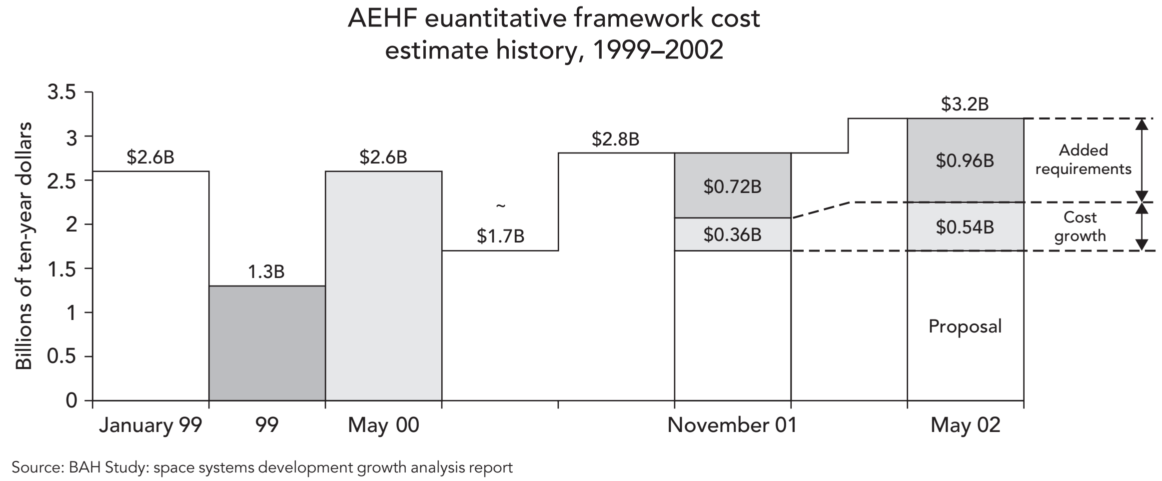

Figure 6: AEHF cost growth due to requirements instability.

There have been success stories to show that controlling requirements growth can keep cost under control. In an effort to control requirements, one successful program cites that the program objectives were "clearly stated in the proposal and were not allowed to creep upward in scope." In order to minimize requirements changes, this program adopted a mantra of keeping the "requirements creep camel's nose from gtting under the tent." As a result, the project officials resisted the desire to add requirements beyond the baseline but rather focused on achieving the original important objectives. In the end, engineering changes were minimal and limited to "make play" changes only. The management team was able to concentrate on managing implementation of the program instead of continually reinventing it. The vehicle was delivered on time and under the cost cap.

Another developer practices a "maintaining the baseline" approach to its large-scale developments. The result of this developer's adherence to a "maintaining the baseline" approach is evident in its successful completion of over 60 systems, the majority of which were on time and schedule and with a few even experiencing negative cost growths. Other keys to success mentioned include "simple interfaces and stable requirements" and setting a program mandate of a "just say no gate to new requirements past PDR" and to lock "program requirements at System Readiness Review (SRR)." One response stated that the government "needs to understand requirements completely as the baseline is established" and that the "baseline should be done before releasing the RFP."

Prior to program initiation, the DSB report (DOD, 2003) recommends: (1) the assessment of the impact of proposed requirements, with an emphasis on cost; (2) the creation of an approved requirements definition; and (3) that new or revised requirements must be accepted by the requirements lead prior to utilization. These steps must be completed before program acquisition initiation. Finally, the BAH report (2002) recommends that the concept of operations (CONOPS) and appropriate requirements documents always precede new acquisition starts.

It must be noted that at times the interplay between technology immaturity and requirements can muddy the requirements waters. Many programs cite requirements instability as a primary cause of schedule and cost growth. However, a program can have a very good requirements definition that meets customer needs but technology immaturity will cause a requirements redefinition in an attempt to make requirements fit the technology. If this technology immaturity is not recognized, this looks like an inadequate requirements definition. Care should be taken when analyzing the root causes of a cost or schedule overrun.

In summary, requirements changes during the program execution phase can have significant impacts on a program's life-cycle cost and schedule. Best practices for successful programs recommend having a government approved requirements baseline early in the program and a no change policy after the program initiation milestone.

Ineffective Acquisition Strategy and Contractual Practices

The study data suggest that best contractual practices and acquisition strategy indicate that block buys, contracting methods, award fees, and incentive structures should be considered as part of the preacquisition phase. Many of the study responses state that government should consider block buys of large-scale systems and that this strategy would "permit cost efficiencies, especially if sharing can occur across programs." This strategy may also assist in buying down technology risk and maintaining a robust industrial base compared to buying one system at a time. These comments are in synch and intertwined with the corporate technology roadmaps in the second section of this paper.

With regards to negotiating contracts, all the industry RFI responses supported Alpha contracting, which is negotiating that takes place face-to-face throughout the entire contract to address any issue. Alpha contracting is based on a government and contractor partnership aimed at finding solutions together. One response indicates that “Alpha contracting saves time,” and another states it is best to consider award fee criteria and metrics based on “shoulder-to-shoulder” Alpha contracting. Overall, industry supports Alpha contracting since it seems to minimize communication issues and speed decisions.

The other common theme centered on award fees and how to develop and execute them. For example, one response suggested to “incentivize the contractor both positively and negatively and institute innovative reward techniques for cost reduction.” Also the government should consider a “metrics-based award fee criteria.” Another response stated that the government should “balance financial incentives against risk of failure.” And finally, the data suggest that “incentive structures are most effective when fee is aligned with program objectives” and use a “tailored mix of base, award, and incentive fees.”

In summary, the data suggest that the government should consider block buy approaches to reduce technology risks and to maintain a strong industrial base. The government should consider implementing Alpha contracting because it was mentioned as the best approach for defining and negotiating contracts. The responses regarding incentive structure indicate that the government should consider incentives thoroughly prior to releasing a request for proposals (RFP). Furthermore, the government should consider whether award fees should be applied for cost reduction and what mix of incentive structures is the best approach to motivating developers of large-scale systems.

Unrealistic Program Baselines

In addressing the root causes of inaccurate cost and schedule baselines, the study data recommend that the government should establish the program baseline prior to releasing the RFP. As stated in the DSB (DOD, 2003), unrealistic cost estimates lead to unrealistic budgets and unexecutable programs. The industry responses, interviews, and reports all support this view and further state that most initial program estimates for large-scale programs do not accurately reflect the total life-cycle program cost. This current state of affairs has several root causes: (1) advocacy, not realism, dominates the program formulation phase; (2) inadequate technical, operational, and system understanding in the preacquisition phase; (3) a sense of urgency to insert a program budget wedge; and (4) a reliance on contractor cost proposals.

As shown in Table 2 (GAO, 2006b), most DOD programs are costing more and taking longer. Furthermore, this table shows the significant reduction in the buying power of the DOD for each of these programs, which achieves a reduced return on investment. Many of these programs suffer from technology and design issues (i.e., an approved cost, schedule, and performance baseline).

More specifically, the responses and interviews recommend that “a program baseline has to be established at the time of the proposal to create a cost/schedule baseline for the program.” Furthermore, if a baseline is not created early in the program, the results can be disastrous, as one response states that “unrealistic cost and schedule expectations during proposal result in catastrophic consequences.” Another response pointed out on a program that suffered cost growth, “plans were unrealistic; we never had a baseline until well into the program.” Finally, regarding initial cost estimates, many of the responses and interviews suggest having the cost personnel to be an integral part of the program office. As one response states, “cost groups should be part of the program not external,” and another interview states that cost groups “drive while they are looking in the rear view mirror—estimates based on past.” The results

Program	Initial Estimate →	Initial Quantity	Latest Estimate →	Latest Quantity	Percent of Unit Cost Increase
Joint Strike Fighter	$189.8 billion	2,866 aircraft	$206.3 billion	2,458 aircraft	26.7
Future Combat Systems	$82.6 billion	15 systems	$127.5 billion	15 systems	54.4
F-22A Raptor	$81.1 billion	648 aircraft	$65.4 billion	181 aircraft	188.7
Evolved Expendable Launch Vehicle	$15.4 billion	181 vehicles	$28.0 billion	138 vehicles	137.8
Space-Based Infrared System High	$4.1 billion	5 satellites	$10.2 billion	3 satellites	315.4
Expeditionary Fighting Vehicle	$8.1 billion	1,025 vehicles	$11.1 billion	1,025 vehicles	35.9

Table 2: Examples of DOD programs with reduced buying power (GAO, 2006b).

	First Full Estimate	Latest Estimate	Percentage Change
Billions of constant 2006 dollars			
Total cost	$547.7	$627.4	14.6
RDT&E cost	$120.4	$164.9	37.0
Weighted average acquisition cycle time	154.5 months	180.2 months	16.7

Table 3: Cost and cycle time growth for 26 weapon systems.

have been that many weapons programs cost more, and acquisition times continue to increase (GAO, 2006b), as shown in Table 3.

One common theme that arose during this study on initial cost estimates revolves around low bid proposals. The industry responses, interviews, and reports mention that the lowest bidder approach is rarely effective at controlling cost. In most cases, the initial cost and schedule baselines are not realistic when the government tries to buy at the lowest cost. In these cases, the contractor is motivated to produce the lowest possible price when cost is used as the dominant variable. The study data suggest that "cost and schedule margins are not realistic when government tries to buy lowest cost." The reason for a low bid estimate may be symptomatic of the fact that since 1986 many tier 2 firms have consolidated under five aerospace primes. During this consolidation, many critical systems were considered for competition by both DOD and IC customers. In an effort to consolidate, both incumbent and nonincumbent firms offered aggressive bids because these long-term programs can sustain a business sector for many years.

A common practice of limiting cost growth is establishing an early program baseline that is maintained throughout the entire development. Industry and labs that build and deliver large-scale systems provide evidence that drivers of successful large-scale programs to include adequate, stable, and properly phased funding with an acknowledged management reserve to include a sufficient margin at the outset of the program. As one response noted, "two elements of program execution that strongly affect cost effectiveness are technical requirements (maturity and stability) and funding (adequacy, timing, and stability). The government and contractor must join together to proactively manage these elements."

The topic of management reserve deserves special attention as it was mentioned in almost all studies, reports, and RFI responses as an acquisition strategy requirement. In some government agencies, the program managers are not allowed to officially budget an acknowledged management reserve for their programs. This lack of management reserve forces the program manager to manage with no margin when an issue arises but to shift baseline dollars. The effect is that it weakens the program manager's ability to manage the program efficiently and effectively. Both the DSB (DOD, 2003) and BAH (2002) reports recommended that programs be budgeted to the 80th percentile of the cost estimate probability distribution not the mean of cost distribution and that the government should establish a 20–25% reserve within this amount. Their recommended assessments include independent cost estimates, independent program reviews, and independent senior advisory reviews at key milestones.

One successful program cites establishing adequate schedule and cost margins at the beginning of the development phase and carefully managed their consumption. The result was a program that was delivered on time and cost. A design to cost approach, where the best performance is achieved within a fixed cost, was also mentioned as a cost-reducing technique in several RFI responses. In order to employ this approach, an organization must perform extensive system trade studies prior to ATP in order to clearly understand the system impacts of trading cost and performance. This approach has been very successful for maintaining cost and schedule by one developer in several of its successful large-scale programs.

In summary, prior to releasing a RFP, the DOD and IC must do a better job estimating cost and schedules for major acquisitions. The data presented in this section suggest that the government must establish a high fidelity program baseline, using the latest cost, schedule, and risk tools, prior to releasing the RFP. At a high level, this includes developing a high-confidence cost estimate, integrated master schedule, and a government fixed (all requirements are approved) baseline.

Inadequate Systems Engineering

The continual push and pull between requirements and the technical solution is controlled and monitored by the systems engineering function. Systems engineering serves as the glue that binds the technical solution to the high-level requirements and maintains the program baseline. The results of this study show that inadequate systems engineering, coupled with a broken requirements process and immature technology, inevitably leads to program failure. Experienced systems engineers must be familiar with high-confidence system engineering tools that are needed to enable a comprehensive, intelligent understanding of the trades during the conceptual design phase of a program. Systems engineers must be able to decompose the system or subsystem under development to clearly understand the basic functions and potential limitations to avoid changes late in the acquisition life cycle.

Best practices from the International Council on Systems Engineering (INCOSE) systems engineering handbook (2004) states that the mission concept of operations (CONOPS), systems requirements document (SRD), statement of work (SOW), RFP, and contract data requirements list (CDRL) are of major use in the preconcept phase. The INCOSE handbook also recommends that the Systems Engineering Management Plan (SEMP)—the top-level plan that defines how the project will be organized, structured, and conducted, and describes the total engineering control process—be prepared early in the project, submitted to the customer, and used in technical management for the study and development phases of the project.

Inadequate systems engineering in government programs prior to ATP has been a frequent theme in all of the reports, studies, interviews, and RFI responses. One recent article by the GAO (2007b) on the Air Force's largest transport plane program that is currently over cost by $1B and behind schedule cites that the root cause was that the programs "failed at basic systems engineering practices" and that the contractor and government "underestimated the complexity" of the program. Nowinski and Kohler (2006) stated that critical front-end systems engineering trades, studies, and planning have not been performed on most major new government developments. According to the authors, these shortcomings have resulted in unanticipated design and test issues late in the development cycle, leading to extraordinary cost and schedule growth for many government systems. The DSB report (DOD, 2003) also noted that clear tradeoffs among cost, schedule, risk, and requirements have not been well supported by rigorous up-front systems engineering, budget, and management processes for most large-scale acquisitions.

Clearly, the data from this study recommend that the government should invest in systems engineering, understanding interfaces, technology assessment, system trades, and risk management prior to releasing an RFP. One interview captures these thoughts as the following: "Fact finding skill has atrophied. The government must know exactly what it wants—it must work system specs, interface control documents (ICDs), component specs in parallel with engineering development—including test verification (test is 40–60% of cost) to a mature state before RFP release. The seeds of failure are sown before RFP release." An RFI response suggests that the government evaluate all proposed concepts early on and gain consensus among the government, mission partners, users, and Congress. In addition, the responses recommend that the government not start a program without a CONOPS document and approved requirements baseline. Success factors on many programs are directly tied to "disciplined systems engineering, well-defined interfaces, and a single program office are essential elements of a successful program." The issue of interface management arose from several data sources as they stated that the government and industry "don't manage interfaces well" and that a successful program took "great care to minimize any interface changes, internally and externally." In particular, one source suggested "invest in systems engineering, specs, interfaces, technology, trades, and risks before acquisition RFP release" and having a "collaborative government-contractor SE team." Another response echoed the same sentiments on collaboration with, "in particular, stable requirements, collaborative systems engineering environment, and demonstrated technology."

All interviews and responses cite strong systems engineering as a critical factor for successful programs. One industry program implemented rigorous systems engineering ensured that the large-scale system requirements to implement the mission objectives were systematically flowed down to all elements of the program while keeping requirements within the capability of the available hardware. All requirements were documented in a database that linked all parent-child relationships and all verifications were also tracked in the database. Wherever practical, requirements were verified by test. In a faster, better, cheaper implementation, analyses and testing were performed to bound the design parameter ranges so that they did not have to be repeated when final "as built" design and performance data became available, saving weeks in the delivery schedule. Other programs that did not experience cost or schedule growth cite "extensive systems engineering and performance trades were conducted in the preacquisition phase and none after ATP." Best practices include the use of "risk identification, quantification, and management in source selection to improve cost realism." And finally, establishing "solid system specification (A-spec) and SRD early both established the technical and mission requirements."

In summary, the study data state that the lack of experienced systems engineering personnel has directly impacted the cost growth associated with several government programs. There have been considerable issues with managing requirements, interfaces, and trade studies in many recent government programs that experienced cost growth on both the government and contractor sides. Many sources cite the "loss of good systems engineering in the government and industry" as a reason for these issues. The up-front systems engineering must include: understanding interfaces, technology assessments, system trades, and risk management prior to releasing an RFP. It is clear that the DOD and IC must invest in people and processes that implement rigorous systems engineering in the preacquisition phase.

Inexperienced Workforce and High Turnover

Workforce issues should also be considered as part of the preacquisition activities. As Nowinski and Kohler (2006) stated, "The importance of a competent and experienced government program office cannot be underestimated." All of the reports, studies, interviews, and RFI responses point toward an inexperienced workforce and the short tenures of government personnel as major contributors to cost growth on government programs. Many state that short tenures of government program managers and other critical personnel make it difficult to enforce accountability and maintain the level of support to achieve acquisition success. As one response stated, it is "hard to establish accountability with high turnover." This is a huge loss for both the government and contractor for several reasons: (1) the loss of corporate program knowledge, (2) the learning curve and subsequent time for the new personnel to come up to speed, and (3) the time it takes to re-establish trust between the government program manager and contractor. The consequences of short program manager and critical personnel can be bad decisions, slow decisions, and inaction that can lead to cost and schedule growth. Finally, the study data indicate that the frequent senior management turnover is problematic in the government. When agency heads change every few years, they change the direction of the organization, leading to organizational turnover. One consequence can be that new management can implement greater internal reviews due to lack of familiarity of a program, ultimately leading to delays in the program.

In order to strengthen the government's acquisition staff, the DSB (DOD, 2003) recommends that all program managers be given an executable program with realistic requirements, budget, and schedule and extend tours of duty to a minimum of four years. Substantiation of this recommendation can be found in a recent GAO (2006c) report that stated while still in the preacquisition phase, Transformational Satellite Communication System (TSAT) and Space Radar have already cycled through one program director each. Moreover, the SBIRS-High program has had at least three program directors. Both SBIRS-High and TSAT have experienced significant cost growth, while Space-Based Radar is currently undergoing a program restructure. In many cases, the short tenure of the program manager and critical personnel encourage a short-term view of success that may lead to the suppression of bad news in order to maintain support for the program. Furthermore, the issue is "compounded by large numbers of staff, SETAs, and consultants, who are not directly responsible for end-to-end mission success." In general, all cite that the DOD and IC "reliance on support contractors perpetuates inability to develop future program managers/acquisition experts and delays decision process." As one interview states, "We don't need process—we need decision makers who know what they are doing."

A recommendation to retain acquisition personnel from the Defense Acquisition Performance Assessment report (DOD, 2006) suggests that the "SecDef should seek legislation to retain high performance military personnel in the acquisition workforce to include allowing military personnel to remain in uniform past the limitations imposed by the Defense Officer Personnel Management Act and augment their pay to offset the 'declining marginal return' associated with retired pay entitlement."

In the data from a recent *Harvard Business Review* article, Moss-Kanter (2006) found that for R&D team members to be truly productive, they have to have been with an organization for at least two years. In most government acquisition agencies, the civilian and military tours are on the order of a few years. Thus, when an individual is at his or her knowledge peak and can provide the most value, he or she is transferred into another position, usually out of the organization.

One remedy to the current acquisition workforce tenure issues is to review the experience level and tenure of all personnel involved in a major government development. One source suggests that "5–6 year rotations about right" and that "continuity was key" in their success. The data and interviews suggest large-scale developments that achieved considerable success in managing cost did so by establishing a small, experienced, and consistent team throughout the entire large-scale program. One data source states that "the primary key to success was the exemplary partnership demonstrated by the experienced, lean Government and Contractor team." Further proof can be found in the success of one industry program that attributed its success to: (1) maintaining a mission focus; (2) a lean, empowered, co-located team; (3) a focus on people versus processes; (4) an emphasis on product vs. paper; and (5) technology backups when development problems were incurred. This large-scale system met or exceeded all KPPs. It continues to fully operate and satisfy customer expectations more than three months beyond the design life. And finally, one lab reports that "the government team was more knowledgeable in many cases than the prime contractor . . . continuity of people was key."

In summary, an inexperienced workforce coupled with high turnover rates can be significant contributors to cost and schedule growth on many DOD and IC programs. These issues of inexperience and short program manager tenure must be addressed in order to reverse the current upward cost growth trends on many DOD and IC programs.

Conclusions

The results of this study are unambiguous that establishing a proper baseline in preacquisition offers the greatest impact on the acquisition success of a large-scale acquisition program. In order to contain cost and schedule growth on future DOD and IC large-scale acquisitions, the following best practices should be completed prior to entering the execution phase of a large-scale development. They include the following:

- Review and ensure all technologies are mature to a TRL of 6 and do not require extensive rework to be integrated.
- Review all program office personnel with a focus on the length of tour and experience level to ensure experienced personnel will be available for a minimum of four years.
- Have a government-approved requirements baseline that includes inputs from users and mission partners.
- Review the number and detail of KPPs and keep it to a maximum of six KPPs.
- Complete system and technology trades between performance cost and schedule, and have an end-to-end risk assessment.
- Complete system specification (A-Spec), CONOPS, SOW, SRD, and SEMP.
- Establish an end-to-end test program guideline, including software descriptions.
- Identify parts issues and establish dual sources if a part is on the critical path.
- Establish interface specification documentation for all hardware and software.
- Establish the acquisition strategy and contract vehicle and appropriate incentive structure.
- Establish a high-confidence cost and schedule baseline with identified management reserve.
- Establish a comprehensive stakeholder communication plan that expedites the timely communication of accurate program information for the execution phase.
- Review the industrial base capability for completing the program. This includes reviewing the prime, subcontractor, vendor, and suppliers.

Furthermore, in order to reduce cost and stem future cost growth, the study data suggest that government organizations should align technology development with program acquisition plans to reduce technology risk and maintain the industrial base. These integrated corporate technology roadmaps, which should consider evolvable architectures and technology maturation plans, must be developed to provide seamless flow from the technology development organizations to the operational organizations.

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