This GAO document *Cost Estimating and Assessment Guide* (GAO-09-3SP) is made available as a supplement to DOE's *Cost Estimating* Guide (DOE G 430.1-1). Contents of this GAO document that may be useful include

- The Best Practices checklist of seventeen items to help prepare cost estimates (starting on page 45),
- Changes in the uncertainty of cost estimates as technology develops (Figure 4),
- The 48 case studies throughout the document,
- Nine graded levels of technology readiness defined in Appendix XII, and
- Earned Value related award-fee criteria provided in Appendix XIII.

Project personnel should use the guide as applicable to Office of Science projects.

United States Government Accountability Office

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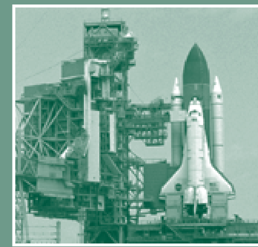
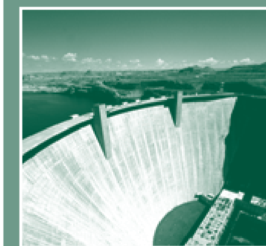
Applied Research and Methods




GAO COST ESTIMATING AND ASSESSMENT GUIDE

Best Practices for Developing and Managing Capital Program Costs

March 2009

GAO-09-3SP

PREFACE

The U.S. Government Accountability Office is responsible for, among other things, assisting the Congress in its oversight of the federal government, including agencies' stewardship of public funds. To use public funds effectively, the government must meet the demands of today's changing world by employing effective management practices and processes, including the measurement of government program performance. In addition, legislators, government officials, and the public want to know whether government programs are achieving their goals and what their costs are. To make those evaluations, reliable cost information is required and federal standards have been issued for the cost accounting that is needed to prepare that information.[1] We developed the Cost Guide in order to establish a consistent methodology that is based on best practices and that can be used across the federal government for developing, managing, and evaluating capital program cost estimates.

For the purposes of this guide, a cost estimate is the summation of individual cost elements, using established methods and valid data, to estimate the future costs of a program, based on what is known today.[2] The management of a cost estimate involves continually updating the estimate with actual data as they become available, revising the estimate to reflect changes, and analyzing differences between estimated and actual costs—for example, using data from a reliable earned value management (EVM) system.[3]

The ability to generate reliable cost estimates is a critical function, necessary to support the Office of Management and Budget's (OMB) capital programming process.[4] Without this ability, agencies are at risk of experiencing cost overruns, missed deadlines, and performance shortfalls—all recurring problems that our program assessments too often reveal. Furthermore, cost increases often mean that the government

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[1] Federal Accounting Standards Advisory Board, *Statement of Federal Financial Accounting Standards No. 4: Managerial Cost Accounting Standards and Concepts* (Washington, D.C.: July 1995).

[2] In the context of the Cost Guide, a program refers to all phases in a capital asset's life cycle—that is, concept analysis, technology definition, requirements planning, acquisition, and operations and maintenance.

[3] EVM is a project management tool that integrates the technical scope of work with schedule and cost elements for investment planning and control. It compares the value of work accomplished in a given period with the value of the work expected in that period. Differences in expectations are measured in both cost and schedule variances. The Office of Management and Budget (OMB) requires agencies to use EVM in their performance-based management systems for the parts of an investment in which development effort is required or system improvements are under way.

[4] Office of Management and Budget, *Preparation, Submission, and Execution of the Budget*, Circular No. A-11 (Washington, D.C.: Executive Office of the President, June 2006); *Management of Federal Information Resources*, Circular No. A-130 Revised (Washington, D.C.: Executive Office of the President, Nov. 28, 2000); and *Capital Programming Guide: Supplement to Circular A-11, Part 7, Preparation, Submission, and Execution of the Budget* (Washington, D.C.: Executive Office of the President, June 2006). www.whitehouse.gov/omb/circulars/index.html.

cannot fund as many programs as intended or deliver them when promised. The methodology outlined in this guide is a compilation of best practices that federal cost estimating organizations and industry use to develop and maintain reliable cost estimates throughout the life of a government acquisition program. By default, the guide will also serve as a guiding principle for our auditors to evaluate the economy, efficiency, and effectiveness of government programs.

The U.S. Government Accountability Office, the Congressional Budget Office (CBO), and others have shown through budget simulations that the nation is facing a large and growing structural deficit in the long term, primarily because the population is aging and health care costs are rising. As Comptroller General David Walker noted, "Continuing on this unsustainable path will gradually erode, if not suddenly damage, our economy, our standard of living and ultimately our national security."[5] New budgetary demands and demographic trends will place serious budgetary pressures on federal discretionary spending, as well as on other federal policies and programs, in the coming years.

As resources become scarce, competition for them will increase. It is imperative, therefore, that government acquisition programs deliver as promised, not only because of their value to their users but because every dollar spent on one program will mean one less available dollar to fund other efforts. To get better results, programs will need higher levels of knowledge when they start and standardized monitoring metrics such as EVM so that better estimates can be made of total program costs at completion.

[5] GAO, *21st Century Challenges: Reexamining the Base of the Federal Government*, GAO-05-325SP (Washington, D.C.: February 2005), p. 1.

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ABBREVIATIONS

ACWP	actual cost of work performed
ANSI	American National Standards Institute
AOA	analysis of alternatives
BAC	budget at completion
BCA	business case analysis
BCWP	budgeted cost for work performed
BCWS	budgeted cost for work scheduled
CAIG	Cost Analysis Improvement Group
CBO	Congressional Budget Office
CEA	cost-effectiveness analysis
CER	cost estimating relationship
COSMIC	Common Software Measurement International Consortium
CPI	cost performance index
CPR	contract performance report
C/SCSC	Cost/Schedule and Control System Criteria
CSDR	cost and software data report
DAU	Defense Acquisition University
DCAA	Defense Contract Audit Agency
DCMA	Defense Contract Management Agency
DOD	Department of Defense
EA	economic analysis
EAC	estimate at completion
EIA	Electronic Industries Alliance
ERP	enterprise resource planning
EVM	earned value management
FAR	Federal Acquisition Regulation
GR&A	ground rules and assumptions
IBR	integrated baseline review
ICA	independent cost assessment
ICE	independent cost estimate
IGCE	independent government cost estimate
IMS	integrated master schedule
IT	information technology
LCCE	life-cycle cost estimate
NAR	nonadvocate review
NASA	National Aeronautics and Space Administration
NDIA	National Defense Industrial Association
OMB	Office of Management and Budget
OTB	overtarget baseline
OTS	overtarget schedule
PMB	performance measurement baseline
PMI	Project Management Institute
SCEA	Society of Cost Estimating and Analysis
SEI	Software Engineering Institute
SLOC	source line of code
SPI	schedule performance index
TCPI	to complete performance index
WBS	work breakdown structure

INTRODUCTION

Because federal guidelines are limited on processes, procedures, and practices for ensuring credible cost estimates, the Cost Guide is intended to fill that gap. Its purpose is twofold—to address generally accepted best practices for ensuring credible program cost estimates (applicable across government and industry) and to provide a detailed link between cost estimating and EVM. Providing that link is especially critical, because it demonstrates how both elements are needed for setting realistic program baselines and managing risk.

As a result, government managers and auditors should find in the Cost Guide principles to guide them as they assess (1) the credibility of a program's cost estimate for budget and decision making purposes and (2) the program's status using EVM. Throughout this guide, we refer to program cost estimates that encompass major system acquisitions, as well as government in-house development efforts for which a cost estimate must be developed to support a budget request.

The basic information in the Cost Guide includes the purpose, scope, and schedule of a cost estimate; a technical baseline description; a work breakdown structure (WBS); ground rules and assumptions; how to collect data; estimation methodologies; software cost estimating; sensitivity and risk analysis; validating a cost estimate; documenting and briefing results; updating estimates with actual costs; EVM; and the composition of a competent cost estimating team.[6] The guide discusses pitfalls associated with cost estimating and EVM that can lead government agencies to accept unrealistic budget requests—as when risks are embedded in an otherwise logical approach to estimating costs. Since the Department of Defense (DOD) is considered the leader in government cost estimating, the guide relies heavily on DOD for terminology and examples that may not be used by, or even apply to, other federal agencies.

Chapters 1–17 of the Cost Guide discuss the importance of cost estimating and best practices associated with creating credible cost estimates. They describe how cost estimates predict, analyze, and evaluate a program's cost and schedule and serve as a critical program control planning tool. Once cost estimates have been presented to and approved by management, the chapters also establish the basis for measuring actual performance against the approved baseline plan using an EVM system.

Those chapters explain how EVM, if it is to work, must have a cost estimate that identifies the effort that is needed—the work breakdown structure—and the period of time over which the work is to be performed—the program schedule.[7] In essence, the cost estimate is the basis for establishing the program's

[6] Experienced and well trained staff are crucial to developing high-quality cost estimates.

[7] There is at this time no standard work breakdown structure for major automated information systems; there is only a generic cost element structure that DOD requires for major automated information system acquisition decisions.

detailed schedule, and it identifies the bounds for how much program costs can be expected to vary, depending on the uncertainty analysis. When all these tasks are complete, the cost estimate can be used to lay the foundation for the performance measurement baseline (PMB), which will measure actual program performance.

Since sound acquisition management requires more than just a reliable cost estimate at a project's outset, chapters 18–20 provide guidance on converting the cost estimate into an executable program and a means for managing program costs. Our program assessments have too often revealed that not integrating cost estimation, system development oversight, and risk management—three key disciplines, interrelated and essential to effective acquisition management—has resulted in programs costing more than planned and delivering less than promised. Therefore, chapters 18–20 address best practices in implementing and integrating these disciplines and using them to manage costs throughout the life of a program.

OMB has set the expectation that programs will maintain current estimates of cost. This requires rigorous performance-based program management, which can be satisfied with EVM. Chapters 18–20 address the details of EVM, which is designed to integrate cost estimation, system development oversight, and risk management. Additionally, for programs classified as major acquisitions—regardless of whether the development work is completed in-house or under contract—the use of EVM is a requirement for development, as specified by OMB.[8] The government may also require the use of EVM for other acquisitions, in accordance with agency procedures.

Since linking cost estimating and EVM results in a better view of a program and allows for greater understanding of program risks, cost estimators and EVM analysts who join forces can use each other's data to update program costs and examine differences between estimated and actual costs. This way, scope changes, risks, and other opportunities can be presented to management in time to plan for and mitigate their impact. In addition, program status can be compared to historical data to better understand variances. Finally, cost estimators can help EVM analysts calculate a cumulative probability distribution to determine the level of confidence in the baseline.

But bringing a program to successful completion requires knowing potential risks and identifying ways to respond to them before they happen—using risk management to identify, mitigate, and assign resources to manage risks so that their impact can be minimized. This requires the support of many program management and engineering staff and it results in better performance and more reliable predictions of program outcomes. By integrating EVM data and risk management, program managers can develop current estimates at completion (EAC) for all levels of management, including OMB reporting requirements. Therefore, chapters 18–20 expand on these concepts by examining program cost planning, execution, and updating.

[8] Major acquisition and investment means that a system or project requires special management attention because (1) of its importance to the mission or function of the agency, a component of the agency, or another organization; (2) it supports financial management and obligates more than $500,000 annually; (3) it has significant program or policy implications; (4) it has high executive visibility; (5) it has high development, operating, or maintenance costs; or (6) it is defined as major by the agency's capital planning and investment control process.

The Guide's Case Studies

The Cost Guide contains a number of case studies drawn from GAO program reviews. The case studies highlight problems typically associated with cost estimates and augment the key points and lessons learned that the chapters discuss. For example, GAO has found that in many programs cost growth results from optimistic assumptions about technological enhancements. Experts on cost estimating have also found that many program managers believe they can deliver state-of-the-art technology upgrades within a constrained budget before proof is available that the requirements are feasible. Studies have shown that it costs more to develop technology from scratch than to develop it incrementally over time.[9] Appendix II gives some background information for each program used in the case studies. (Appendix I is a list of auditing agencies.)

The Cost Guide in Relation to Established Standards

Our intent is to use this Cost Guide in conjunction with Government Auditing Standards and Standards for Internal Control in the Federal Government, commonly referred to as the yellow book and the green book, respectively.[10] If auditors cite compliance with these standards and internal controls and find inconsistencies between them and the Cost Guide, they should defer to the yellow and green books for the prevailing rules.

This guide's reference list identifies cost estimating guides and sources available from other government agencies and organizations that we relied on to determine the processes, practices, and procedures most commonly recommended in the cost estimating community. Users of the guide may wish to refer to those references for more information. In addition, we relied on information from the Society of Cost Estimating and Analysis (SCEA), which provides standards for cost estimating, and the Project Management Institute (PMI), which provides EVM standards.[11]

The Guide's Readers

The federal audit community is the primary audience for this guide. In addition, agencies that do not have a formal policy for conducting or reviewing cost estimates will benefit from it, because it will inform them of the criteria GAO uses in assessing a cost estimate's credibility. Besides GAO, auditing agencies include Inspectors General and audit services such as the Naval Audit Service and the Army Audit Agency. Appendix I lists other auditing agencies that GAO may contact at the start of an audit. The list may help ease the burden on agencies as they work to meet the needs of various oversight offices and should help speed up delivery of data request items.

We intend to periodically update the Cost Guide. Comments and suggestions from experienced users are always welcome, as are recommendations from experts in the cost estimating and EVM disciplines.

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[9] For more information on these studies, see GAO, Best Practices: Successful Application to Weapon Acquisitions Requires Changes in DOD's Environment, GAO/NSIAD-98-56 (Washington, D.C.: Feb. 24, 1998), pp. 8 and 62.

[10] See Comptroller General of the United States, Government Auditing Standards: January 2007 Revision, GAO-07-162G (Washington, D.C.: January 2007), and GAO, Standards for Internal Control in the Federal Government: Exposure Draft, GAO/AIMD-98-21.3.1 (Washington, D.C.: December 1997).

[11] Further information on SCEA and PMI is at www.sceaonline.org and www.pmi.org.

Acknowledgments

The Cost Guide team thanks the many members of the cost community who helped make the guide a reality. After we discussed our plans for developing the guide with members of the cost community, several experts expressed interest in working with us. The number of experts who helped us create this guide grew over time, beginning with our first meeting in June 2005. Their contributions were invaluable.

Together with these experts, GAO has developed a guide that clearly outlines its criteria for assessing cost estimates and EVM data during audits and that we believe will benefit all agencies in the federal government. We would like to thank everyone who gave their time by attending meetings, giving us valuable documentation, and providing comments. Those who worked with us on this guide are listed in appendix III. Additional acknowledgments are in appendix XVI.

CHAPTER 1

The Characteristics of Credible Cost Estimates and a Reliable Process for Creating Them

More than 30 years ago, we reported that realistic cost estimating was imperative when making wise decisions in acquiring new systems. In 1972, we published a report called *Theory and Practice of Cost Estimating for Major Acquisitions*, in which we stated that estimates of the cost to develop and produce weapon systems were frequently understated, with cost increases on the order of $15.6 billion from early development estimates.[12] In that report, we identified factors in the cost estimating function that were causing this problem and offered suggestions for solving or abating the problem of unexpected cost growth.

We found that uniform guidance on cost estimating practices and procedures that would be the basis for formulating valid, consistent, and comparable estimates was lacking within DOD. In fact, evidence showed that each military service issued its own guidance for creating cost estimates and that the guidance ranged from a detailed estimating manual to a few general statements. In addition, we reported that cost estimators often ignored this guidance.[13]

In that 1972 report, we also stated that cost estimates for specific systems were frequently revisions of previously developed estimates and that accurate revisions of both the original and updated cost estimates required documentation showing data sources, assumptions, methods, and decisions basic to the estimates. However, we discovered that in virtually every system we reviewed for the report, documentation supplying such information was inaccurate or lacking. Among the resulting difficulties were that

- known costs had been excluded without adequate or valid justification;
- historical cost data used for computing estimates were sometimes invalid, unreliable, or unrepresentative;
- inflation was not always included or was not uniformly treated when it was included; and
- understanding the proper use of the estimates was hindered because the estimates were too low.[14]

Another finding was that readily retrievable cost data that could serve in computing cost estimates for new weapon systems were generally lacking. Additionally, organized and systematic efforts were not made to

[12] Comptroller General of the United States, *Theory and Practice of Cost Estimating for Major Acquisitions*, B-163058 (Washington, D.C.: July 24, 1972), p. 1.

[13] Comptroller General of the United States, *Theory and Practice of Cost Estimating for Major Acquisitions*, pp. 26–27.

[14] Comptroller General of the United States, *Theory and Practice of Cost Estimating for Major Acquisitions*, pp. 28–32.

gather actual cost information to achieve comparability between data collected on various weapon systems or to see whether the cost data the contractors reported were accurate and consistent.[15]

Our conclusion was that without realism and objectivity in the cost estimating process, bias and overoptimism creep into estimates that advocates of weapon systems prepare, and the estimates tend to be too low. Therefore, staff not influenced by the military organization's determination to field a weapon system, or by the contractor's intention to develop and produce the system, should review every weapon system at major decision points in the acquisition.[16]

Basic Characteristics of Credible Cost Estimates

The basic characteristics of effective estimating have been studied and highlighted many times. Their summary, in table 1, is from our 1972 report, *Theory and Practice of Cost Estimating for Major Acquisitions*. These characteristics are still valid today and should be found in all sound cost analyses.

Table 1: GAO's 1972 Version of the Basic Characteristics of Credible Cost Estimates

Characteristic	Description
Clear identification of task	Estimator must be provided with the system description, ground rules and assumptions, and technical and performance characteristics Estimate's constraints and conditions must be clearly identified to ensure the preparation of a well-documented estimate
Broad participation in preparing estimates	All stakeholders should be involved in deciding mission need and requirements and in defining system parameters and other characteristics Data should be independently verified for accuracy, completeness, and reliability
Availability of valid data	Numerous sources of suitable, relevant, and available data should be used Relevant, historical data should be used from similar systems to project costs of new systems; these data should be directly related to the system's performance characteristics
Standardized structure for the estimate	A standard work breakdown structure, as detailed as possible, should be used, refining it as the cost estimate matures and the system becomes more defined The work breakdown structure ensures that no portions of the estimate are omitted and makes it easier to make comparisons to similar systems and programs
Provision for program uncertainties	Uncertainties should be identified and allowance developed to cover the cost effect Known costs should be included and unknown costs should be allowed for
Recognition of inflation	The estimator should ensure that economic changes, such as inflation, are properly and realistically reflected in the life-cycle cost estimate
Recognition of excluded costs	All costs associated with a system should be included; any excluded costs should be disclosed and given a rationale
Independent review of estimates	Conducting an independent review of an estimate is crucial to establishing confidence in the estimate; the independent reviewer should verify, modify, and correct an estimate to ensure realism, completeness, and consistency

[15] Comptroller General of the United States, *Theory and Practice of Cost Estimating for Major Acquisitions*, pp. 31–32.

[16] Comptroller General of the United States, *Theory and Practice of Cost Estimating for Major Acquisitions*, p. 32.

Characteristic	Description
Revision of estimates for significant program changes	Estimates should be updated to reflect changes in a system's design requirements. Large changes that affect costs can significantly influence program decisions

Source: GAO.

In a 2006 survey to identify the characteristics of a good estimate, participants from a wide variety of industries—aerospace, automotive, energy—as well as consulting firms and the U.S. Navy and Marine Corps corroborated the continuing validity of the characteristics in table 1.

Despite the fact that these basic characteristics have been published and known for decades, we find that many agencies still lack the ability to develop cost estimates that can satisfy them. Case studies 1 and 2, drawn from GAO reports, show the kind of cross-cutting findings we have reported in the past.

Because of findings like those in case studies 1 and 2, the Cost Guide provides best practice processes, standards, and procedures for developing, implementing, and evaluating cost estimates and EVM systems and data. By satisfying these criteria, agencies should be able to better manage their programs and inform decision makers of the risks involved.

Case Study 1: Basic Estimate Characteristics, from *NASA*, GAO-04-642

GAO found that the National Aeronautics and Space Administration's (NASA) basic cost-estimating processes—an important tool for managing programs—lacked the discipline needed to ensure that program estimates were reasonable. Specifically, none of the 10 NASA programs GAO reviewed in detail met all GAO's cost-estimating criteria, which are based on criteria Carnegie Mellon University's Software Engineering Institute developed. Moreover, none of the 10 programs fully met certain key criteria—including clearly defining the program's life cycle to establish program commitment and manage program costs, as required by NASA.

In addition, only 3 programs provided a breakdown of the work to be performed. Without this knowledge, the programs' estimated costs could be understated and thereby subject to underfunding and cost overruns, putting programs at risk of being reduced in scope or requiring additional funding to meet their objectives. Finally, only 2 programs had a process in place for measuring cost and performance to identify risks.

GAO, *NASA: Lack of Disciplined Cost-Estimating Processes Hinders Effective Program Management*, GAO-04-642 (Washington, D.C.: May 28, 2004).

Case Study 2: Basic Estimate Characteristics, from *Customs Service Modernization*, GAO/AIMD-99-41

GAO analyzed the U.S. Customs Service approach to deriving its $1.05 billion Automated Commercial Environment life-cycle cost estimate with Software Engineering Institute (SEI) criteria. SEI had seven questions for decision makers to use in assessing the reliability of a project's cost estimate and detailed criteria to help evaluate how well a project satisfies each question. Among the criteria were several very significant and closely intertwined requirements that are at the core of effective cost estimating. Specifically, embedded in several of the questions were requirements for using (1) formal cost models; (2) structured and documented processes for determining the software size and reuse inputs to the models; and (3) relevant, measured, and normalized historical cost data (estimated and actual) to calibrate the models.

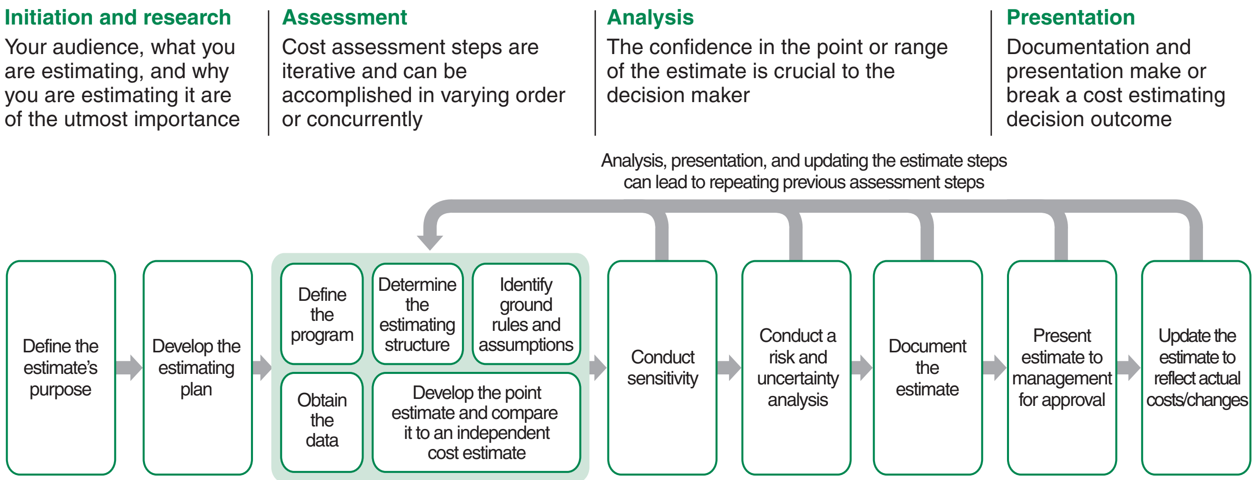
GAO found that Customs did not satisfy any of these requirements. Instead of using a cost model, it used an unsophisticated spreadsheet to extrapolate the cost of each Automated Commercial Environment increment. Its approach to determining software size and reuse was not documented and was not well supported or convincing. Customs had no historical project cost data when it developed the $1.05 billion estimate and did not account for relevant, measured, and normalized differences in the increments. Clearly, such fundamental changes can dramatically affect system costs and should have been addressed explicitly in Customs' cost estimates.

GAO, *Customs Service Modernization: Serious Management and Technical Weaknesses Must Be Corrected*, GAO/AIMD-99-41 (Washington, D.C.: Feb. 26, 1999).

A Reliable Process for Developing Credible Cost Estimates

Certain best practices should be followed if accurate and credible cost estimates are to be developed. These best practices represent an overall process of established, repeatable methods that result in high-quality cost estimates that are comprehensive and accurate and that can be easily and clearly traced, replicated, and updated. Figure 1 shows the cost estimating process.

Figure 1: The Cost Estimating Process



Source: GAO.

We have identified 12 steps that, followed correctly, should result in reliable and valid cost estimates that management can use for making informed decisions. Table 2 identifies all 12 steps and links each one to the chapter in this guide where it is discussed.

Table 2: The Twelve Steps of a High-Quality Cost Estimating Process

Step	Description	Associated task	Chapter
1	Define estimate's purpose	■ Determine estimate's purpose, required level of detail, and overall scope; ■ Determine who will receive the estimate	5
2	Develop estimating plan	■ Determine the cost estimating team and develop its master schedule; ■ Determine who will do the independent cost estimate; ■ Outline the cost estimating approach; ■ Develop the estimate timeline	5 and 6
3	Define program characteristics	■ In a technical baseline description document, identify the program's purpose and its system and performance characteristics and all system configurations; ■ Any technology implications; ■ Its program acquisition schedule and acquisition strategy; ■ Its relationship to other existing systems, including predecessor or similar legacy systems; ■ Support (manpower, training, etc.) and security needs and risk items; ■ System quantities for development, test, and production; ■ Deployment and maintenance plans	7
4	Determine estimating structure	■ Define a work breakdown structure (WBS) and describe each element in a WBS dictionary (a major automated information system may have only a cost element structure); ■ Choose the best estimating method for each WBS element; ■ Identify potential cross-checks for likely cost and schedule drivers; ■ Develop a cost estimating checklist	8
5	Identify ground rules and assumptions	■ Clearly define what the estimate includes and excludes; ■ Identify global and program-specific assumptions, such as ■ the estimate's base year, including time-phasing and life cycle; ■ Identify program schedule information by phase and program acquisition strategy; ■ Identify any schedule or budget constraints, inflation assumptions, and travel costs; ■ Specify equipment the government is to furnish as well as the use of existing facilities or new modification or development; ■ Identify prime contractor and major subcontractors; ■ Determine technology refresh cycles, technology assumptions, and new technology to be developed; ■ Define commonality with legacy systems and assumed heritage savings; ■ Describe effects of new ways of doing business	9

Step	Description	Associated task	Chapter
6	Obtain data	■ Create a data collection plan with emphasis on collecting current and relevant technical, programmatic, cost, and risk data; ■ Investigate possible data sources; ■ Collect data and normalize them for cost accounting, inflation, learning, and quantity adjustments; ■ Analyze the data for cost drivers, trends, and outliers and compare results against rules of thumb and standard factors derived from historical data; ■ Interview data sources and document all pertinent information, including an assessment of data reliability and accuracy; ■ Store data for future estimates	10
7	Develop point estimate and compare it to an independent cost estimate	■ Develop the cost model, estimating each WBS element, using the best methodology from the data collected, [a] and including all estimating assumptions; ■ Express costs in constant year dollars; ■ Time-phase the results by spreading costs in the years they are expected to occur, based on the program schedule; ■ Sum the WBS elements to develop the overall point estimate; ■ Validate the estimate by looking for errors like double counting and omitted costs; ■ Compare estimate against the independent cost estimate and examine where and why there are differences; ■ Perform cross-checks on cost drivers to see if results are similar; ■ Update the model as more data become available or as changes occur and compare results against previous estimates	11, 12, and 15
8	Conduct sensitivity analysis	■ Test the sensitivity of cost elements to changes in estimating input values and key assumptions; ■ Identify effects on the overall estimate of changing the program schedule or quantities; ■ Determine which assumptions are key cost drivers and which cost elements are affected most by changes	13
9	Conduct risk and uncertainty analysis	■ Determine and discuss with technical experts the level of cost, schedule, and technical risk associated with each WBS element; ■ Analyze each risk for its severity and probability; ■ Develop minimum, most likely, and maximum ranges for each risk element; ■ Determine type of risk distributions and reason for their use; ■ Ensure that risks are correlated; ■ Use an acceptable statistical analysis method (e.g., Monte Carlo simulation) to develop a confidence interval around the point estimate; ■ Identify the confidence level of the point estimate; ■ Identify the amount of contingency funding and add this to the point estimate to determine the risk-adjusted cost estimate; ■ Recommend that the project or program office develop a risk management plan to track and mitigate risks	14

Step	Description	Associated task	Chapter
10	Document the estimate	▪ Document all steps used to develop the estimate so that a cost analyst unfamiliar with the program can recreate it quickly and produce the same result; ▪ Document the purpose of the estimate, the team that prepared it, and who approved the estimate and on what date; ▪ Describe the program, its schedule, and the technical baseline used to create the estimate; ▪ Present the program's time-phased life-cycle cost; ▪ Discuss all ground rules and assumptions; ▪ Include auditable and traceable data sources for each cost element and document for all data sources how the data were normalized; ▪ Describe in detail the estimating methodology and rationale used to derive each WBS element's cost (prefer more detail over less); ▪ Describe the results of the risk, uncertainty, and sensitivity analyses and whether any contingency funds were identified; ▪ Document how the estimate compares to the funding profile; ▪ Track how this estimate compares to any previous estimates	16
11	Present estimate to management for approval	▪ Develop a briefing that presents the documented life-cycle cost estimate; ▪ Include an explanation of the technical and programmatic baseline and any uncertainties; ▪ Compare the estimate to an independent cost estimate (ICE) and explain any differences; ▪ Compare the estimate (life-cycle cost estimate (LCCE)) or independent cost estimate to the budget with enough detail to easily defend it by showing how it is accurate, complete, and high in quality; ▪ Focus in a logical manner on the largest cost elements and cost drivers; ▪ Make the content clear and complete so that those who are unfamiliar with it can easily comprehend the competence that underlies the estimate results; ▪ Make backup slides available for more probing questions; ▪ Act on and document feedback from management; ▪ Request acceptance of the estimate	17
12	Update the estimate to reflect actual costs and changes	▪ Update the estimate to reflect changes in technical or program assumptions or keep it current as the program passes through new phases or milestones; ▪ Replace estimates with EVM EAC and Independent estimate at completion (EAC) from the integrated EVM system; ▪ Report progress on meeting cost and schedule estimates; ▪ Perform a post mortem and document lessons learned for elements whose actual costs or schedules differ from the estimate; ▪ Document all changes to the program and how they affect the cost estimate	16, 18, 19, and 20

Source: GAO, DHS, DOD, DOE, NASA, SCEA, and industry.

[a] In a data-rich environment, the estimating approach should precede the investigation of data sources; in reality, a lack of data often determines the approach.

Each of the 12 steps is important for ensuring that high-quality cost estimates are developed and delivered in time to support important decisions.[17] Unfortunately, we have found that some agencies do not incorporate all the steps and, as a result, their estimates are unreliable. For example, in 2003, we completed a cross-cutting review at the National Aeronautics and Space Administration (NASA) that showed that the lack of an overall process affected NASA's ability to create credible cost estimates (case study 3).

Case Study 3: Following Cost Estimating Steps, from *NASA*, GAO-04-642

NASA's lack of a quality estimating process resulted in unreliable cost estimates throughout each program's life cycle. As of April 2003, the baseline development cost estimates for 27 NASA programs varied considerably from their initial baseline estimates. More than half the programs' development cost estimates increased. For some of these programs, the increase was as much as 94 percent. In addition, the baseline development estimates for 10 programs that GAO reviewed in detail were rebaselined—some as many as four times.

The Checkout and Launch Control System (CLCS) program—whose baseline had increased from $206 million in fiscal year 1998 to $399 million by fiscal year 2003—was ultimately terminated. CLCS' cost increases resulted from poorly defined requirements and design and fundamental changes in the contractors' approach to the work. GAO also found that

- the description of the program objectives and overview in the program commitment agreement was not the description used to generate the cost estimate;
- the total life cycle and WBS were not defined in the program's life-cycle cost estimate;
- the 1997 nonadvocate review identified the analogy to be used as well as six different projects for parametric estimating, but no details on the cost model parameters were documented; and
- no evidence was given to explain how the schedule slip, from June 2001 to June 2005, affected the cost estimate.

GAO recommended that NASA establish a framework for developing life-cycle cost estimates that would require each program to base its cost estimates on a WBS that encompassed both in-house and contractor efforts and also to prepare a description of cost analysis requirements. NASA concurred with the recommendation; it intended to revise its processes and its procedural requirements document and cost-estimating handbook accordingly.

GAO, *NASA: Lack of Disciplined Cost-Estimating Processes Hinders Effective Program Management*, GAO-04-642 (Washington, D.C.: May 28, 2004).

NASA has since developed a cost estimating handbook that reflects a "renewed appreciation within the Agency for the importance of cost estimating as a critical part of project formulation and execution." It has also stated that "There are newly formed or regenerated cost organizations at NASA Headquarters . . . . The field centers cost organizations have been strengthened, reversing a discouraging trend of decline."

[17] The 12 steps outlined in table 2 are appropriate for estimating the costs of large, complex programs. We note, however, that planning trade-offs, initial rough-order estimations, and other less visible analyses can be accomplished in less time than the process outlined in the table.

Finally, NASA reported in its cost handbook that "Agency management, from the Administrator and Comptroller on down, is visibly supportive of the cost estimating function."[18]

While these are admirable improvements, even an estimate that meets all these steps may be of little use or may be overcome by events if it is not ready when needed. Timeliness is just as important as quality. In fact, the quality of a cost estimate may be hampered if the time to develop it is compressed. When this happens, there may not be enough time to collect historical data. Since data are the key drivers of an estimate's quality, their lack increases the risk that the estimate may not be reliable. In addition, when time is a factor, an independent cost estimate (ICE) may not be developed, further adding to the risk that the estimate may be overly optimistic. This is not an issue for DOD's major defense acquisition programs, because an ICE is required for certain milestones.

Relying on a standard process that emphasizes pinning down the technical scope of the work, communicating the basis on which the estimate is built, identifying the quality of the data, determining the level of risk, and thoroughly documenting the effort should result in cost estimates that are defensible, consistent, and trustworthy. Furthermore, this process emphasizes the idea that a cost estimate should be a "living document," meaning that it will be continually updated as actual costs begin to replace the original estimates. This last step links cost estimating with data that are collected by an EVM system, so that lessons learned can be examined for differences and their reasons. It also provides valuable information for strengthening the credibility of future cost estimates, allowing for continuous process improvement.

[18] NASA, Cost Analysis Division, 2004 NASA *Cost Estimating Handbook* (Washington, D.C.: 2004), p. i. www.nasa.gov/offices/pae/organization/cost_analysis_division.html.

CHAPTER 2

Why Government Programs Need Cost Estimates and the Challenges in Developing Them

Cost estimates are necessary for government acquisition programs for many reasons: to support decisions about funding one program over another, to develop annual budget requests, to evaluate resource requirements at key decision points, and to develop performance measurement baselines. Moreover, having a realistic estimate of projected costs makes for effective resource allocation, and it increases the probability of a program's success. Government programs, as identified here, include both in-house and contract efforts.

For capital acquisitions, *OMB's Capital Programming Guide* helps agencies use funds wisely in achieving their missions and serving the public. The *Capital Programming Guide* stresses the need for agencies to develop processes for making investment decisions that deliver the right amount of funds to the right projects. It also highlights the need for agencies to identify risks associated with acquiring capital assets that can lead to cost overruns, schedule delays, and assets that fail to perform as expected.

OMB's guide has made developing accurate life-cycle cost estimates a priority for agencies in properly managing their portfolios of capital assets that have an estimated life of 2 years or more. Examples of capital assets are land; structures such as office buildings, laboratories, dams, and power plants; equipment like motor vehicles, airplanes, ships, satellites, and information technology hardware; and intellectual property, including software.

Developing reliable cost estimates has been difficult for agencies across the federal government. Too often, programs cost more than expected and deliver results that do not satisfy all requirements. According to the 2002 *President's Management Agenda*:

> Everyone agrees that scarce federal resources should be allocated to programs and managers that deliver results. Yet in practice, this is seldom done because agencies rarely offer convincing accounts of the results their allocations will purchase. There is little reward, in budgets or in compensation, for running programs efficiently. And once money is allocated to a program, there is no requirement to revisit the question of whether the results obtained are solving problems the American people care about.[19]

The need for reliable cost estimates is at the heart of two of the five governmentwide initiatives in that agenda: improved financial performance and budget and performance integration. These initiatives are

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[19] President George W. Bush, *The President's Management Agenda: Fiscal Year 2002* (Washington, D.C.: Executive Office of the President, OMB, 2002), p. 27.

aimed at ensuring that federal financial systems produce accurate and timely information to support operating, budget, and policy decisions and that budgets are based on performance. With respect to these initiatives, President Bush called for changes to the budget process to better measure the real cost and performance of programs.

In response to the 2002 *President's Management Agenda, OMB's Capital Programming Guide* requires agencies to have a disciplined capital programming process that sets priorities between new and existing assets.[20] It also requires agencies to perform risk management and develop cost estimates to improve the accuracy of cost, schedule, and performance management. These activities should help mitigate difficult challenges associated with asset management and acquisition. In addition, the *Capital Programming Guide* requires an agency to develop a baseline assessment for each major program it plans to acquire. As part of this baseline, a full accounting of life-cycle cost estimates, including all direct and indirect costs for planning, procurement, operations and maintenance, and disposal is expected.

The capital programming process, as promulgated in OMB's *Capital Programming Guide*, outlines how agencies should use long-range planning and a disciplined budget process to effectively manage a portfolio of capital assets that achieves program goals with the least life-cycle costs and risks. It outlines three phases: (1) planning and budgeting, (2) acquisition, and (3) management in use, often referred to as operations and maintenance. For each phase, reliable cost estimates are essential and necessary to establish realistic baselines from which to measure future progress.

Regarding the planning and budgeting phase, the federal budget process is a cyclical event. Each year in January or early February, the president submits budget proposals for the year that begins October 1. They include data for the most recently completed year, the current year, the budget year, and at least the 4 years following the budget year. The budget process has four phases:

1. executive budget formulation,
2. congressional budget process,
3. budget execution and control, and
4. audit and evaluation.

Budget cycles overlap—the formulation of one budget begins before action has been completed on the previous one. (Appendix IV gives an overview of the federal budget process, describing its phases and the major steps and time periods for each phase.)

For the acquisition and management in use phases, reliable cost estimates are also important for program approval and for the continued receipt of annual funding. However, cost estimating is difficult. To develop a sound cost estimate, estimators must possess a variety of skills and have access to high-quality data. Moreover, credible cost estimates take time to develop; they cannot be rushed. Their many challenges increase the possibility that estimates will fall short of cost, schedule, and performance goals. If cost analysts recognize these challenges and plan for them early, this can help organizations mitigate these risks.

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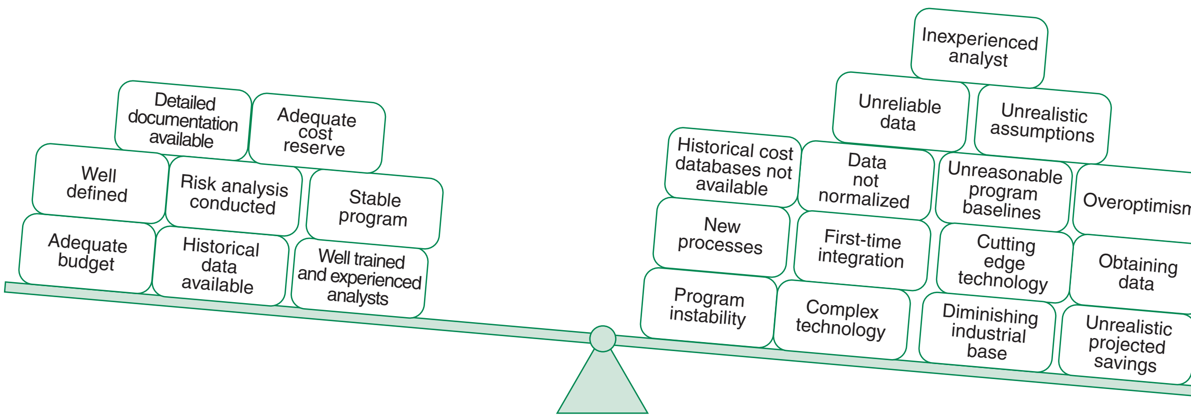
[20] OMB first issued the Capital Programming Guide as a Supplement to the 1997 version of Circular A-11, Part 3. We refer to the 2006 version. See under Circulars at OMB's Web site, www.whitehouse.gov/omb.

Cost Estimating Challenges

Developing a good cost estimate requires stable program requirements, access to detailed documentation and historical data, well-trained and experienced cost analysts, a risk and uncertainty analysis, the identification of a range of confidence levels, and adequate contingency and management reserves.[21] Even with the best of these circumstances, cost estimating is difficult. It requires both science and judgment. And, since answers are seldom if ever precise, the goal is to find a "reasonable" answer. However, the cost estimator typically faces many challenges. These challenges often lead to bad estimates—that is, estimates that contain poorly defined assumptions, have no supporting documentation, are accompanied by no comparisons to similar programs, are characterized by inadequate data collection and inappropriate estimating methodologies, are sustained by irrelevant or out-of-date data, provide no basis or rationale for the estimate, and can show no defined process for generating the estimate. Figure 2 illustrates some of the challenges a cost estimator faces and some of the ways to mitigate them.

Figure 2: Challenges Cost Estimators Typically Face



Source: GAO.

Some cost estimating challenges are widespread. Deriving high-quality cost estimates depends on the quality of, for example, historical databases. It is often not possible for the cost analyst to collect the kinds of data needed to develop cost estimating relationships (CERs), analysis of development software cost, engineering build-up, and many other practices. In most cases, the better the data are, the better the resulting estimate will be. Since much of a cost analyst's time is spent obtaining and normalizing data, experienced and well-trained cost analysts are necessary. Too often, individuals without these skills are thrown into performing a cost analysis to meet a pressing need (see case study 4). In addition, limited program resources (funds and time) often constrain broad participation in cost estimation processes and force the analyst (or cost team) to reduce the extent to which trade-off, sensitivity, and even uncertainty analyses are performed.

[21] For our purposes in this Cost Guide, contingency reserve represents funds held at or above the government program office for "unknown unknowns" that are outside a contractor's control. In this context, contingency funding is added to an estimate to allow for items, conditions, or events for which the state, occurrence, or effect is uncertain and that experience shows are likely to result in additional costs. Management reserve funds, in contrast, are for "known unknowns" that are tied to the contract's scope and managed at the contractor level. Unlike contingency reserve, which is funding related, management reserve is budget related. The value of the contract includes these known unknowns in the budget base, and the contractor decides how much money to set aside. We recognize that other organizations may use the terms differently.

Case Study 4: Cost Analysts' Skills, from *NASA*, GAO-04-642

GAO found that NASA's efforts to improve its cost-estimating processes were undermined by ineffective use of its limited number of cost-estimating analysts. For example, headquarters officials stated that as projects entered the formulation phase, they typically relied on program control and budget specialists—not cost analysts—to provide the financial services to manage projects. Yet budget specialists were generally responsible for obligating and spending funds—not for conducting cost analyses that underlay the budget or ensuring that budgets were based on reasonable cost estimates—and, therefore, they tended to assume that the budget was realistic.

GAO, *NASA: Lack of Disciplined Cost-Estimating Processes Hinders Effective Program Management*, GAO-04-642 (Washington, D.C.: May 28, 2004).

Many cost estimating challenges can be traced to overoptimism. Cost analysts typically develop their estimates from technical baselines that program offices provide. Since program technical baselines come with uncertainty, recognizing this uncertainty can help form a better understanding of where problems will occur in the execution phase. For example, if a program baseline states that its total source lines of code will be 100,000 but the eventual total is 200,000, the cost will be underestimated. Or if the baseline states that the new program will reuse 80,000 from a legacy system but can eventually reuse only 10,000, the cost will be underestimated. This is illustrated in case study 5.

Case Study 5: Recognizing Uncertainty, from *Customs Service Modernization*, GAO/AIMD-99-41

Software and systems development experts agree that early project estimates are imprecise by definition and that their inherent imprecision decreases during a project's life cycle as more information becomes known. The experts emphasize that to be useful, each cost estimate should indicate its degree of uncertainty, possibly as an estimated range or qualified by some factor of confidence. The U.S. Customs Service did not reveal the degree of uncertainty of its cost estimate for the Automated Commercial Environment (ACE) program to managers involved in investment decisions. For example, Customs did not disclose that it made the estimate before fully defining ACE functionality. Instead, Customs presented its $1.05 billion ACE life-cycle cost estimate as an unqualified point estimate. This suggests an element of precision that cannot exist for such an undefined system, and it obscures the investment risk remaining in the project.

GAO, *Customs Service Modernization: Serious Management and Technical Weaknesses Must Be Corrected*, GAO/AIMD-99-41 (Washington, D.C.: Feb. 26, 1999).

Program proponents often postulate the availability of a new technology, only to discover that it is not ready when needed and program costs have increased. Proponents also often make assumptions about the complexity or difficulty of new processes, such as first-time integration efforts, which may end up to be unrealistic. More time and effort lead directly to greater costs, as case study 6 demonstrates.

Case Study 6: Using Realistic Assumptions, from *Space Acquisitions*, GAO-07-96

In five of six space system acquisition programs GAO reviewed, program officials and cost estimators assumed when cost estimates were developed that critical technologies would be mature and available. They made this assumption even though the programs had begun without complete understanding of how long they would run or how much it would cost to ensure that the technologies could work as intended. After the programs began, and as their development continued, the technology issues ended up being more complex than initially believed.

For example, for the National Polar-orbiting Operational Satellite System (NPOESS), DOD and the U.S. Department of Commerce committed funds for developing and producing satellites before the technology was mature. Only 1 of 14 critical technologies was mature at program initiation, and it was found that 1 technology was less mature after the contractor conducted more verification testing.

GAO found that the program was later beset by significant cost increases and schedule delays, partly because of technical problems such as the development of key sensors.

GAO, *Space Acquisitions: DOD Needs to Take More Action to Address Unrealistic Initial Cost Estimates of Space Systems*, GAO-07-96 (Washington, D.C.: Nov. 17, 2006).

Collecting historical data and dedicating the time needed to do this continuously is another challenge facing cost estimators. Certain acquisition policy changes and pressured scheduling have had the unintended consequence of curtailing the generation of a great deal of historical data used for cost estimating. Outside of highly specific technology areas, it is often difficult for the cost analyst to collect the kinds of data needed to develop software cost estimates, valid CERs, and detailed engineering build-up estimates.

In addition, limited program resources in terms of both funds and time often constrain broad participation in cost estimation processes and force the analyst or cost team to reduce the extent to which trade-off, sensitivity, and even uncertainty analyses are performed. Addressing these critical shortfalls is important and requires policy and cultural adjustments to fix.

Program stability presents another serious challenge to cost analysts. A risk to the program also arises when the contractor knows the program's budget. The contractor is pressured into presenting a cost estimate that fits the budget instead of a realistic estimate. Budget decisions drive program schedules and procurement quantities. If development funding is reduced, the schedule can stretch and costs can increase; if production funding is reduced, the number of quantities to be bought will typically decrease, causing unit procurement costs to increase. For example, projected savings from initiatives such as multiyear procurement—contracting for purchase of supplies or services for more than one program year—may disappear, as can be seen in case study 7.

Case Study 7: Program Stability Issues, from *Combating Nuclear Smuggling*, GAO-06-389

According to officials of Customs and Border Protection (CBP) and the Pacific Northwest National Laboratory (PNNL), recurrent difficulties with project funding were the most important explanations of schedule delays. Specifically, according to Department of Homeland Security and PNNL officials, CBP had been chronically late in providing appropriated funds to PNNL, hindering its ability to meet program deployment goals. For example, PNNL did not receive its fiscal year 2005 funding until September 2005, the last month of the fiscal year. According to PNNL officials, because of this delay, some contracting activities in all deployment phases had had to be delayed or halted; the adverse effects on seaports were especially severe. For example, PNNL reported in August 2005 that site preparation work at 13 seaports had ceased because PNNL had not received its fiscal year 2005 funding allocation.

GAO, *Combating Nuclear Smuggling: DHS Has Made Progress Deploying Radiation Detection Equipment at U.S. Ports-of-Entry, but Concerns Remain*, GAO-06-389 (Washington, D.C.: Mar. 22, 2006).

Stability issues can also arise when expected funding is cut. For example, if budget pressures cause breaks in production, highly specialized vendors may no longer be available or may have to restructure their prices to cover their risks. When this happens, unexpected schedule delays and cost increases usually result. A quantity change, even if it does not result in a production break, is a stability issue that can increase costs by affecting workload. Case study 8, from a GAO report on Navy shipbuilding, illustrates this point.

Case Study 8: Program Stability Issues, from *Defense Acquisitions*, GAO-05-183

Price increases contributed to growth in materials costs. For example, the price of array equipment on Virginia class submarines rose by $33 million above the original price estimate. In addition to inflation, a limited supplier base for highly specialized and unique materials made ship materials susceptible to price increases. According to the shipbuilders, the low rate of ship production affected the stability of the supplier base. Some businesses closed or merged, leading to reduced competition for their services and higher prices. In some cases, the Navy lost its position as a preferred customer and the shipbuilder had to wait longer to receive materials. With a declining number of suppliers, more ship materials contracts went to single and sole source vendors. Over 75 percent of the materials for Virginia class submarines—reduced from 14 ships to 9 over a 10-year period—were produced by single source vendors.

GAO, *Defense Acquisitions: Improved Management Practices Could Help Minimize Cost Growth in Navy Shipbuilding Programs*, GAO-05-183 (Washington, D.C.: Feb. 28, 2005).

Significantly accelerating (sometimes called crashing) development schedules also present risks. In such cases, technology tends to be incorporated before it is ready, tests are reduced or eliminated, or logistics support is not in place. As case study 9 shows, the result can be a reduction in costs in the short term but significantly increased long-term costs as problems are discovered, technology is back-fit, or logistics support is developed after the system is in the field.

Case Study 9: Development Schedules, from ***Defense Acquisitions*****, GAO-06-327**

Time pressures caused the Missile Defense Agency (MDA) to stray from a knowledge-based acquisition strategy. Key aspects of product knowledge, such as technology maturity, are proven in a knowledge-based strategy before committing to more development. MDA followed a knowledge-based strategy without fielding elements such as the Airborne Laser and Kinetic Energy Interceptor. But it allowed the Ground-Based Midcourse Defense program to concurrently become mature in its technology, complete design activities, and produce and field assets before end-to-end system testing—all at the expense of cost, quantity, and performance goals. For example, the performance of some program interceptors was questionable because the program was inattentive to quality assurance. If the block approach continued to feature concurrent activity as a means of acceleration, MDA's approach might not be affordable for the considerable amount of capability that was yet to be developed and fielded.

GAO, *Defense Acquisitions: Missile Defense Agency Fields Initial Capability but Falls Short of Original Goals*, GAO-06-327 (Washington, D.C.: Mar. 15, 2006).

In developing cost estimates, analysts often fail to adequately address risk, especially risks that are outside the estimator's control or that were never conceived to be possible. This can result in point estimates that give decision makers no information about their likelihood of success or give them meaningless confidence intervals. A risk analysis should be part of every cost estimate, but it should be performed by experienced analysts who understand the process and know how to use the appropriate tools. On numerous occasions, GAO has encountered cost estimates with meaningless confidence intervals because the analysts did not understand the underlying mathematics or tools. An example is given in case study 10.

Case Study 10: Risk Analysis, from ***Defense Acquisitions*****, GAO-05-183**

In developing cost estimates for eight case study ships, U.S. Navy cost analysts did not conduct uncertainty analyses to measure the probability of cost growth. Uncertainty analyses are particularly important, given uncertainties inherent in ship acquisition, such as the introduction of new technologies and the volatility of overhead rates. Despite the uncertainties, the Navy did not test the validity of the cost analysts' assumptions in estimating construction costs for the eight case study ships, and it did not identify a confidence level for estimates.

Specifically, it did not conduct uncertainty analyses, which generate values for parameters that are less than precisely known around a specific set of ranges. For example, if the number of hours to integrate a component into a ship is not precisely known, analysts may put in low and high values. The estimate will generate costs for these variables, along with other variables such as weight, experience, and degree of rework. The result will be a range of estimates that enables cost analysts to make better decisions on likely costs. Instead, the Navy presented its cost estimates as unqualified point estimates, suggesting an element of precision that cannot exist early in the process. Other military services qualify their cost estimates by determining a confidence level of 50 percent.

GAO, *Defense Acquisitions: Improved Management Practices Could Help Minimize Cost Growth in Navy Shipbuilding Programs*, GAO-05-183 (Washington, D.C.: Feb. 28, 2005).

A risk analysis should be used to determine a program's contingency funding. All development programs should have contingency funding because it is simply unreasonable to expect a program not to encounter problems. Problems always occur, and program managers need ready access to funding in order to resolve them without adversely affecting programs (for example, stretching the schedule). Unfortunately, budget cuts often target contingency funding, and in some cases such funding is not allowed by policy. Decision makers and budget analysts should understand that eliminating contingency funding is counterproductive. (See case study 11.)

Case Study 11: Risk Analysis, from *NASA*, GAO-04-642

Only by quantifying cost risk can management make informed decisions about risk mitigation strategies. Quantifying cost risk also provides a benchmark for measuring future progress. Without this knowledge, NASA may have little specific basis for determining adequate financial reserves, schedule margins, and technical performance margins. Managers may thus not have the flexibility they need to address program, technical, cost, and schedule risks, as NASA policy requires.

GAO, *NASA: Lack of Disciplined Cost-Estimating Processes Hinders Effective Program Management*, GAO-04-642 (Washington, D.C.: May 28, 2004).

Too often, organizations encourage goals that are unattainable because there is overoptimism that their organizations can reach them. These decisions follow a thought process that accentuates the positive without truly understanding the pitfalls being faced—in other words, the decision makers are avoiding risk. Recognizing and understanding risk is an important program management discipline, but most program managers believe they are dealing with risks when in fact they have created risk by their assumptions. History shows that program managers tend to be too optimistic. They believe that lessons learned from past programs will apply to their program and everything will work out fine. But a plan is by its nature meant to be optimistic, to ensure that the results will be successful. While program managers believe they build risk into their plan, they often do not put in enough. This is because they believe in the original estimates for the plan without allowing for additional changes in scope, schedule delays, or other elements of risk. In addition, in today's competitive environment, contractor program managers may overestimate what their company can do compared to their competition, since they want to win.

Since most organizations have a limited amount of money for addressing these issues, optimism is prevalent. To properly overcome this optimism, it is important to have an independent view. Through the program planning process, overoptimism can be tempered by challenging the assumptions the plan was based on. This can be done by independently assessing the outcomes, by using comparative data or experts in accomplishing the efforts planned. While this function can be performed either by inside or outside analysts, if the organization is not willing to address and understand the risks its program faces, it will have little hope of effectively managing and mitigating them. Having this "honest broker" approach to working these programs helps bring to light actions that can potentially limit the organization's ability to succeed. Therefore, program managers and their organizations must understand the value and need for risk management by addressing risk proactively and having a plan should risks be realized. Doing so will enable the program management team to use this information to succeed in the future.

Earned Value Management Challenges

OMB recommends that programs manage risk by applying EVM, among other ways. Reliable EVM data usually indicate monthly how well a program is performing in terms of cost, schedule, and technical matters. This information is necessary for proactive program management and risk mitigation. Such systems represent a best practice if implemented correctly, but qualified analytic staff are needed to validate and interpret the data. (See case study 12.)

Case Study 12: Applying EVM, from ***Cooperative Threat Reduction*****, GAO-06-692**

In December 2005, a contractor's self-evaluation stated that the EVM system for the chemical weapons destruction facility at Shchuch'ye, Russia, was fully implemented. DOD characterized the contractor's EVM implementation as a "management failure," citing a lack of experienced and qualified contractor staff. DOD withheld approximately $162,000 of the contractor's award fee because of its concern about the EVM system. In March 2006, DOD officials stated that EVM was not yet a usable tool in managing the Shchuch'ye project. They stated that the contractor needed to demonstrate that it had incorporated EVM into project management rather than simply fulfilling contractual requirements. DOD expected the contractor to use EVM to estimate cost and schedule effects and their causes and, most importantly, to help eliminate or mitigate identified risks. The contractor's EVM staff stated that they underestimated the effort needed to incorporate EVM data into the system, train staff, and develop EVM procedures. The contractor's officials were also surprised by the number of man-hours required to accomplish these tasks, citing high staff turnover as contributing to the problem. According to the officials, working in a remote and isolated area caused many of the non-Russian employees to leave the program rather than extend their initial tour of duty.

GAO, *Cooperative Threat Reduction, DOD Needs More Reliable Data to Better Estimate the Cost and Schedule of the Shchuch'ye Facility*, GAO-06-692 (Washington, D.C.: May 31, 2006).

Case study 12 shows that using EVM requires a cultural change. As with any initiative, an agency's management must show an interest in EVM if its use is to be sustained. Executive personnel should understand EVM terms and analysis products if they expect program managers and teams to use them. Additionally, at the program level, EVM requires qualified staff to independently assess what was accomplished. EVM training should be provided and tracked at all levels of personnel. This does not always happen, and government agencies struggle with how to obtain qualified and experienced personnel.

Perhaps the biggest challenge in using EVM is the trend to rebaseline programs. This happens when the current baseline is not adequate to complete all the work, causing a program to fall behind schedule or run over cost (see case study 13). A new baseline serves an important management control purpose when program goals can no longer be achieved: it gives perspective on the program's current status. However, auditors should be aware that comparing the latest cost estimate with the most recent approved baseline provides an incomplete perspective on a program's performance, because a rebaseline shortens the period of performance reported and resets the measurement of cost growth to zero.

Case Study 13: Rebaselining, from *NASA*, GAO-04-642

Baseline development cost estimates for the programs GAO reviewed varied considerably from the programs' initial baseline estimates. Development cost estimates of more than half the programs increased; for some programs, the increase was significant. The baseline development cost estimates for the 10 programs GAO reviewed in detail were rebaselined—that is, recalculated to reflect new costs, time periods, or resources associated with changes in program objectives, deliverables, or scope and plans. Although NASA provided specific reasons for the increased cost estimates and rebaselinings—such as delays in development or delivery of key system components and funding shortages—it did not have guidance for determining when rebaselinings were justified. Such criteria are important for instilling discipline in the cost estimating process.

GAO, *NASA: Lack of Disciplined Cost-Estimating Processes Hinders Effective Program Management*, GAO-04-642 (Washington, D.C.: May 28, 2004).

These challenges make it difficult for cost estimators to develop accurate estimates. Therefore, it is very important that agencies' cost estimators have adequate guidance and training to help mitigate these challenges. In chapter 3, we discuss audit criteria related to cost estimating and EVM. We also identify some of the guidance we relied on to develop this guide.

CHAPTER 3

Criteria for Cost Estimating, EVM, and Data Reliability

Government auditors use criteria as benchmarks for how well a program is performing. Criteria provide auditors with a context for what is required, what the program's state should be, or what it was expected to accomplish. Criteria are the laws, regulations, policies, procedures, standards, measures, expert opinions, or expectations that define what should exist. When auditors conduct an audit, they should select criteria by whether they are reasonable, attainable, and relevant to the program's objectives.

Criteria include the

- purpose or goals that statutes or regulations have prescribed or that the audited entity's officials have set,
- policies and procedures the audited entity's officials have established,
- technically developed norms or standards,
- expert opinions,
- earlier performance,
- performance in the private sector, and
- leading organizations' best practices.

In developing this guide, we researched legislation, regulations, policy, and guidance for the criteria that most pertained to cost estimating and EVM. Our research showed that while DOD has by far the most guidance on cost estimating and EVM in relation to civil agencies, other agencies are starting to develop policies and guidance. Therefore, we intend this guide as a starting point for auditors to identify criteria.

For each new engagement, however, GAO auditors should exercise diligence to see what, if any, new legislation, regulation, policy, and guidance exists. Auditors also need to decide whether criteria are valid. Circumstances may have changed since they were established and may no longer conform to sound management principles or reflect current conditions. In such cases, GAO needs to select or develop criteria that are appropriate for the engagement's objectives.

Table 3 lists criteria related to cost estimating and EVM. Each criterion is described in more detail in appendix V.

Table 3: Cost Estimating and EVM Criteria for Federal Agencies: Legislation, Regulations, Policies, and Guidance

Type and date	Title	Applicable agency	Notes
Legislation or regulation			
1968	SAR: Selected Acquisition Reports, 10 U.S.C. § 2432 (2006)	DOD	Became permanent law in 1982; applies only to DOD's major defense acquisition programs
1982	Unit Cost Reports ("Nunn-McCurdy"); 10 U.S.C. § 2433 (2006)	DOD	Applies only to DOD's major defense acquisition programs
1983	Independent Cost Estimates; Operational Manpower Requirements, 10 U.S.C. § 2434 (2006)	DOD	Applies only to DOD's major defense acquisition programs
1993	GPRA: Government Performance and Results Act, Pub. L. No. 103-62 (1993)	All	Requires agencies to prepare (1) multiyear strategic plans describing mission goals and methods for reaching them and (2) annual program performance reports to review progress toward annual performance goals
1994	The Federal Acquisition Streamlining Act of 1994, § 5051(a), 41 U.S.C. § 263 (2000).	All civilian agencies	Established congressional policy that agencies should achieve, on average, 90 percent of cost, performance, and schedule goals established for their major acquisition programs; requires an agency to approve or define cost, performance, and schedule goals and to determine whether there is a continuing need for programs that are significantly behind schedule, over budget, or not in compliance with performance or capability requirements, and to identify suitable actions to be taken.
1996	CCA: Clinger-Cohen Act of 1996, 40 U.S.C. §§ 11101–11704 (Supp. V 2005)	All	Requires agencies to base decisions about information technology investments on quantitative and qualitative factors associated with their costs, benefits, and risks and to use performance data to demonstrate how well expenditures support program improvements
2006	Major Automated Information System Programs, 10 U.S.C. §§ 2445a – 2445d (2006)	DOD	Oversight requirements for DOD's major automated information system (MAIS) programs, including estimates of development costs and full life-cycle costs as well as program baseline and variance reporting requirements.

Type and date	Title	Applicable agency	Notes
2006	Federal Acquisition Regulation (FAR), Major Systems Acquisition, 48 C.F.R. part 34, subpart 34.2, Earned Value Management System	All	Earned Value Management System policy was added by Federal Acquisition Circular 2005-11, July 5, 2006, Item I—Earned Value Management System (EVMS) (FAR Case 2004-019)
2008	Defense Federal Acquisition Regulation Supplement; Earned Value Management Systems (DFARS Case 2005–D006), 73 Fed. Reg. 21,846 (April 23, 2008), primarily codified at 48 C.F.R. subpart 234.2, and part 252 (sections 252.234-7001 and 7002)	DOD	DOD's final rule (1) amending the Defense Federal Acquisition Regulation Supplement (DFARS) to update requirements for DOD contractors to establish and maintain EVM systems and (2) eliminating requirements for DOD contractors to submit cost/schedule status reports
Policy			
1976	OMB, *Major Systems Acquisitions*, Circular A-109 (Washington, D.C.: Apr. 5, 1976)	All	
1992	OMB, *Guidelines and Discount Rates for Benefit-Cost Analysis of Federal Programs*, Circular No. A-94 Revised (Washington, D.C.: Oct. 29, 1992)	All	
1995	DOD, E*conomic Analysis for Decisionmaking*, Instruction No. 7041.3 (Washington, D.C.: USD, Nov. 7, 1995)	DOD	
2003	DOD, The Defense Acquisition System, Directive No. 5000.1 (Washington, D.C.: USD, May 12, 2003). Redesignated 5000.01 and certified current as of Nov. 20, 2007.	DOD	States that every program manager must establish program goals for the minimum number of cost, schedule, and performance parameters that describe the program over its life cycle and identify any deviations
2003	DOD, Operation of the Defense Acquisition System, Instruction No. 5000.2 (Washington, D.C.: USD, May 12, 2003). Cancelled and reissued by Instruction No. 5000.02 on Dec. 8, 2008.	DOD	Describes the standard framework for defense acquisition systems: defining the concept, analyzing alternatives, developing technology, developing the system and demonstrating that it works, producing and deploying the system, and operating and supporting it throughout its useful life
2004	National Security Space Acquisition Policy, Number 03-01, Guidance for DOD Space System Acquisition Process (Washington, D.C.: revised Dec. 27, 2004)	DOD	
2005	DOD, "Revision to DOD Earned Value Management Policy," memorandum, Under Secretary of Defense, Acquisition, Technology, and Logistics (Washington, D.C.: Mar. 7, 2005)	DOD	

Type and date	Title	Applicable agency	Notes
2005	OMB, "Improving Information Technology (IT) Project Planning and Execution," memorandum for Chief Information Officers No. M-05-23 (Washington, D.C.: Aug. 4, 2005)	All	
2006	OMB, *Capital Programming Guide*, Supplement to Circular A-11, Part 7, *Preparation, Submission, and Execution of the Budget* (Washington, D.C.: Executive Office of the President, June 2006)	All	
2006	DOD, Cost Analysis Improvement Group (CAIG), Directive No. 5000.04 (Washington, D.C.: Aug. 16, 2006)	DOD	
Guidance			
1992	CAIG, *Operating and Support Cost-Estimating Guide* (Washington, D.C.: DOD, Office of the Secretary, May 1992)	DOD	
1992	DOD, *Cost Analysis Guidance and Procedures*, DOD Directive 5000.4-M (Washington, D.C.: OSD, Dec. 11, 1992)	DOD	
2003	DOD, *The Program Manager's Guide to the Integrated Baseline Review Process* (Washington, D.C.: OSD, April 2003)	DOD	
2004	NDIA, *National Defense Industrial Association (NDIA) Program Management Systems Committee (PMSC) Surveillance Guide* (Arlington, Va.: October 2004)	All	
2005	NDIA, *National Defense Industrial Association (NDIA) Program Management Systems Committee (PMSC) Earned Value Management Systems Intent Guide* (Arlington, Va.: January 2005)	All	
2006	Defense Contract Management Agency, *Department of Defense Earned Value Management Implementation Guide* (Alexandria, Va.: October 2006)	DOD, FAA, NASA	
2006	National Defense Industrial Association, Program Management Systems Committee, "NDIA PMSC ANSI/EIA 748 Earned Value Management System Acceptance Guide," draft, working release for user comment (Arlington, Va.: November 2006)	All	

Type and date	Title	Applicable agency	Notes
2007	American National Standards Institute, *Information Technology Association of America, Earned Value Management Systems* (ANSI/EIA 748-B) (Arlington, Va.: July 9, 2007)	All	
2007	National Defense Industrial Association, Program Management Systems Committee, "NDIA PMSC Earned Value Management Systems Application Guide," draft, working release for user comment (Arlington, Va.: March 2007)	All	

Source: GAO, DOD, and OMB.

Determining Data Reliability

Auditors need to collect data produced from both a program's cost estimate and its EVM system. They can collect these data by questionnaires, structured interviews, direct observations, or computations, among other methods. (Appendix VI is a sample data collection instrument; appendix VII gives reasons why auditors need the information.) After auditors have collected their data, they must judge the data for integrity as well as for quality in terms of validity, reliability, and consistency with fact.

For cost estimates, auditors must confirm that, at minimum, internal quality control checks show that the data are reliable and valid. To do this, they must have source data and must estimate the rationale for each cost element, to verify that

- the parameters (or input data) used to create the estimate are valid and applicable,[22]
- labor costs include a time-phased breakdown of labor hours and rates,
- the calculations for each cost element are correct and the results make sense,
- the program cost estimate is an accurate total of subelement costs, and
- escalation was properly applied to account for differences in the price of goods and services over time.

Auditors should clarify with cost estimators issues about data and methodology. For example, they might ask what adjustments were made to account for differences between the new and existing systems with respect to design, manufacturing processes, and types of materials. In addition, auditors should look for multiple sources of data that converge toward the same number, in order to gain confidence in the data used to create the estimate.

It is particularly important that auditors understand problems associated with the historical data—such as program redesign, schedule slips, and budget cuts—and whether the cost estimators "cleansed the

[22] The auditor must ask the cost estimator if the technical assumptions for a new program have been tested for reasonableness. A program whose technical assumptions are not supported by historical data may be a high-risk program or its data may not be valid. Closing the gap between what a program wants to achieve and what has been achieved in the past is imperative for proper data validation.

data" to remove their effects. According to experts in the cost community, program inefficiencies should not be removed from historical data, since the development of most complex systems usually encounters problems. The experts stress that removing data associated with past problems is naïve and introduces unnecessary risk. (This topic is discussed in chapter 10.)

With regard to EVM, auditors should request a copy of the system compliance or validation letter that shows the contractor's ability to satisfy the 32 EVM guidelines (discussed in chapter 18).[23] These guidelines are test points to determine the quality of a contractor's EVM system. Contract performance reports (CPR) formally submitted to the agency should be examined for reasonableness, accuracy, and consistency with other program status reports as a continuous measure of the EVM system quality and robustness. Auditors should also request a copy of the integrated baseline review (IBR) results (also discussed in chapter 18) to see what risks were identified and whether they were mitigated. Auditors should request copies of internal management documents or reports that use EVM data to ensure that EVM is being used for management, not just for external reporting. Finally, to ensure that EVM data are valid and accurate, auditors should look for evidence that EVM analysis and surveillance are performed regularly by staff trained in this specialty.

[23] For DOD programs, the Defense Contract Management Agency (DCMA) should have a copy of the EVM validation letter.

CHAPTER 4

Cost Analysis Overview

Although "cost estimating" and "cost analysis" are often used interchangeably, cost estimating is a specific activity within cost analysis. Cost analysis is a powerful tool, because it requires a rigorous and systematic analysis that results in a better understanding of the program being acquired. This understanding, in turn, leads to improved program management in applying resources and mitigating program risks.

Differentiating Cost Analysis and Cost Estimating

Cost analysis, used to develop cost estimates for such things as hardware systems, automated information systems, civil projects, manpower, and training, can be defined as

- the effort to develop, analyze, and document cost estimates with analytical approaches and techniques;
- the process of analyzing, interpreting, and estimating the incremental and total resources required to support past, present, and future systems—an integral step in selecting alternatives; and
- a tool for evaluating resource requirements at key milestones and decision points in the acquisition process.

Cost estimating involves collecting and analyzing historical data and applying quantitative models, techniques, tools, and databases to predict a program's future cost. More simply, cost estimating combines science and art to predict the future cost of something based on known historical data that are adjusted to reflect new materials, technology, software languages, and development teams.

Because cost estimating is complex, sophisticated cost analysts should combine concepts from such disciplines as accounting, budgeting, computer science, economics, engineering, mathematics, and statistics and should even employ concepts from marketing and public affairs. And because cost estimating requires such a wide range of disciplines, it is important that the cost analyst either be familiar with these disciplines or have access to an expert in these fields.

Main Cost Estimate Categories

Auditors are likely to encounter two main cost estimate categories:

- a life-cycle cost estimate (LCCE) that may include independent cost estimates, independent cost assessments, or total ownership costs, and
- a business case analysis (BCA) that may include an analysis of alternatives or economic analyses.

Auditors may also review other types of cost estimates, such as independent cost assessments (ICA), nonadvocate reviews (NAR), and independent government cost estimates (IGCE). These types of estimates are commonly developed by civilian agencies.

Life-Cycle Cost Estimate

A life-cycle cost estimate provides an exhaustive and structured accounting of all resources and associated cost elements required to develop, produce, deploy, and sustain a particular program. Life cycle can be thought of as a "cradle to grave" approach to managing a program throughout its useful life. This entails identifying all cost elements that pertain to the program from initial concept all the way through operations, support, and disposal. An LCCE encompasses all past (or sunk), present, and future costs for every aspect of the program, regardless of funding source.

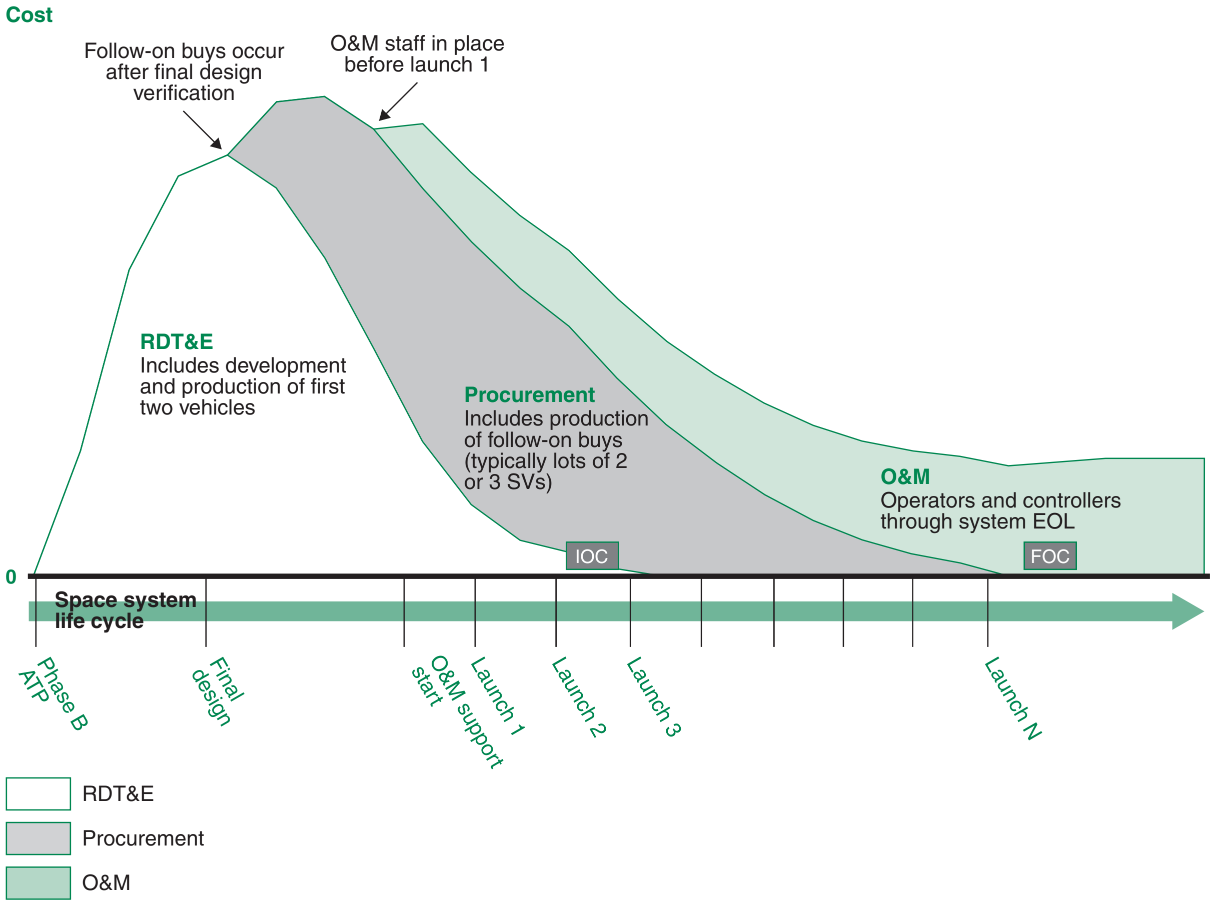
Life-cycle costing enhances decision making, especially in early planning and concept formulation of acquisition. Design trade-off studies conducted in this period can be evaluated on a total cost basis, as well as on a performance and technical basis. A life-cycle cost estimate can support budgetary decisions, key decision points, milestone reviews, and investment decisions.

The LCCE usually becomes the program's budget baseline. Using the LCCE to determine the budget helps to ensure that all costs are fully accounted for so that resources are adequate to support the program. DOD identifies four phases that an LCCE must address: research and development, procurement and investment, operations and support, and disposal. Civilian agencies may refer to the first two as development, modernization, and enhancement and may include in them acquisition planning and funding. Similarly, civilian agencies may refer to operations and support as "steady state" and include them in operations and maintenance activities. Although these terms mean essentially the same thing, they can differ from agency to agency. DOD's four phases are described below.

1. Research and development include development and design costs for system engineering and design, test and evaluation, and other costs for system design features. They include costs for development, design, startup, initial vehicles, software, test and evaluation, special tooling and test equipment, and facility changes.
2. Procurement and investment include total production and deployment costs (e.g., site activation, training) of the prime system and its related support equipment and facilities. Also included are any related equipment and material furnished by the government, initial spare and repair parts, interim contractor support, and other efforts.
3. Operations and support are all direct and indirect costs incurred in using the prime system—manpower, fuel, maintenance, and support—through the entire life cycle. Also included are sustaining engineering and other collateral activities.
4. Disposal, or inactivation, includes the costs of disposing of the prime equipment after its useful life.

Because they encompass all possible costs, LCCEs provide a wealth of information about how much programs are expected to cost over time. This information can be displayed visually to show what funding is needed at a particular time and when the program is expected to move from one phase to another. For example, figure 3 is a life-cycle cost profile for a hypothetical space system.

Figure 3: Life-Cycle Cost Estimate for a Space System



Source: DOD.

Note: O&M = operations and maintenance; RDT&E = research, development, test, and evaluation; SV = space vehicle; EOL = end of life; IOC = initial operational capacity; FOC = full operational capacity.

Figure 3 illustrates how space systems must invest heavily in research and development because once a system is launched into space, it cannot be retrieved for maintenance. Other systems such as aircraft, ships, and information technology systems typically incur hefty operations costs in relation to development and production costs. Such mission operations costs are very large because the systems can be retrieved and maintained and therefore require sophisticated logistics support and recurring broad-based training for large user populations. Thus, having full life-cycle costs is important for successfully planning program resource requirements and making wise decisions.

Business Case Analysis

A business case analysis, sometimes referred to as a cost benefit analysis, is a comparative analysis that presents facts and supporting details among competing alternatives. A BCA considers not only all the life-cycle costs that an LCCE identifies but also quantifiable and nonquantifiable benefits. It should be unbiased by considering all possible alternatives and should not be developed solely for supporting a predetermined solution. Moreover, a BCA should be rigorous enough that independent auditors can review it and clearly understand why a particular alternative was chosen.

A BCA seeks to find the best value solution by linking each alternative to how it satisfies a strategic objective. Each alternative should identify the

- relative life-cycle costs and benefits;
- methods and rationale for quantifying the life-cycle costs and benefits;
- effect and value of cost, schedule, and performance tradeoffs;
- sensitivity to changes in assumptions; and
- risk factors.

On the basis of this information, the BCA then recommends the best alternative. In addition to supporting an investment decision, the BCA should be considered a living document and should be updated often to reflect changes in scope, schedule, or budget. In this way, the BCA is a valuable tool for validating decisions to sustain or enhance the program.

Auditors may encounter other estimates that fall into one of the two main categories of cost estimates. For example, an auditor may examine an independent cost estimate, independent cost assessment, independent government cost estimates, total ownership cost, or rough order of magnitude estimate—all variations of a life-cycle cost estimate. Similarly, instead of reviewing a business case analysis, an auditor may review an analysis of alternatives (AOA), a cost-effectiveness analysis (CEA), or an economic analysis (EA). Each of these analyses is a variation, in one form or another, of a BCA. Table 4 looks more closely at the different types of cost estimates that can be developed.

Table 4: Life-Cycle Cost Estimates, Types of Business Case Analyses, and Other Types of Cost Estimates

Estimate type	Level of effort	Description
Life-cycle cost estimate		
Independent cost estimate	Usually requires a large team, may take many months to accomplish, and addresses the full LCCE	An ICE, conducted by an organization independent of the acquisition chain of command, is based on the same detailed technical and procurement information used to make the baseline estimate—usually the program or project LCCE. ICEs are developed to support new programs or conversion, activation, modernization, or service life extensions and to support DOD milestone decisions for major defense acquisition programs.[a] An estimate might cover a program's entire life cycle, one program phase, or one high-value, highly visible, or high-interest item within a phase. ICEs are used primarily to validate program or project LCCEs and are typically reconciled with them. Because the team performing the ICE is independent, it provides an unbiased test of whether the program office cost estimate is reasonable. It is also used to identify risks related to budget shortfalls or excesses

Estimate type	Level of effort	Description
Total ownership cost estimate	Requires a large team, may take many months to accomplish, and addresses the full LCCE	Related to LCCE but broader in scope, a total ownership cost estimate consists of the elements of life-cycle cost plus some infrastructure and business process costs not necessarily attributable to a program. Infrastructure includes acquisition and central logistics activities; nonunit central training; personnel administration and benefits; medical care; and installation, communications, and information infrastructure to support military bases. It is normally found in DOD programs
Business case analysis		
Analysis of alternatives and cost effectiveness analysis	Requires a large team, may take many months to accomplish, and addresses the full LCCE	AOA compares the operational effectiveness, suitability, and LCCE of alternatives that appear to satisfy established capability needs. Its major components are a CEA and cost analysis. AOAs try to identify the most promising of several conceptual alternatives; analysis and conclusions are typically used to justify initiating an acquisition program. An AOA also looks at mission threat and dependencies on other programs. When an AOA cannot quantify benefits, a CEA is more appropriate. A CEA is conducted whenever it is unnecessary or impractical to consider the dollar value of benefits, as when various alternatives have the same annual monetary benefits. Both the AOA and CEA should address each alternative's advantages, disadvantages, associated risks, and uncertainties and how they might influence the comparison
Economic analysis and cost benefit analysis	Requires a large team, may take many months to accomplish, and addresses the full LCCE	EA is a conceptual framework for systematically investigating problems of choice. Posing various alternatives for reaching an objective, it analyzes the LCCE and benefits of each one, usually with a return on investment analysis. Present value is also an important concept: Since an LCCE does not consider the time value of money, it is necessary to determine when expenditures for alternatives will be made. EA expands cost analysis by examining the effects of the time value of money on investment decisions. After cost estimates have been generated, they must be time-phased to allow for alternative expenditure patterns. Assuming equal benefits, the alternative with the least present value cost is the most desirable: it implies a more efficient allocation of resources
Other		
Rough order of magnitude	May be done by a small group or one person; can be done in hours, days, or weeks; and may cover only a portion of the LCCE	Developed when a quick estimate is needed and few details are available. Usually based on historical ratio information, it is typically developed to support what-if analyses and can be developed for a particular phase or portion of an estimate to the entire cost estimate, depending on available data. It is helpful for examining differences in high-level alternatives to see which are the most feasible. Because it is developed from limited data and in a short time, a rough order of magnitude analysis should never be considered a budget-quality cost estimate

Estimate type	Level of effort	Description
Independent cost assessment	Requires a small group; may take months to accomplish, depending on how much of the LCCE is being reviewed	An ICA is an outside, nonadvocate's evaluation of a cost estimate's quality and accuracy, looking specifically at a program's technical approach, risk, and acquisition strategy to ensure that the program's cost estimate captures all requirements. Typically requested by a program manager or outside source, it may be used to determine whether the cost estimate reflects the program of record. It is not as formal as an ICE and does not have to be performed by an organization independent of the acquisition chain of command, although it usually is. An ICA usually does not address a program's entire life cycle
Independent government cost estimate	Requires a small group, may take months to accomplish, and covers only the LCCE phase under contract	An IGCE is conducted to check the reasonableness of a contractor's cost proposal and to make sure that the offered prices are within the budget range for a particular program. The program manager submits it as part of a request for contract funding. It documents the government's assessment of the program's most probable cost and ensures that enough funds are available to execute it. It is also helpful in assessing the feasibility of individual tasks to determine if the associated costs are reasonable
Estimate at completion	Requires nominal effort once all EVM data are on hand and have been determined reliable; covers only the LCCE phase under contract	An EAC is an independent assessment of the cost to complete authorized work based on a contractor's historical EVM performance. It uses various EVM metrics to forecast the expected final cost: EAC = actual costs incurred + (budgeted cost for work remaining / EVM performance factor). The performance factor can be based on many different EVM metrics that capture cost and schedule status to date

Source: GAO, DOD, NIH, OMB, and SCEA.

[a]For more detail, see app. V, ICEs, 10 U.S.C. § 2434.

The Overall Significance of Cost Estimates

Not an end in itself, cost estimating is part of a total systems analysis. It is a critical element in any acquisition process and helps decision makers evaluate resource requirements at milestones and other important decision points.

Cost estimates

- establish and defend budgets and
- drive affordability analysis.

Cost estimates are integral to determining and communicating a realistic view of likely cost and schedule outcomes that can be used to plan the work necessary to develop, produce, install, and support a program.

Cost estimating also provides valuable information to help determine whether a program is feasible, how it should be designed, and the resources needed to support it. Further, cost estimating is necessary for making program, technical, and schedule analyses and to support other processes such as

- selecting sources;
- assessing technology changes, analyzing alternatives, and performing design trade-offs; and
- satisfying statutory and oversight requirements.

Cost Estimates in Acquisition

An acquisition program focuses on the cost of developing and procuring an end item and whether enough resources and funding are available. The end product of the acquisition process is a program capability that meets its users' needs at a reasonable price. During the acquisition process, decisions must be made on how best to consume labor, capital, equipment, and other finite resources. A realistic cost estimate allows better decision making, in that an adequate budget can accomplish the tasks that ultimately increase a program's probability of success.

Acquisition is an event-driven process, in that programs must typically pass through various milestones or investment reviews in which they are held accountable for their accomplishments. Cost estimates play an important role in these milestone or investment decisions. For example, in government programs, a cost estimate should be validated if a major program is to continue through its many acquisition reviews and other key decision points.

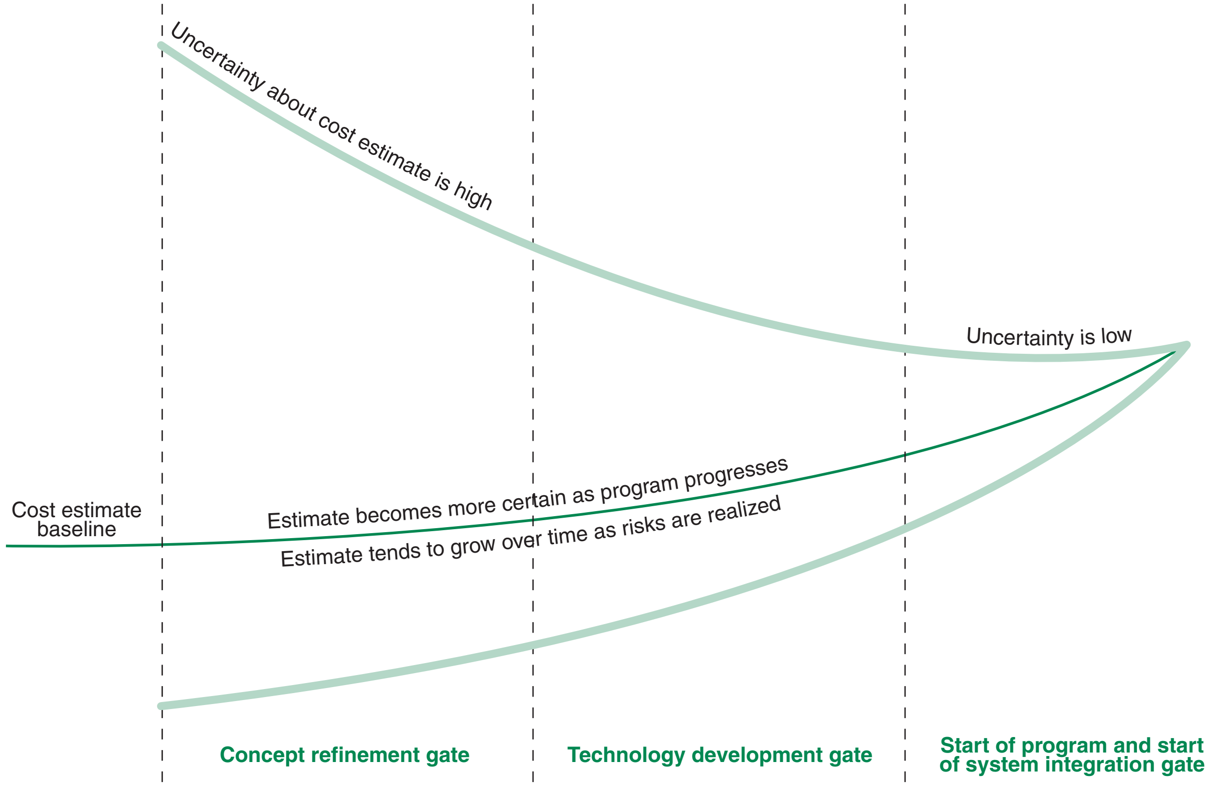
Validation involves testing an estimate to see if it is reasonable and includes all necessary costs. Testing can be as simple as comparing results with historical data from similar programs or using another estimating method to see if results are similar. Industry requires similar scrutiny throughout development, in what is commonly referred to as passing through specific gates.

Once a cost estimate has been accepted and approved, it should be updated periodically as the program matures and as schedules and requirements change. Updated estimates help give management control over a project's resources when new requirements are called for under tight budget conditions. This is especially important early in a project, when less is known about requirements and the opportunity for change (and cost growth) is greater. As more knowledge is gained, programs can retire some risk and reduce the potential for unexpected cost and schedule growth.

Cost estimates tend to become more certain as actual costs begin to replace earlier estimates. This happens when risks are either mitigated or realized. If risks actually occur, the resulting cost growth becomes absorbed by the cost estimate.

For this reason, it is important to continually update estimates with actual costs, so that management has the best information available for making informed decisions. In addition, narrow risk ranges should be viewed as suspect, because more cost estimates tend to overrun than underrun. These processes are illustrated in what is commonly called the "cone of uncertainty," which are depicted in figure 4.

Figure 4: Cone of Uncertainty



Source: GAO.

It is important to have a track record of the estimate so one can measure growth from what the estimate should have been. Therefore, tying growth and risk together is critical because the risk distribution identifies the range of anticipated growth.

The Importance of Cost Estimates in Establishing Budgets

A program's approved cost estimate is often used to create the budget spending plan. This plan outlines how and at what rate the program funding will be spent over time. Since resources are not infinite, budgeting requires a delicate balancing act to ensure that the rate of spending closely mirrors available resources and funding. And because cost estimates are based on assumptions that certain tasks will happen at specific times, it is imperative that funding be available when needed so as to not disrupt the program schedule.

Because a reasonable and supportable budget is essential to a program's efficient and timely execution, a competent estimate is the key foundation of a good budget. For a government agency, accurate estimates help in assessing the reasonableness of a contractor's proposals and program budgets. Credible cost estimates also help program offices justify budgets to the Congress, OMB, department secretaries, and others. Moreover, cost estimates are often used to help determine how budget cuts may hinder a program's progress or effectiveness.

Outside the government, contractors need accurate estimates of the costs required to complete a task in order to ensure maximum productivity and profitability. Estimates that are too low can reduce profits if the contract is firm fixed price, and estimates that are too high will diminish a contractor's ability to compete in the marketplace.

While contractors occasionally propose unrealistically low cost estimates for strategic purposes—for example, "buying-in"—such outcomes can be attributed to poor cost estimating. This sometimes happens when contractors are highly optimistic in estimating potential risks. As a program whose budget is based on such estimates is developed, it becomes apparent sooner or later that either the developer or the customer must pay for a cost overrun, as case study 14 indicates.

Case Study 14: Realistic Estimates, from *Defense Acquisitions*, GAO-05-183

In negotiating the contract for the first four Virginia class ships, program officials stated that they were constrained in negotiating the target price to the amount funded for the program, risking cost growth at the outset. The shipbuilders said that they accepted a challenge to design and construct the ships for $748 million less than their estimated costs, because the contract protected their financial risk. Despite the significant risk of cost growth, the Navy did not identify any funding for probable cost growth, given available guidance at the time. The fiscal year 2005 President's Budget showed that budgets for the two Virginia class case study ships had increased by $734 million. However, on the basis of July 2004 data, GAO projected that additional cost growth on contracts for the two ships would be likely to reach $840 million, perhaps higher. In the fiscal year 2006 budget, the Navy requested funds to cover cost expected increases reaching to approximately $1 billion.

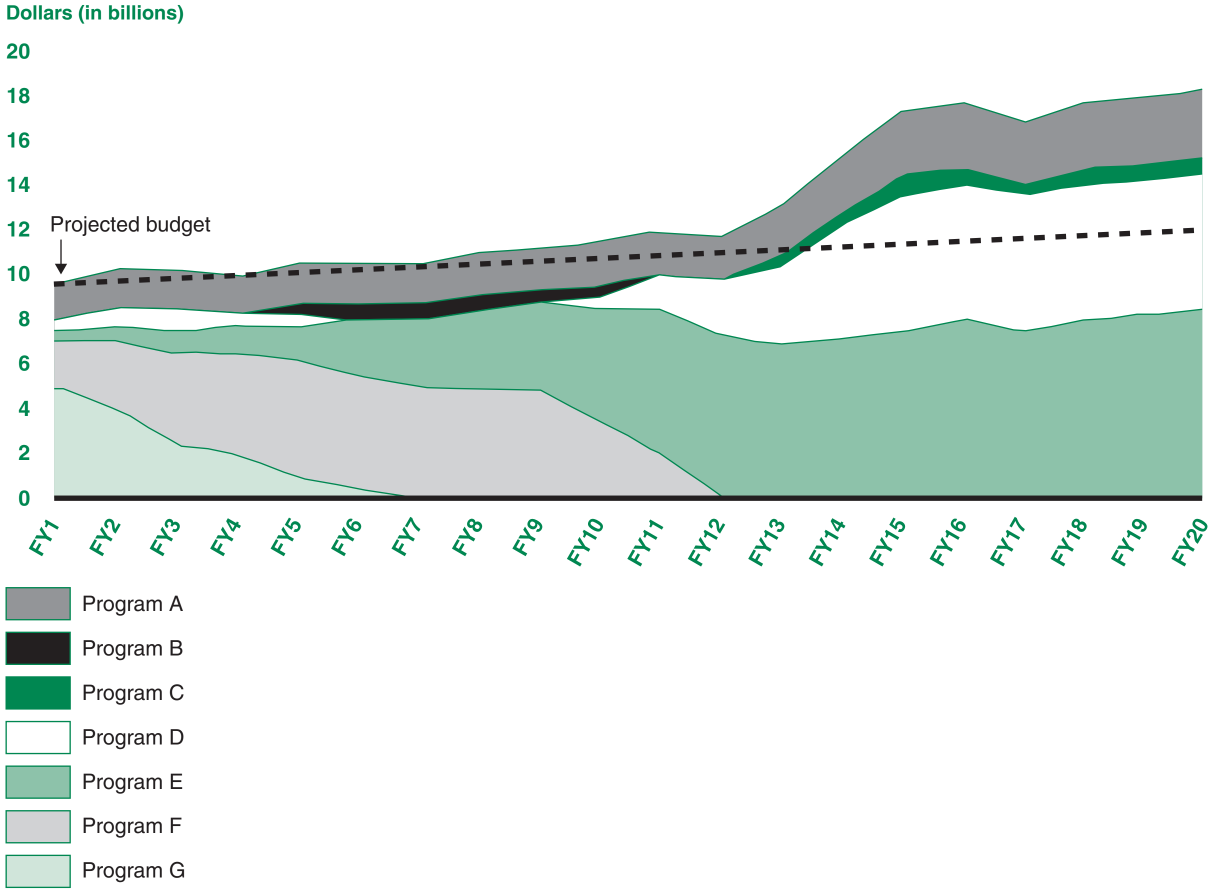
GAO, *Defense Acquisitions: Improved Management Practices Could Help Minimize Cost Growth in Navy Shipbuilding Programs*, GAO-05-183 (Washington, D.C.: Feb. 28, 2005).

Cost Estimates and Affordability

Affordability is the degree to which an acquisition program's funding requirements fit within the agency's overall portfolio plan. Whether a program is affordable depends a great deal on the quality of its cost estimate. Therefore, agencies can follow the 12-step estimating process we outlined in chapter 1 to ensure that they are creating and making decisions based on credible cost estimates. The 12-step process addresses best practices, including defining the program's purpose, developing the estimating plan, defining the program's characteristics, determining the estimating approach, identifying ground rules and assumptions, obtaining data, developing the point estimate, conducting sensitivity analysis, performing a risk or uncertainty analysis, documenting the estimate, presenting it to management for approval, and updating it to reflect actual costs and changes. Following these steps ensures that realistic cost estimates are developed and presented to management, enabling them to make informed decisions about whether the program is affordable within the portfolio plan.

Decision makers should consider affordability at each decision point in a program's life cycle. It is important to know the program's cost at particular intervals, in order to ensure that adequate funding is available to execute the program according to plan. Affordability analysis validates that the program's acquisition strategy has an adequate budget for its planned resources (see figure 5).

Figure 5: An Affordability Assessment



Source: DOD.

In figure 5, seven programs A–G are plotted against time, with the resources they will need to support their goals. The benefit of plotting the programs together gives decision makers a high-level analysis of their portfolio and the resources they will need in the future. In this example, it appears that funding needs are relatively stable in fiscal years 1–12, but from fiscal year 12 to fiscal year 16, an increasing need for additional funding is readily apparent. This is commonly referred to as a bow-wave, meaning there is an impending spike in the requirement for additional funds. Whether these funds will be available will determine which programs remain within the portfolio. Because the programs must compete against one another for limited funds, it is considered a best practice to perform the affordability assessment at the agency level, not program by program.

While approaches may vary, an affordability assessment should address requirements at least through the programming period and, preferably, several years beyond. Thus, LCCEs give decision makers important information in that not all programs require the same type of funding profile. In fact, different commodities require various outlays of funding and are affected by different cost drivers. Figure 6 illustrates this point with typical funding curves by program phase. It shows that while some programs may cost less to develop—for example, research and development in construction programs differ from fixed-wing aircraft—they may require more or less funding for investment, operations, and support in the out-years.

Figure 6: Typical Capital Asset Acquisition Funding Profiles by Phase

Source: GAO and DOD.

Line graphs or sand charts like those in figure 5, therefore, are often used to show how a program fits within the organizational plan, both overall and by individual program components. Such charts allow decision makers to determine how and if the program fits within the overall budget. It is very important for LCCEs to be both realistic and timely, available to decision makers as early as possible. Case studies 15 and 16 show how this often does not happen.

Case Study 15: Importance of Realistic LCCEs, from ***Combating Nuclear Smuggling*****, GAO-07-133R**

The Department of Homeland Security's (DHS) Domestic Nuclear Detection Office (DNDO) had underestimated life-cycle costs for plastic scintillators and advanced spectroscopic portal monitors. Although DNDO's analysis assumed a 5-year life cycle for both, DNDO officials told GAO that a 10-year life cycle was more reasonable. DNDO's analysis had assumed annual maintenance costs at 10 percent of their procurement costs: maintenance costs for the scintillators would be about $5,500 per year per unit, based on a $55,000 purchase price, and maintenance costs for the monitors would be about $38,000 per year per unit, based on a $377,000 purchase price. DNDO's analysis had not accounted for about $181 million in potential maintenance costs for the monitors alone. With the much higher maintenance costs, and doubling the life cycle, the long-term implications would be magnified.

GAO, *Combating Nuclear Smuggling: DHS's Cost-Benefit Analysis to Support the Purchase of New Radiation Detection Portal Monitors Was Not Based on Available Performance Data and Did Not Fully Evaluate All the Monitors' Costs and Benefits*, GAO-07-133R (Washington, D.C.: Oct. 17, 2006).

Case Study 16: Importance of Realistic LCCEs, from *Space Acquisitions*, GAO-07-96

GAO has in the past identified a number of causes behind cost growth and related problems in DOD's major space acquisition programs, but several consistently stand out. On a broad scale, DOD starts more weapons programs than it can afford, creating competition for funding that encourages low-cost estimating and optimistic scheduling, overpromising, suppressing bad news, and for space programs, forsaking the opportunity to identify and assess potentially better alternatives. Programs focus on advocacy at the expense of realism and sound management.

With too many programs in its portfolio, DOD is invariably forced to shift funds to and from programs—particularly as programs experience problems that require more time and money. Such shifts, in turn, have had costly, reverberating effects. In previous testimony and reports, GAO has stressed that DOD could avoid costly funding shifts.

It could do this by developing an overall investment strategy to prioritize systems in its space portfolio with an eye toward balancing investments between legacy systems and new programs, as well as between science and technology programs and acquisition investments. Such prioritizing would also reduce incentives to produce low estimates.

GAO, *Space Acquisitions: DOD Needs to Take More Action to Address Unrealistic Initial Cost Estimates of Space Systems*, GAO-07-96 (Washington, D.C.: Nov. 17, 2006).

Evolutionary Acquisition and Cost Estimation

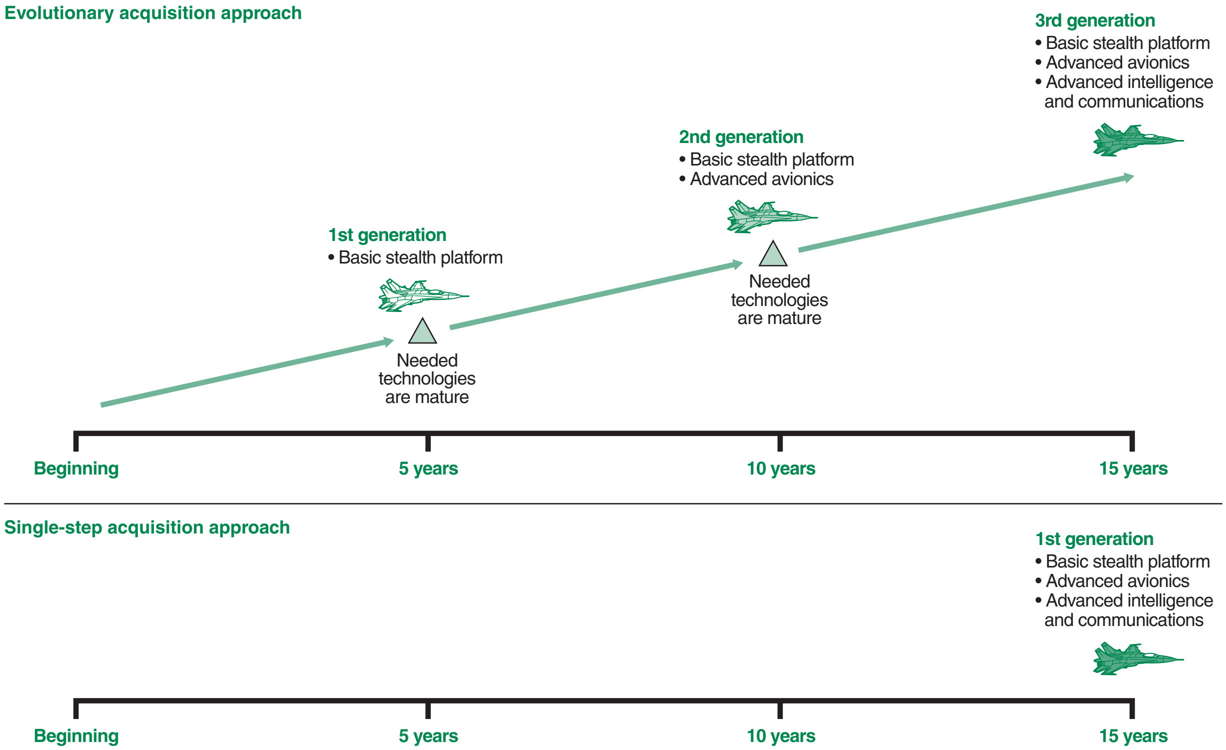
GAO has reported that evolutionary acquisition is in line with commercial best practices.[24] In evolutionary acquisition, a program evolves to its ultimate capabilities on the basis of mature technologies and available resources. This approach allows commercial companies to develop and produce more sophisticated products faster and less expensively than their predecessors.

Commercial companies have found that trying to capture the knowledge required to stabilize a product design that entails significant new technical content is an unmanageable task, especially if the goal is to reduce development cycle times and get the product to the marketplace as quickly as possible. Therefore, product features and capabilities that cannot be achieved in the initial development are planned for development in the product's future generations, when the technology has proven mature and other resources are available.

Figure 7 compares evolutionary to single-step acquisition, commonly called the big bang approach. An evolutionary environment for developing and delivering new products reduces risk and makes cost more predictable. While a customer may not initially receive an ultimate capability, the product is available sooner, with higher quality and reliability and at a lower and more predictable cost. With this approach, improvements can be planned for the product's future generations. (See case study 17.)

[24] GAO, *Best Practices: Better Acquisition Outcomes Are Possible If DOD Can Apply Lessons from F/A-22 Program*, GAO-03-645T (Washington, D.C.: Apr. 11, 2003), pp. 2–3.

Figure 7: Evolutionary and Big Bang Acquisition Compared



Source: GAO.

Case Study 17: Evolutionary Acquisition and Cost Estimates, from *Best Practices*, GAO-03-645T

The U.S. Air Force F/A-22 tactical fighter acquisition strategy was, at the outset, to achieve full capability in a big bang approach. By not using an evolutionary approach, the F/A-22 took on significant risk and onerous technological challenges. While the big bang approach might have allowed the Air Force to compete more successfully for early funding, it hamstrung the program with many new, undemonstrated technologies, preventing the program from knowing cost and schedule ramifications throughout development. Cost, schedule, and performance problems resulted.

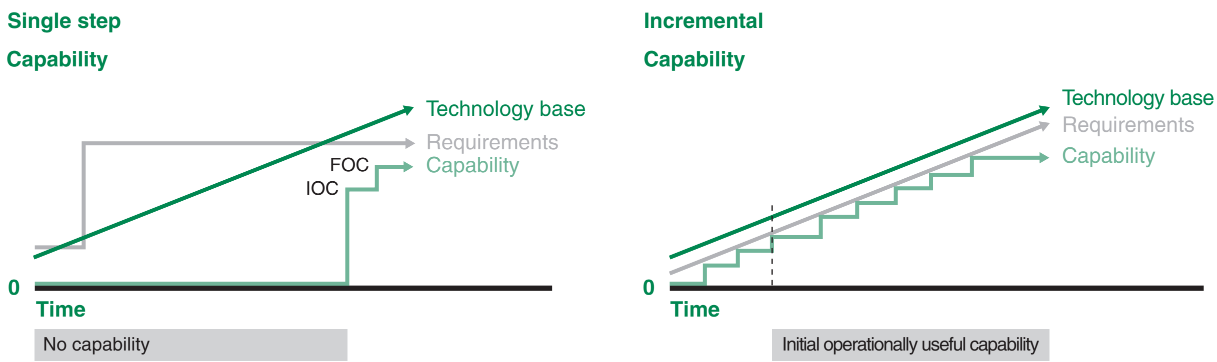
GAO, *Best Practices: Better Acquisition Outcomes Are Possible If DOD Can Apply Lessons from F/A-22 Program*, GAO-03-645T (Washington, D.C.: Apr. 11, 2003).

Two development processes support evolutionary acquisition: incremental development and spiral development. Both processes are based on maturing technology over time instead of trying to do it all at once, as in the big bang approach. Both processes allow for developing hardware and software in manageable pieces by inserting new technology and capability over time. This usually results in fielding an initial hardware or software increment (or block) of capability with steady improvements over less time than is possible with a full development effort.

Incremental Development

In incremental development, a desired capability is known at the beginning of the program and is met over time by developing several increments, each dependent on available mature technology. A core set of functions is identified and released in the first increment. Each new increment adds more functionality, and this process continues until all requirements are met. This assumes that the requirements are known up front and that lessons learned can be incorporated as the program matures. (See fig. 8.)

Figure 8: Incremental Development



Source: GAO.

Note: IOC = initial operational capability; FOC = final operational capability.

The advantages of incremental development are that a working product is available after the first increment and that each cycle results in greater capability. In addition, the program can be stopped when an increment is completed and still provide a usable product. Project management and testing can be easier, because the program is broken into smaller pieces. Its disadvantages are that the majority of the requirements must be known early, which is sometimes not feasible. In addition, cost and schedule overruns may result in an incomplete system if the program is terminated, because each increment only delivers a small part of the system at a time. Finally, operations and support for the program are often less efficient because of the need for additional learning for each increment release. (See case study 18.)

Case Study 18: Incremental Development, from ***Customs Service Modernization*****, GAO/AIMD-99-41**

The U.S. Customs Service was developing and acquiring the Automated Commercial Environment (ACE) program in 21 increments. At the time of GAO's review, Customs defined the functionality of only the first 2 increments, intending to define more later. Customs had nonetheless estimated costs and benefits for and had committed to investing in all 21 increments. It had not estimated costs and benefits for each increment and did not know whether each increment would produce a reasonable return on investment. Furthermore, once it had deployed an increment at a pilot site for evaluation, Customs was not validating that estimated benefits had actually been achieved. It did not even know whether the program's first increment, being piloted at three sites, was producing expected benefits or was cost-effective. Customs could determine only whether the first increment was performing at a level "equal to or better than" the legacy system.

GAO, *Customs Service Modernization: Serious Management and Technical Weaknesses Must Be Corrected*, GAO/AIMD-99-41 (Washington, D.C.: Feb. 26, 1999).

Spiral Development

In spiral development, a desired capability is identified but the end-state requirements are not yet known. These requirements are refined through demonstration and risk management, based on continuous user feedback. This approach allows each increment to provide the best possible capability. Spiral development is often used in the commercial market, because it significantly reduces technical risk while incorporating new technology. The approach can, however, lead to increased cost and schedule risks. Spiral development can also present contract challenges due to repeating phases, trading requirements, and redefining deliverables.

The advantage of spiral development is that it provides better risk management, because user needs and requirements are better defined. Its disadvantage is that the process is a lot harder to manage and usually results in increased cost and longer schedule.

While both incremental and spiral development have advantages and disadvantages, their major difference is the knowledge of the final product available to the program from the outset. With incremental development, the program office is aware of the final product to be delivered but develops it in stages. With spiral development, the final version of the product remains undetermined until the final stage has been completed—that is, the final product design is not known while the system is being built.

Even though it is a best practice to follow evolutionary development rather than the big bang approach, it often makes cost estimating more difficult, because it requires that cost estimates be developed more frequently. In some cases, cost estimates made for programs are valid only for the initial increment or spiral, because future increments and spirals are not the product they were at the outset. Nevertheless, this approach is considered a best practice because it is helps avoid unrealistic cost estimates, resulting in more realistic long-range investment funding and more effective resource allocation. Moreover, realistic cost estimates help management decide between competing options and increase the probability that the programs will succeed.

1. Best Practices Checklist: The Estimate

- ☐ The cost estimate type is clearly defined and is appropriate for its purpose.
- ☐ The cost estimate contains all elements suitable to its type—ICA, ICE, IGCE, LCCE, rough order of magnitude, total ownership cost: development, procurement, operating and support, disposal costs, and all sunk costs.
  - ✓ AOA, CEA, EA, cost-benefit analysis: consistently evaluate all alternatives.
  - ✓ EA, cost-benefit analysis: portray estimates as present values.
- ☐ All program costs have been estimated, including all life-cycle costs.
- ☐ The cost estimate is independent of funding source and appropriations.
- ☐ An affordability analysis has been performed at the agency level to see how the program fits within the overall portfolio.
  - ✓ The agency has a process for developing cost estimates that includes the 12-step best practice process outlined in chapter 1.
  - ✓ An overall agency portfolio sand chart displays all costs for every program.
- ☐ The estimate is updated as actual costs become available from the EVM system or requirements change.
- ☐ Post mortems and lessons learned are continually documented.

CHAPTER 5

The Cost Estimate's Purpose, Scope, and Schedule

A cost estimate is much more than just a single number. It is a compilation of many lower-level cost element estimates that span several years, based on the program schedule. Credible cost estimates are produced by following the rigorous 12 steps outlined in chapter 1 and are accompanied by detailed documentation. The documentation addresses the purpose of the estimate, the program background and system description, its schedule, the scope of the estimate (in terms of time and what is and is not included), the ground rules and assumptions, all data sources, estimating methodology and rationale, the results of the risk analysis, and a conclusion about whether the cost estimate is reasonable. Therefore, a good cost estimate—while taking the form of a single number—is supported by detailed documentation that describes how it was derived and how the expected funding will be spent in order to achieve a given objective.

Purpose

The purpose of a cost estimate is determined by its intended use, and its intended use determines its scope and detail. Cost estimates have two general purposes: (1) to help managers evaluate affordability and performance against plans, as well as the selection of alternative systems and solutions, and (2) to support the budget process by providing estimates of the funding required to efficiently execute a program.

More specific applications include providing data for trade studies, independent reviews, and baseline changes. Regardless of why the cost estimate is being developed, it is important that the program's purpose link to the agency's missions, goals, and strategic objectives. The purpose of the program should also address the benefits it intends to deliver, along with the appropriate performance measures for benchmarking progress.

Scope

To determine an estimate's scope, cost analysts must identify the customer's needs. That is, the cost estimator must determine if the estimate is required by law or policy or is requested. For example, 10 U.S.C. § 2434 requires an independent cost estimate before a major defense acquisition program can advance into system development and demonstration or production and deployment. The statute specifies that the full life-cycle cost—all costs of development, procurement, military construction, and operations and support, without regard to funding source or management control—must be provided to the decision maker for consideration.

In other cases, a program manager might want initially to address development and procurement, with estimates of operations and support to follow. However, if an estimate is to support the comparative analysis of alternatives, all cost elements of each alternative should be estimated to make each alternative's cost transparent in relation to the others.

Where appropriate, the program manager and the cost estimating team should work together to determine the scope of the cost estimate. The scope will be determined by such issues as the time involved, what elements of work need to be estimated, who will develop the cost estimates, and how much cost estimating detail will be included. Where the program is in its life cycle will influence the quantity of detail for the cost estimate as well as the amount of data to be collected. For example, early in the life cycle the project may have a concept with no solid definition of the work involved. A cost estimate at this point in the life cycle will probably not require extensive detail. As the program becomes better defined, more detailed estimates should be prepared.

Once the cost analysts know the context of the estimate or the customer's needs, they can determine the estimate's scope by its intended use and the availability of data. For example, if an independent cost analyst is typically given the time and other resources needed to conduct a thorough analysis, the analysis is expected to be more detailed than a what-if exercise. For either, however, more data are likely to be available for a system in production than for one that is in the early stages of development.

More detail, though, does not necessarily mean greater accuracy. Pursuing too much detail too early may be detrimental to an estimate's quality. If a detailed technical description of the system being analyzed is lacking, along with detailed cost data, analysts will find it difficult to identify and estimate all the cost elements. It may be better to develop the estimate at a relatively high system level to ensure capturing all the lower-level elements. This is the value of so-called parametric estimating tools, which operate at a higher level of detail and are used when a system lacks detailed technical definition and cost data. These techniques also allow the analyst to link cost and schedule to measures of system size, functionality, or complexity in advance of detailed design definition.

Analysts should develop, and tailor, an estimate plan whose scope coincides with data availability and the estimate's ultimate use. For a program in development, which is estimated primarily with parametric techniques and factors, the scope might be at a higher level of the WBS. (WBS is discussed in ch. 8.) As the program enters production, a lower level of detail would be expected.

As the analysts develop and revise the estimating plan, they should keep management informed of the initial approach and any changes in direction or method.[25] Since the plan serves as an agreement between the customer and cost estimating team, it must clearly reflect the approved approach and should be distributed formally to all participants and organizations involved.

Schedule

Regardless of an estimate's ultimate use and its data availability, time can become an overriding constraint on its detail. When defining the elements to be estimated and when developing the plan, the cost estimating team must consider its time constraints relative to team staffing. Without adequate time to develop a competent estimate, the team may be unable to deliver a product of sufficiently high quality. For example, a rough-order-of-magnitude estimate could be developed in days, but a first-time budget-quality estimate would likely require many months. If, however, that budget estimate were simply an update to a

[25] An estimate that supports an independent estimate for a DOD program presumably entails no requirement that the independent cost estimating team keep program management informed. Instead, the program office and independent cost estimators would be expected to maintain communication and brief one another on their results, so as to understand any differences between the two estimates.

previous estimate, it could be done faster. The more detail required, the more time and staff the estimate will require. It is important, therefore, that auditors understand the context of the cost estimate—why and how it was developed and whether it was an initial or follow-on estimate. (See case study 19.)

Case Study 19: The Estimate's Context, from ***DOD Systems Modernization*****, GAO-06-215**

Program officials told GAO that they had not developed the 2004 cost estimate in accordance with all SEI's cost estimating criteria, because they had only a month to complete the economic analysis. By not following practices associated with reliable estimates—by not making a reliable estimate of system life-cycle costs—the Navy had decided on a course of action not based on sound and prudent decision making. This meant that the Navy's investment decision was not adequately justified and that to the extent that program budgets were based on cost estimates, the likelihood of funding shortfalls and inadequate funding reserves was increased.

GAO, *DOD Systems Modernization: Planned Investment in the Naval Tactical Command Support System Needs to Be Reassessed*, GAO-06-215 (Washington, D.C.: Dec. 5, 2005).

After the customer has defined the task, the cost estimating team should create a detailed schedule that includes realistic key decision points or milestones and that provides margins for unforeseen, but not unexpected, delays. The team must ensure that the schedule is not overly optimistic. If the team wants or needs to compress the schedule to meet a due date, compression is acceptable as long as additional resources are available to complete the effort that fewer analysts would have accomplished in the longer period of time. If additional resources are not available, the estimate's scope must be reduced.

The essential point is that the team must attempt to ensure that the schedule is reasonable. When this is not possible, the schedule must be highlighted as having curtailed the team's depth of analysis and the estimate's resulting confidence level.

2. Best Practices Checklist: Purpose, Scope, and Schedule

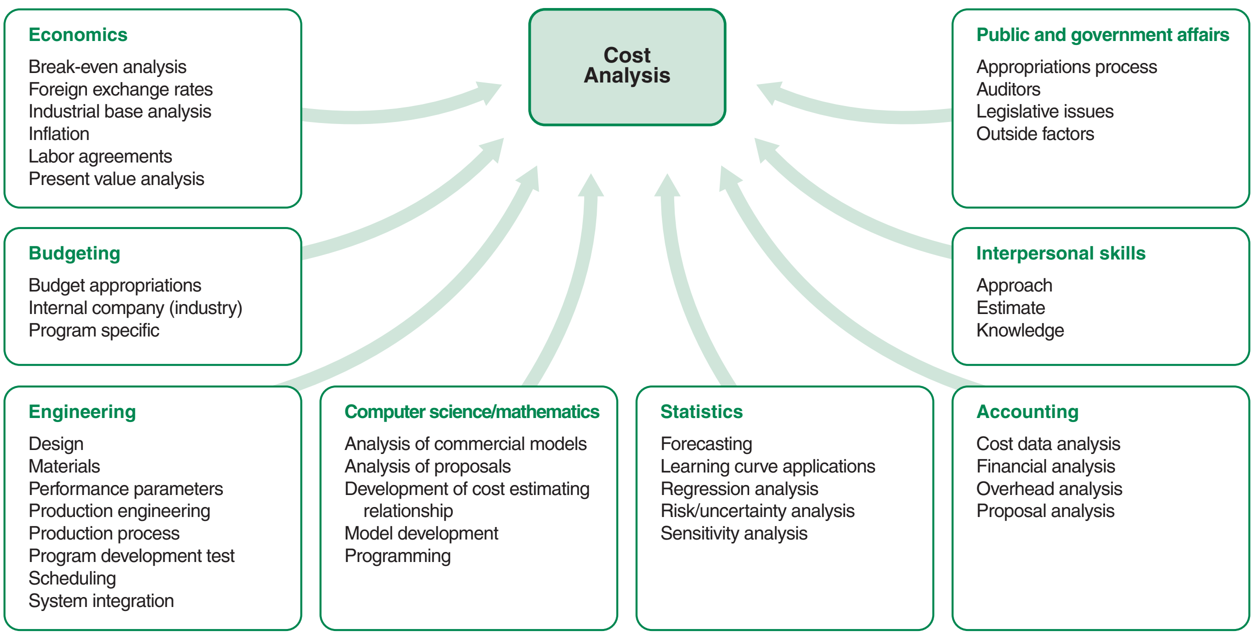
- ☐ The estimate's purpose is clearly defined.
- ☐ Its scope is clearly defined.
- ☐ The level of detail the estimate is to be conducted at is consistent with the level of detail available for the program. For example, an engineering build-up estimate should be conducted only on a well-defined program.
- ☐ The team has been allotted adequate time and resources to develop the estimate.

CHAPTER 6

The Cost Assessment Team

Cost estimates are developed with an inexact knowledge of what the final technical solution will be. Therefore, the cost assessment team must manage a great deal of risk—especially for programs that are highly complex or on technology's cutting edge. Since cost estimates seek to define what a given solution will ultimately cost, the estimate must be bound by a multitude of assumptions and an interpretation of what the historical data represent. This tends to be a subjective effort, and these important decisions are often left to a cost analyst's judgment. A cost analyst must possess a variety of skills to develop a high-quality cost estimate that satisfies the 12 steps identified in chapter 1, as figure 9 illustrates.

Figure 9: Disciplines and Concepts in Cost Analysis



Source: GAO.

Each discipline in figure 9 applies to cost estimating in its own unique way. For example, having an understanding of economics and accounting will help the cost estimator better understand the importance of inflation effects and how different accounting systems capture costs. Budgeting knowledge is important for knowing how to properly allocate resources over time so that funds are available when needed. Because cost estimates are often needed to justify enhancing older systems, having an awareness of engineering, computer science, mathematics, and statistics will help identify cost drivers and the type of data needed to develop the estimate. It also helps for the cost estimator to have adequate technical knowledge when meeting with functional experts so that credibility and a common understanding of the technical aspects of the program can be quickly established. Finally, cost estimators who are able to "sell" and present their estimate by defending it with solid facts and reliable data stand a better chance of its being used as a basis for program funding. In addition, cost estimators need to have solid interpersonal skills, because working and communicating with subject matter experts is vital for understanding program requirements.

Team Composition and Organization

Program office cost estimates are normally prepared by a multidisciplinary team whose members have functional skills in financial management, engineering, acquisition and logistics, scheduling, and mathematics, in addition to communications.[26] The team should also include participants or reviewers from the program's operating command, product support center, maintenance depot, and other units affected in a major way by the estimate.[27] Team members might also be drawn from other organizations. In the best case, the estimating team is composed of persons who have experience in estimating all cost elements of the program. Since this is seldom possible, the team leader should be familiar with the team members' capabilities and assign tasks accordingly. If some are experienced in several areas, while others are relatively inexperienced in all areas, the team leader should assign the experienced analysts responsibility for major sections of the estimate while the less experienced analysts work under their supervision.

An analytic approach to cost estimates typically entails a written study plan detailing a master schedule of specific tasks, responsible parties, and due dates. For complex efforts, the estimating team might be organized as a formal, integrated product team. For independent estimates, the team might be smaller and less formal. In either case, the analysis should be coordinated with all stakeholders, and the study plan should reflect each team member's responsibilities.

What is required of a cost estimating team depends on the type and purpose of the estimate and the quantity and quality of the data. More detailed estimates generally require larger teams, more time and effort, and more rigorous techniques. For example, a rough-order-of-magnitude estimate—a quick, high-level cost estimate—generally requires less time and effort than a budget-quality estimate. In addition, the estimating team must be given adequate time to develop the estimate. Following the 12 steps takes time and cannot be rushed—rushing would significantly risk the quality of the results.

One of the most time consuming steps in the cost estimating process is step 6: obtaining the data. Enough time should be scheduled to collect the data, including visiting contractor sites to further understand the strengths and limitations of the data that have been collected. If there is not enough time to develop the estimate, then the schedule constraint should be clearly identified in the ground rules and assumptions, so that management understands the effect on the estimate's quality and confidence.

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[26] Since schedules are the foundation of the performance plan, having a scheduling staff member integrated on the team is critical for validating the plan's reasonableness. A scheduler can determine the feasibility of the network schedule by analyzing its durations.

[27] An independent cost estimate for a major defense acquisition program under 10 U.S.C. § 2434 must be prepared by an office or other entity (such as the Office of the Secretary of Defense Cost Analysis Improvement Group) that is not under the supervision, direction, or control of the military department, defense agency, or other component directly responsible for carrying out the program's development or acquisition. If the decision authority has been delegated to an official of the military department, defense agency, or other DOD component, then the estimate must be prepared by an office or other entity not directly responsible for carrying out the development or acquisition.

Cost estimating requires good organizational skills, in order to pull together disparate data for each cost element and to package it in a meaningful way. It also requires engineering and mathematical skills, to fully understand the quality of the data available. Excellent communication skills are also important for clarifying the technical aspects of a program with technical specialists. If the program has no technical baseline description, or if the cost estimating team must develop one, it is essential that the team have access to the subject matter experts—program managers, system and software engineers, test and evaluation analysts—who are familiar with the program or a program like it. Moreover, team members need good communication skills to interact with these experts in ways that are meaningful and productive.

Cost Estimating Team Best Practices

Centralizing the cost estimating team and process—cost analysts working in one group but supporting many programs—represents a best practice, according to the experts we interviewed. Centralization facilitates the use of standardized processes, the identification of resident experts, a better sharing of resources, commonality and consistency of tools and training, more independence, and a career path with more opportunities for advancement. Centralizing cost estimators and other technical and business experts also allows for more effective deployment of technical and business skills while ensuring some measure of independence.

A good example is in the Cost Analysis Improvement Group (CAIG) in the Office of the Secretary of Defense. Its cost estimates are produced by a centralized group of civilian government personnel to ensure long-term institutional knowledge and no bias toward results. Some in the cost estimating community consider a centralized cost department that provides cost support to multiple program offices, with a strong organizational structure and support from its leadership, to be a model.

In contrast, decentralization often results in ad hoc processes, limited government resources (requiring contractor support to fill the gaps), and decreased independence, since program offices typically fund an effort and since program management personnel typically rate the analysts' performance. The major advantage of a decentralized process is that analysts have better access to technical experts. Under a centralized process, analysts should thus make every effort to establish contacts with appropriate technical experts.

Finally, organizations that develop their own centralized cost estimating function but outside the acquiring program represent the best practice over organizations that develop their cost estimates in a decentralized or ad hoc manner under the direct control of a program office. One of the many benefits of centralized structure is the ability to resist pressure to lower the cost estimate when it is higher than the allotted budget. Furthermore, reliance on support contractors raises questions from the cost estimating community about whether numbers and qualifications of government personnel are sufficient to provide oversight of and insight into contractor cost estimates. Other experts in cost estimating suggested that reliance on support contractors can be a problem if the government cannot evaluate how good a cost estimate is or if the ability to track it is lacking. Studies have also raised the concern that relying on support contractors makes it more difficult to retain institutional knowledge and instill accountability. Therefore, to mitigate any bias in the cost estimate, government customers of contractor-produced cost estimates must have a high enough level of experience to determine whether the cost estimate conforms to the best practices outlined in this Guide.

Certification and Training For Cost Estimating and EVM Analysis

Since the experience and skills of the members of a cost estimating team are important, various organizations have established training programs and certification procedures. For example, SCEA's certification program provides a professional credential to both members and nonmembers for education, training, and work experience and a written examination on basic concepts and methods for cost estimating. Another example is the earned value professional certification offered by the Association for the Advancement of Cost Engineering International that PMI's College of Performance Management endorses; it requires candidates to have the requisite experience and the ability to pass a rigorous written exam.

Under the Defense Acquisition Workforce Improvement Act, DOD established a variety of certification programs through the Defense Acquisition University (DAU).[28] DAU provides a full range of basic, intermediate, and advanced certification training; assignment-specific training; performance support, job-relevant applied research; and continuous learning opportunities. Although DAU's primary mission is to train DOD employees, all federal employees are eligible to attend as space is available. One career field is in business, cost estimating, and financial management. Certification levels are based on education, experience, and training. Since this certification is available to all federal employees, it is considered a minimum training requirement for cost estimators.

In addition to the mandatory courses in table 5, DAU encourages analysts to be trained in courses identified in its Core Plus Development Guide. These courses cover a wide range of cost estimating and earned value topics, such as acquisition reporting concepts and policy requirements, analysis of alternatives, baseline maintenance, basic software acquisition management, business case analysis, business management modernization, contract source selection, cost as an independent variable, economic analysis, EVM system validation and surveillance, integrated acquisition for decision makers, operating and support cost analysis, principles of schedule management, program management tools, and risk management. The standards for the business, cost estimating, and financial management levels of certification are shown in table 5.

Table 5: Certification Standards in Business, Cost Estimating, and Financial Management in the Defense Acquisition Education, Training, and Career Development Program

Level		Education	Experience	Training
I	Desired	Baccalaureate		
	Mandatory		1 year of acquisition in business, cost estimating, or financial management	ACQ 101: Fundamentals of Systems Acquisition Management and 2 of the following: BCF 101: Fundamentals of Cost Analysis BCF 102: Fundamentals of Earned Value BCF 103: Fundamentals of Business Financial Management

[28] Defense Acquisition Workforce Improvement Act, codified at 10 U.S.C. ch. 87.

Level		Education	Experience	Training
II	Desired	Baccalaureate	2 additional years in business, cost estimating, or financial management	
	Mandatory		2 years of acquisition in business, cost estimating, or financial management	ACQ 201: (Parts A & B) Intermediate Systems Acquisition and BCF 205: Contractor Business Strategies and, if not taken at Level I, BCF 101: Fundamentals of Cost Analysis or BCF 102: Fundamentals of Earned Value Management or BCF 103: Fundamentals of Business Financial Management and one of the following: BCF 203: Intermediate Earned Value Management or BCF 204: Intermediate Cost Analysis or BCF 211: Acquisition Business Management
III	Desired	Baccalaureate or 24 semester hours among 10 courses[a] or Master's	4 additional years of acquisition in business, cost estimating, or financial management	
	Mandatory			BCF 301: Business, Cost Estimating, and Financial Management Workshop

Source: DAU.

[a]The 10 courses are accounting, business finance, contracts, economics, industrial management, law, marketing, organization and management, purchasing, and quantitative methods.

When reviewing an agency's cost estimate, an auditor should question the cost estimators about whether they have both the requisite formal training and substantial on-the-job training to develop cost estimates and keep those estimates updated with EVM analysis. Continuous learning by participating in cost estimating and EVM conferences is important for keeping abreast of the latest techniques and maximizing lessons learned. Agency cost estimators and EVM analysts, as well as GAO's auditors, should attend such conferences to keep their skills current. Maintaining skills is essential if subject matter experts are to be relied on to apply best practices in their roles.

While formal training is important, so is on-the-job training and first-hand knowledge from participating in plant and site visits. On-site visits to see what is being developed and how engineering and manufacturing are executed are invaluable to cost estimators and auditors. To understand the complexity of the tasks necessary to deliver a product, site visits should always be included in the audit plan.

SEI's Checklists and Criteria for Evaluating the Cost and Schedule Estimating Capabilities of Software Organizations lists six requisites for reliable estimating and gives examples of evidence needed to satisfy them. It also contains a checklist for estimating whether an organization provides its commitment and support to the estimators. SEI's criteria are helpful for determining whether cost estimators have the skills and training to effectively develop credible cost estimates. (See appendix VIII for a link to SEI's material.)

While much of this Cost Guide's focus is on cost estimating, in chapter 18 we focus on EVM and how it follows the cost estimate through its various phases and determines where there are cost and schedule variances and why. This information is vitally important to keeping the estimate updated and for keeping abreast of program risks. Because of performance measurement requirements (including the use of EVM), OMB issued policy guidance in August 2005 to agency chief information officers on improving information technology projects. OMB stated that the Federal Acquisition Institute (co-located with DAU) was expanding EVM system training to the program management and contracting communities and instructed agencies to refer to DAU's Web site for a community of practice that includes the following resources:[29]

- 6 hours of narrated EVM tutorials (Training Center),
- descriptions and links to EVM tools (Tools),
- additional EVM-related references and guides (Community Connection),
- DOD policy and contracting guidance (Contract Documents and DOD Policy and Guidance),
- a discussion forum (Note Board), and
- an on-line reference library (Research Library).

Such resources are important for agencies and auditors in understanding what an EVM system can offer for improving program management.

3. Best Practices Checklist: Cost Assessment Team

- ☐ The estimating team's composition is commensurate with the assignment (see SEI's checklists for more details).
  - ✓ The team has the proper number and mix of resources.
  - ✓ Team members are from a centralized cost-estimating organization.
  - ✓ The team includes experienced and trained cost analysts.
  - ✓ The team includes, or has direct access to, analysts experienced in the program's major areas.
  - ✓ Team members' responsibilities are clearly defined.
  - ✓ Team members' experience, qualifications, certifications, and training are identified.
  - ✓ The team participated in on-the-job training, including plant and site visits.
- ☐ A master schedule with a written study plan has been developed.
- ☐ The team has access to the necessary subject matter experts.

[29] DAU's Web site is at https://acc.dau.mil/evm.

CHAPTER 7

Technical Baseline Description Definition and Purpose

Key to developing a credible estimate is having an adequate understanding of the acquisition program—the acquisition strategy, technical definition, characteristics, system design features, and technologies to be included in its design. The cost estimator can use this information to identify the technical and program parameters that will bind the cost estimate. The amount of information gathered directly affects the overall quality and flexibility of the estimate. Less information means more assumptions must be made, increasing the risk associated with the estimate. Therefore, the importance of this step must be emphasized, because the final accuracy of the cost estimate depends on how well the program is defined.

The objective of the technical baseline is to provide in a single document a common definition of the program—including a detailed technical, program, and schedule description of the system—from which all LCCEs will be derived—that is, program and independent cost estimates. At times, the information in the technical baseline will drive or facilitate the use of a particular estimating approach. However, the technical baseline should be flexible enough to accommodate a variety of estimating methodologies. It is also critical that the technical baseline contain no cost data, so that it can be used as the common baseline for independently developed estimates.[30]

In addition to providing a comprehensive program description, the technical baseline is used to benchmark life-cycle costs and identify specific technical and program risks. In this way, it helps the estimator focus on areas or issues that could have a major cost effect.

Process

In general, program offices are responsible for developing and maintaining the technical baseline throughout the life cycle, since they know the most about their program. A best practice is to assign an integrated team of various experts—system engineers, design experts, schedulers, test and evaluation experts, financial managers, and cost estimators—to develop the technical baseline at the beginning of the project. The program manager and the senior executive oversight committee approve the technical baseline to ensure that it contains all information necessary to define the program's systems and develop the cost estimate.

Furthermore, the technical baseline should be updated in preparation for program reviews, milestone decisions, and major program changes. The credibility of the cost estimate will suffer if the technical baseline is not maintained. Without explicit documentation of the basis of a program's estimates, it is difficult to update the cost estimate and provide a verifiable trace to a new cost baseline as key assumptions change during the course of the program's life.

[30] As used in this Cost Guide, the technical baseline is similar to DOD's Cost Analysis Requirements Description (CARD) and NASA's Cost Analysis Data Requirement (CADRE).

It is normal and expected that early program technical baselines will be imprecise or incomplete and that they will evolve as more information becomes known. However, it is essential that the technical baseline provide the best available information at any point in time. To try to create an inclusive view of the program, assumptions should be made about the unknowns and should be agreed on by management. These assumptions and their corresponding justifications should be documented in the technical baseline, so their risks are known from the beginning.

Schedule

The technical baseline must be available in time for all cost estimating activities to proceed on schedule. This often means that it is submitted as a draft before being made final. The necessary lead time will vary by organization. One example is the CAIG in the Office of the Secretary of Defense, which requires that the Cost Analysis Requirements Description be submitted in draft 180 days before the Defense Acquisition Board milestone and that in final form 45 days before the milestone review.

Contents

Since the technical baseline is intended to serve as the baseline for developing LCCEs, it must provide information on development, testing, procurement, installation and replacement, operations and support, planned upgrades, and disposal. In general, a separate technical baseline should be prepared for each alternative; as the program matures, the number of alternatives and, therefore, technical baselines decreases. Although technical baseline content varies by program (and possibly even by alternative), it always entails a number of sections, each focusing on a particular aspect of the program being assessed. Table 6 describes typical technical baseline elements.

Table 6: Typical Technical Baseline Elements

Element	Description
System purpose	Describes the system's mission and how it fits into the program; should give the estimator a concept of its complexity and cost
Detailed technical system and performance characteristics	Includes key functional requirements and performance characteristics; the replaced system (if applicable); who will develop, operate, and maintain the system; descriptions of hardware and software components (including interactions, technical maturity of critical components, and standards); system architecture and equipment configurations (including how the program will interface with other systems); key performance parameters; information assurance; operational concept; reliability analysis; security and safety requirements; test and evaluation concepts and plans
Work breakdown structure	Identifies the cost and technical data needed to develop the estimate
Description of legacy or similar systems	A legacy (or heritage or predecessor) system has characteristics similar to the system being estimated; often the new program is replacing it. The technical baseline includes a detailed description of the legacy hardware and software components; technical protocols or standards; key performance parameters; operational and maintenance logistics plan; training plan; phase-out plan; and the justification for replacing the system

Element	Description
Acquisition plan or strategy	Includes the competition strategy, whether multiyear procurement will be used, and whether the program will lease or buy certain items; it should identify the type of contract awarded or to be awarded and, if known, the contractor responsible for developing and implementing the system
Development, test, and production quantities and program schedule	Includes quantities required for development, test (e.g., test assets), and production; lays out an overall development and production schedule that identifies the years of its phases—the schedule should include a standard Gantt chart with major events such as milestone reviews, design reviews, and major tests—and that addresses, at a high level, major program activities, their duration and sequence, and the critical path
System test and evaluation plan	Includes the number of tests and test assets, criteria for entering into testing, exit criteria for passing the test, and where the test will be conducted
Deployment details	Includes standard platform and site configurations for all scenarios (peacetime, contingency, war) and a transition plan between legacy and new systems
Safety plan	Includes any special or unique system safety considerations that may relate to specific safety goals established through standards, laws, regulations, and lessons learned from similar systems
Training plan	Includes training for users and maintenance personnel, any special certifications required, who will provide the training, where it will be held, and how often it will be offered or required
Disposal and environmental effect	Includes identification of environment impact, mitigation plan, and disposal concept
Operational concept	Includes program management details, such as how, where, and when the system will be operated; the platforms on which it will be installed; and the installation schedule
Personnel requirements	Includes comparisons to the legacy system (if possible) in salary levels, skill-level quantity requirements, and where staff will be housed
Logistics support details	Includes maintenance and sparing plans, as well as planned upgrades
Changes from the previous technical baseline	Includes a tracking of changes, with a summary of what changed and why

Source: DOD, DOE, and SCEA.

Programs following an incremental development approach should have a technical baseline that clearly states system characteristics for the entire program. In addition, the technical baseline should define the characteristics to be included in each increment, so that a rigorous LCCE can be developed. For programs with a spiral development approach, the technical baseline tends to evolve as requirements become better defined. In earlier versions of a spiral development program, the technical baseline should clearly state the requirements that are included and those that have been excluded. This is important, since a lack of defined requirements can lead to cost increases and delays in delivering services, as case study 20 illustrates.

Case Study 20: Defining Requirement, from *United States Coast Guard*, GAO-06-623

The U.S. Coast Guard contracted in September 2002 to replace its search and rescue communications system, installed in the 1970s, with a new system known as Rescue 21. The acquisition and initial implementation of Rescue 21, however, resulted in significant cost overruns and schedule delays. By 2005, its estimated total acquisition cost had increased to $710.5 million from 1999's $250 million, and the schedule for achieving full operating capability had been delayed from 2006 to 2011. GAO reported in May 2006 on key factors contributing to the cost overruns and schedule delays, including requirements management. Specifically, GAO found that the Coast Guard did not have a rigorous requirements management process.

Although the Coast Guard had developed high-level requirements, it relied solely on the contractor to manage them. According to Coast Guard acquisition officials, they had taken this approach because of the performance-based contract vehicle. GAO's experience in reviewing major systems acquisitions has shown that it is important for government organizations to exercise strong leadership in managing requirements, regardless of the contracting vehicle.

Besides not effectively managing requirements, Rescue 21 testing revealed numerous problems linked to incomplete and poorly defined user requirements. For example, a Coast Guard usability and operability assessment of Rescue 21 stated that most of the operational advancements envisioned for the system had not been achieved, concluding that these problems could have been avoided if the contract had contained user requirements.

A key requirement was to "provide a consolidated regional geographic display." The contractor provided a capability based on this requirement but, during testing, the Coast Guard operators believed that the maps did not display sufficient detail. Such discrepancies led to an additional statement of work that defined required enhancements to the system interface, such as screen displays.

GAO reported that if deploying Rescue 21 were to be further delayed, Coast Guard sites and services would be affected in several ways. Key functionality, such as improved direction finding and improved coverage of coastal areas, would not be available as planned. Coast Guard personnel at those sites would continue to use outdated legacy communications systems for search and rescue operations, and coverage of coastal regions would remain limited. In addition, delays could result in costly upgrades to the legacy system in order to address communications coverage gaps, as well as other operational concerns.

GAO, *United States Coast Guard: Improvements Needed in Management and Oversight of Rescue System Acquisition*, GAO-06-623 (Washington, D.C.: May 31, 2006).

Fully understanding requirements up front helps increase the accuracy of the cost estimate. While each program should have a technical baseline that addresses each element in table 6, each program's aspects are unique. In the next section, we give examples of system characteristics and performance parameters typically found in government cost estimates, including military weapon systems and civilian construction and information systems.

Key System Characteristics And Performance Parameters

Since systems differ, each one has unique physical and performance characteristics. Analysts need specific knowledge about them before they can develop a cost estimate for a weapon system, an information system, or a construction program.

While the specific physical and performance characteristics for a system being estimated will be dictated by the system and the methodology used to perform the estimate, several general characteristics have been identified in the various guides we reviewed. Table 7 lists general characteristics shared within several system types.

Table 7: General System Characteristics

System	Characteristic	Type
Aircraft	Breakdown of airframe unit weight by material type	
	Combat ceiling and speed	
	Internal fuel capacity	
	Length	
	Load factor	
	Maximum altitude	
	Maximum speed (knots at sea level)	
	Mission and profile	
	Weight	Airframe unit weight, combat, empty, maximum gross, payload, structure
	Wetted area	
	Wing	Wingspan, wing area, wing loading
Automated information systems	Architecture	
	Commercial off-the-shelf software used	
	Customization of commercial off-the-shelf software	
	Expansion factors	
	Memory size	
	Processor type	
	Proficiency of programmers	
	Programming language used	
	Software sizing metric	

System	Characteristic	Type
Construction	Changeover	
	Environmental impact	
	Geography	
	Geology	
	Liability	
	Location	Land value, proximity to major roads, relocation expenses
	Material type	Composite, masonry, metal, tile, wood shake
	Number of stories	
	Permits	
	Public acceptance	
	Square feet	
	Systemization	
Missiles	Height	
	Length	
	Payload	
	Propulsion type	
	Range	
	Sensors	
	Weight	
	Width	
Ships	Acoustic signature	
	Full displacement	
	Full load weight	
	Length overall	
	Lift capacity	
	Light ship weight	
	Margin	
	Maximum beam	
	Number of screws	
	Payload	
	Propulsion type	
	Shaft horsepower	
Space	Attitude	
	Design life and reliability	
	Launch vehicle	
	Mission and duration	
	Orbit type	
	Pointing accuracy	
	Satellite type	
	Thrust	
	Weight and volume	

System	Characteristic	Type
Tanks and trucks	Engine	
	Height	
	Horsepower	
	Length	
	Weight	
	Width	
	Payload	

Source: DOD and GAO.

Once a system's unique requirements have been defined, they must be managed and tracked continually throughout the program's development. If requirements change, both the technical baseline and cost estimate should be updated so that users and management can understand the effects of the change. When requirements are not well managed, users tend to become disillusioned, and costs and schedules can spin out of control, as case study 21 demonstrates.

Case Study 21: Managing Requirements, from ***DOD Systems Modernization*****, GAO-06-215**

The Naval Tactical Command Support System (NTCSS) was started in 1995 to help U.S. Navy personnel manage ship, submarine, and aircraft support activities. At the time of GAO's review, about $1 billion had been spent to partially deploy NTCSS to about half its intended sites. In December 2005, GAO reported that the Navy had not adequately conducted requirements management and testing activities for the system. For example, requirements had not been prioritized or traced to related documentation to ensure that the system's capabilities would meet users' needs. As a result, failures in developmental testing had prevented NTCSS's latest component from passing operational testing twice over the preceding 4 years. From the Navy's data, the recent trend in key indicators of system maturity, such as the number and nature of reported system problems and change proposals, showed that problems with NTCSS had persisted and that they could involve costly rework. In addition, the Navy did not know the extent to which NTCSS's optimized applications were meeting expectations—even though the applications had been deployed to 229 user sites since 1998—because metrics to demonstrate that the expectations had been met had not been defined and collected.

GAO, DOD *Systems Modernization: Planned Investment in the Naval Tactical Command Support System Needs to Be Reassessed*, GAO-06-215 (Washington, D.C.: Dec. 5, 2005).

Case study 21 shows that an inability to manage requirements leads to additional costs and inefficient management of resources. To manage requirements, they must first be identified. The bottom line is that the technical baseline should document the underlying technical and program assumptions necessary to develop a cost estimate and update changes as they occur. Moreover, the technical baseline should also identify the level of risk associated with the assumptions so that the estimate's credibility can be determined. As we stated previously, the technical baseline should mature in the same manner as the program evolves. Because it is evolutionary, earlier versions of the technical baseline will necessarily include more assumptions and, therefore, more risk, but these should decline as risks become either realized or retired.

4. Best Practices Checklist: Technical Baseline Description

- ☐ There is a technical baseline:
  - ✓ The technical baseline has been developed by qualified personnel such as system engineers.
  - ✓ It has been updated with technical, program, and schedule changes, and it contains sufficient detail of the best available information at any given time.
  - ✓ The information in the technical baseline generally drives the cost estimate and the cost estimating methodology.
  - ✓ The cost estimate is based on information in the technical baseline and has been approved by management.
- ☐ The technical baseline answers the following:
  - ✓ What the program is supposed to do—requirements;
  - ✓ How the program will fulfill its mission—purpose;
  - ✓ What it will look like—technical characteristics;
  - ✓ Where and how the program will be built—development plan;
  - ✓ How the program will be acquired—acquisition strategy;
  - ✓ How the program will operate—operational plan;
  - ✓ Which characteristics affect cost the most—risk.

CHAPTER 8

Work Breakdown Structure

A work breakdown structure is the cornerstone of every program because it defines in detail the work necessary to accomplish a program's objectives. For example, a typical WBS reflects the requirements, what must be accomplished to develop a program, and provides a basis for identifying resources and tasks for developing a program cost estimate. A WBS is also a valuable communication tool between systems engineering, program management, and other functional organizations because it provides a clear picture of what needs to be accomplished and how the work will be done. Accordingly, it is an essential element for identifying activities in a program's integrated master schedule. In addition, it provides a consistent framework for planning and assigning responsibility for the work. Initially set up when the program is established, the WBS becomes successively detailed over time as more information becomes known about the program.

A WBS is a necessary program management tool because it provides a basic framework for a variety of related activities like estimating costs, developing schedules, identifying resources, determining where risks may occur, and providing the means for measuring program status using EVM. Furthermore, a well structured WBS helps promote accountability by identifying work products that are independent of one another. It also provides the framework to develop a schedule and cost plan that can easily track technical accomplishments—in terms of resources spent in relation to the plan as well as completion of activities and tasks—enabling quick identification of cost and schedule variances.

Best Practice: Product-Oriented WBS

A WBS deconstructs a program's end product into successive levels with smaller specific elements until the work is subdivided to a level suitable for management control. By breaking work down into smaller elements, management can more easily plan and schedule the program's activities and assign responsibility for the work. It also facilitates establishing a schedule, cost, and EVM baseline. Establishing a product-oriented WBS is a best practice because it allows a program to track cost and schedule by defined deliverables, such as a hardware or software component. This allows a program manager to more precisely identify which components are causing cost or schedule overruns and to more effectively mitigate the root cause of the overruns.

A WBS breaks down product-oriented elements into a hierarchical structure that shows how elements relate to one another as well as to the overall end product. A 100 percent rule is followed that states that "the next level of decomposition of a WBS element (child level) must represent 100 percent of the work applicable to the next higher (parent) element."[31] This is considered a best practice by many experts in cost

[31] Gregory T. Haugan, *Work Breakdown Structures for Projects, Programs, and Enterprises* (Vienna, Va.: Management Concepts, 2008), p. 38.

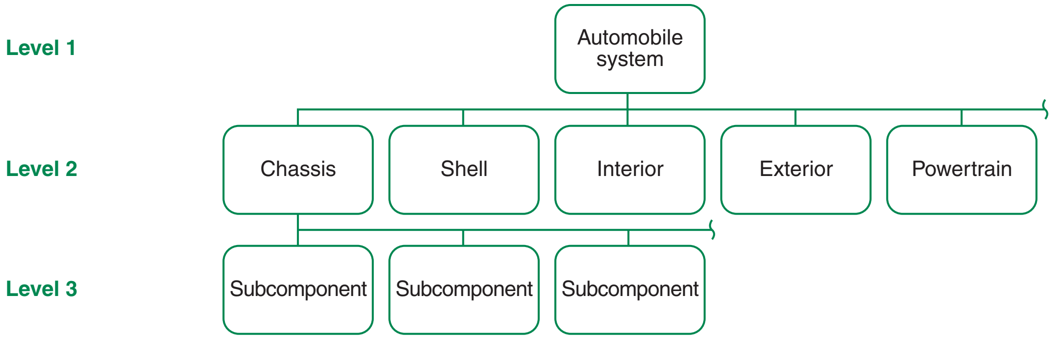
estimating, because a product-oriented WBS following the 100 percent rule ensures that all costs for all deliverables are identified. Failing to include all work for all deliverables can lead to schedule delays and subsequent cost increases. It can also result in confusion among team members. To avoid these problems, standardizing the WBS is a best practice in organizations where there is a set of program types that are standard and typical. This enables an organization to simplify the development of the top-level program work breakdown structures by publishing the standard. It also facilitates an organization's ability to collect and share data from common WBS elements among many programs. The more data that are available for creating the cost estimate, the higher the confidence level will be.

Its hierarchical nature allows the WBS to logically sum the lower-level elements that support the measuring of cost, schedule, and technical analysis in an EVM system. A good WBS clearly defines the logical relationship of all program elements and provides a systematic and standardized way for collecting data across all programs. Therefore, a WBS is an essential part of developing a program's cost estimate and enhancing an agency's ability to collect data necessary to support future cost estimates. Moreover, when appropriately integrated with systems engineering, cost estimating, EVM, and risk management, a WBS provides the basis to allow program managers to have a better view into a program's status, facilitating continual improvement.

A WBS is developed and maintained by a systems engineering process that produces a product-oriented family tree of hardware, software, services, data, and facilities. It can be thought of as an illustration of what work will be accomplished to satisfy a program's requirements. The WBS diagrams the effort in small discrete pieces, or elements, to show how each one relates to the others and to the program as a whole. These elements such as hardware, software, and data are further broken down into specific lower-level elements. The lowest level of the WBS is defined as the work package level.

The number of levels for a WBS varies from program to program and depends on a program's complexity and risk. Work breakdown structures need to be expanded to a level of detail that is sufficient for planning and successfully managing the full scope of work. However, each WBS should, at the very least, include three levels. The first level represents the program as a whole and therefore contains only one element—the program's name. The second level contains the major program segments, and level three contains the lower-level components or subsystems for each segment. These relationships are illustrated in figure 10, which depicts a very simple automobile system WBS.

Figure 10: A Product-Oriented Work Breakdown Structure



Source: © 2005 MCR, LLC, "Developing a Work Breakdown Structure."

In figure 10, all level 2 elements would also have level 3 subcomponents; chassis is the example in the figure. For some level 2 elements, level 3 would be the lowest level of breakdown; for others, still lower levels would be required. The elements at each lower level of breakdown are called "children" of the next higher level, which are the "parents." The parent–child relationship allows for logical connections and relationships to emerge and a better understanding of the technical effort involved. It also helps improve the ability to trace relationships within the cost estimate and EVM system.

In the example in figure 10, the chassis would be a child of the automobile system but the parent of subcomponents 1–3. In constructing a WBS, the 100 percent rule always applies. That is, the sum of a parent's children must always equal the parent. Thus, in figure 10, the sum of chassis, shell, interior, and so on must equal the automobile system. In this way, the WBS makes sure that each element is defined and related to only one work effort, so that all activities are included and accounted for. It also helps identify the specialists who are needed to complete the work and who will be responsible so that effort is not duplicated.

It is important to note that a product-oriented WBS reflects cost, schedule, and technical performance on specific portions of a program, while a functional WBS does not provide that level of detail. For example, an overrun on a specific item in figure 10 (for example, powertrain) might cause program management to change a specification, shift funds, or modify the design. If the WBS were functionally based (for example, in manufacturing, engineering, or quality control), then management would not have the right information to get to the root cause of the problem. Therefore, since only a product-oriented WBS relates costs to specific hardware elements—the basis of most cost estimates—it represents a cost estimating best practice. Case study 22 highlights problems that can occur by not following this best practice.

Case Study 22: Product-Oriented Work Breakdown Structure, from *Air Traffic Control*, GAO-08-756

Federal Aviation Administration (FAA) required the use of EVM on its major information technology investments. GAO found key components not fully consistent with best practices. We reported that leading organizations establish EVM policies that require programs to use a product-oriented structure for defining work products. FAA's policy and guidance are not consistent with best practices because it requires its programs to establish a standard WBS using a function-oriented structure. FAA work is thus delineated by functional activities, such as design engineering, requirements analysis, and quality control. A product-oriented WBS would reflect cost, schedule, and technical performance on specific deliverables.

Without a product-oriented approach, program managers may not have the detailed information needed to make decisions on specific program components. For example, cost overruns associated with a specific radar component could be quickly identified and addressed using a product-oriented structure. If a function-oriented structure were used, these costs could be spread out over design, engineering, etc.

FAA program managers using a product-oriented WBS need to transfer their data to FAA's required function-oriented WBS when reporting to management. EVM experts agree that such mapping efforts are time-consuming, subject to error, and not always consistent. Until FAA establishes a standard product-oriented WBS, program officials may not be obtaining the information they need.

GAO, *Air Traffic Control: FAA Uses Earned Value Techniques to Help Manage Information Technology Acquisitions, but Needs to Clarify Policy and Strengthen Oversight*, GAO-08-756 (Washington, D.C.: July 18, 2008).

Since best practice is for the WBS prime mission elements to be product-oriented, the WBS should not be structured or organized at a second or third level according to any element not a product or not being in or itself a deliverable:

- design engineering, requirements analysis, logistics, risk, quality assurance, and test engineering (all functional engineering efforts), aluminum stock (a material resource), and direct costs (an accounting classification);[32]
- program acquisition phases (for example, development and procurement) and types of funds used in those phases (for example, research, development, test, and evaluation);
- rework, retesting, and refurbishing, which should be treated as activities of the WBS element;
- nonrecurring and recurring classifications, for which reporting requirements should be structured to ensure that they are segregated;
- cost saving efforts—such as total quality management initiatives and acquisition reform initiatives—included in the elements they affect, not captured separately;
- the organizational structure of the program office or contractor;
- the program schedule—instead the WBS will drive the necessary schedule activities;
- meetings, travel, and computer support, which should be included in the WBS elements they are associated with;
- generic terms (terms for WBS elements should be as specific as possible); and
- tooling, which should be included with the equipment being produced.

While functional activities are necessary for supporting a product's development, the WBS should not be organized around them. Only products should drive the WBS, not common support activities. Moreover, the WBS dictionary should state where the functional elements fall within the products and how the statement of work elements come together to make specific products.

Common WBS Elements

In addition to including product-oriented elements, every WBS includes program management as a level 2 element and other common elements like integration and assembly, government furnished equipment, and government testing. Table 8 lists and describes common elements that support the program. For instance, systems engineering, program management, integration, and testing are necessary support functions for developing, testing, producing, and fielding hardware or software elements.

Table 8: Common Elements in Work Breakdown Structures

Common element	Description
Integration, assembly, test, and checkout	All effort of technical and functional activities associated with the design, development, and production of mating surfaces, structures, equipment, parts, materials, and software required to assemble level 3 equipment (hardware and software) elements into level 2 mission equipment (hardware and software)

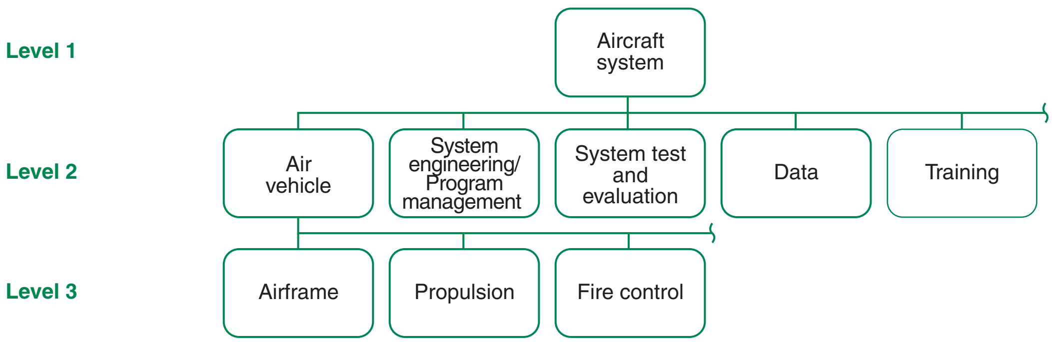
[32] When following the product-oriented best practice, there should not be WBS elements for various functional activities like design engineering, logistics, risk, or quality, because these efforts should be embedded in each activity.

System engineering	The technical and management efforts of directing and controlling a totally integrated engineering effort of a system or program
Program management	The business and administrative planning, organizing, directing, coordinating, controlling, and approval actions designated to accomplish overall program objectives not associated with specific hardware elements and not included in systems engineering
Training	Deliverable training services, devices, accessories, aids, equipment, and parts used to facilitate instruction in which personnel will learn to operate and maintain the system with maximum efficiency
Data	The deliverable data that must be on a contract data requirements list, including technical publications, engineering data, support data, and management data needed to configure management, cost, schedule, contractual data management, and program management
System test and evaluation	The use of prototype, production, or specifically fabricated hardware and software to obtain or validate engineering data on the performance of the system in developing program (in DOD, normally funded from research, development, test, and evaluation appropriations); also includes all effort associated with design and production of models, specimens, fixtures, and instrumentation in support of the system-level test program
Peculiar support equipment	Equipment uniquely needed to support the program: vehicles, equipment, tools, and the like to fuel, service, transport, hoist, repair, overhaul, assemble and disassemble, test, inspect, or otherwise maintain mission equipment, as well as equipment or software required to maintain or modify the software portions of the system
Common support equipment	Equipment not unique to the program and available in inventory for use by many programs
Operational and site activation	Installation of mission and support equipment in the operations or support facilities and complete system checkout or shakedown to ensure operational status; may include real estate, construction, conversion, utilities, and equipment to provide all facilities needed to house, service, and launch prime mission equipment
Facilities	Includes construction, conversion, or expansion of existing industrial facilities for production, inventory, and contractor depot maintenance required as a result of the specific system
Initial spares and repair parts	Includes the deliverable spare components, assemblies, and subassemblies used for initial replacement purposes in the materiel system equipment end item

Source: DOD.

Therefore, in addition to having a product-oriented WBS for the prime mission equipment that breaks down the physical pieces of, for example, an aircraft, information technology system, or satellite, the WBS should include these common elements to ensure that all effort is identified at the outset. This, in turn, will facilitate planning and managing the overall effort, since the WBS should be the starting point for developing the detailed schedule. Figure 11 shows a program WBS, including common elements, for an aircraft system.

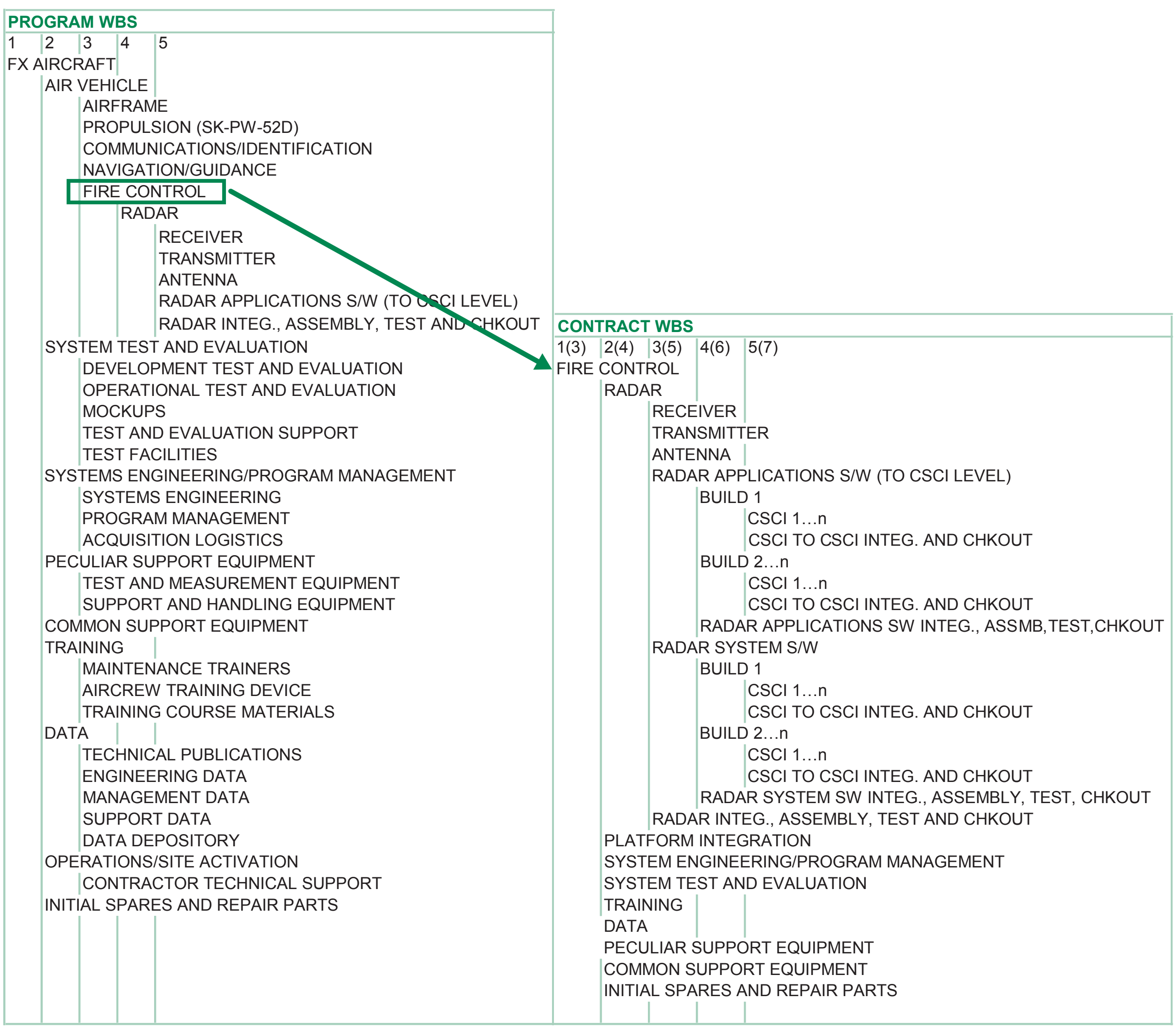
Figure 11: A Work Breakdown Structure with Common Elements



Source: © 2005 MCR, LLC, "Developing a Work Breakdown Structure."

While the top-level WBS encompasses the whole program, the contractor must also develop a contract WBS that extends the lower-level components to reflect its responsibilities. See Figure 12.

Figure 12: A Contract Work Breakdown Structure



Source: DOD.

Figure 12 shows how a prime contractor may require its subcontractor to use the WBS to report work progress. In this example, the fire control effort (a level 3 element in the prime contractor's WBS) is the first level for the subcontractor. Thus, all fire control expenditures at level 1 of the subcontractor's contract WBS would map to the fire control element at level 3 in the program WBS. This shows how a subcontractor would break a level 3 item down to lower levels to accomplish the work, which when rolled up to the prime WBS, would show effort at levels 4–7. Always keep in mind that the structure provided by the prime contractor WBS will identify the work packages that are the responsibility of the subcontractor. The subcontractor will also need to decompose the work further in its own WBS as well.

WBS Development

A WBS should be developed early to provide for a conceptual idea of program size and scope. As the program matures, so should the WBS. Like the technical baseline, the WBS should be considered a living document. Therefore, as the technical baseline becomes further defined with time, the WBS will also reflect more detail. For example, as specification requirements become better known and the statement of work is updated, the WBS will include more elements. As more elements are added to the WBS, the schedule is capable of greater definition, giving more insight into the program's cost, schedule, and technical relationships.

It is important that each WBS be accompanied by a dictionary of the various WBS elements and their hierarchical relationships. A WBS dictionary is simply a document that describes in brief narrative format what work is to be performed in each WBS element. Each element is presented in an outline to show how it relates to the next higher element and what is included to ensure clear relationships. With minor changes and additions the WBS dictionary can be converted into a statement of work. Although not the normal approach, the dictionary may also be expanded by the program manager to describe the resources and processes necessary for producing each element in cost, technical, and schedule terms. Also, since the WBS is product related, it is closely related to, and structured somewhat the same as, an indented bill of materials for the primary product. Like the WBS, its dictionary should be updated when changes occur. After the program is baselined, updating the WBS should be part of a formal process, as in configuration management.

Standardized WBS

Standardizing the WBS is considered a best practice because it enables an organization to collect and share data among programs. Standardizing work breakdown structures results in more consistent cost estimates, allows data to be shared across organizations, and leads to more efficient program execution. WBS standardization also facilitates cost estimating relationship development and allows for common cost measures across multiple contractors and programs. Not standardizing WBSs causes extreme difficulty in comparing costs from one contractor or program to another, resulting in substantial expense to government estimating agencies when collecting and reconciling contractor cost and technical data in consistent format.

The standardized WBS logic should support the engineering perspective on how the program is being built. The WBS should be a communication tool that can be used across all functions within the program. To foster flexibility, WBS standardization should occur at a high level—such as WBS level 3—so that lower levels can be customized to reflect how the specific program's work will be managed. For high-risk or costly elements, however, management can make decisions to standardize the WBS to whatever level is necessary to properly gain insight. Thus, the WBS should be standard at a high level, with flexibility in the lower levels to allow detailed planning once the schedule is laid out. Furthermore, the same standard WBS should be used for developing the cost estimate and the program schedule and setting up the EVM performance measurement baseline. Relying on a standard WBS can enable program managers to better plan and manage their work and helps in updating the cost estimate with actual costs—the final critical step in our twelve steps to a high-quality cost estimate.

A standardized product-oriented WBS can help define high-level milestones and cost driver relationships that can be repeated in future applications. In addition to helping the cost community, standard WBSs can result in better portfolio management. Programs reporting to a standard WBS enable leadership to make better decisions about where to apply contingency reserve and where systemic problems are occurring, like integration and test. Using this information, management can take action by adjusting investment and obtaining lessons learned. As a result, it is easier to manage programs if they are reporting in the same format.

Besides the common elements shown in table 8, DOD has identified, for each defense system, a standard combination of hardware and software that defines the end product for that system. In its 2005 updated WBS handbook, DOD defined and described the WBS, provided instructions on how to develop one, and defined specific defense items.[33] The primary purpose of the handbook is to develop the top levels of the WBS with uniform definitions and a consistent approach. Developed through the cooperation of the military services, with assistance from industry associations, its benefit is improved communication throughout the acquisition process.

In addition to defining a standard WBS for its weapon systems, DOD has developed a common cost element structure that, while not a product-oriented WBS, standardizes the vocabulary for cost elements for automated information systems undergoing DOD review.[34] The cost element structure is also designed to standardize the systems, facilitating the validation process. Furthermore, DOD requires that all the cost elements be included in LCCEs for automated information systems submitted for review. Table 9 gives an example of the cost element structure for an automated information system.

Table 9: Cost Element Structure for a Standard DOD Automated Information System

Element 1 and subelements		Element 2 and subelements		Element 3 and subelements	
1.0	**Investment**	**2.0**	**System operations & support**	**3.0**	**Legacy system phase-out**
1.1	**Program management**	**2.1**	**System management**	**3.1**	**System management**
	1.1.1 Personnel		2.1.1 Personnel		3.1.1 Personnel
	1.1.2 Travel		2.1.2 Travel		3.1.2 Travel
	1.1.3 Other government support		2.1.3 Other government support		3.1.3 Other government support
	1.1.4 Other		2.1.4 Other		

[33] DOD, Department of Defense Handbook: *Work Breakdown Structures for Defense Material Items*, MIL-HDBK-881A (Washington, D.C.: July 30, 2005).

[34] Ronald C. Wilson, *Department of Defense Automated Information Systems Economic Analysis Guide* (Washington, D.C.: Department of Defense, May 1, 1995), att. B, pp. 39–75, Cost Element Structure Definitions.

Element 1 and subelements		Element 2 and subelements		Element 3 and subelements	
1.0	**Investment**	**2.0**	**System operations & support**	**3.0**	**Legacy system phase-out**
1.2	**Concept exploration**	**2.2**	**Annual operations investment**	**3.2**	**Phase-out investment**
	1.2.1 Engineering analysis & specification				3.2.1 Hardware
			2.2.1 Maintenance investment		3.2.2 Software
	1.2.2 Concept exploration hardware		2.2.2 Replenishment spares		3.2.3 Hazardous material handling
	1.2.3 Concept exploration software		2.2.3 Replenishment supplies	**3.3**	**Phase-out operations & support**
	1.2.4 Concept exploration data	**2.3**	**Hardware maintenance**		3.3.1 Hardware maintenance
	1.2.5 Exploration documentation		2.3.1 Hardware maintenance		3.3.2 Software maintenance
	1.2.6 Concept exploration testing		2.3.2 Maintenance support		3.3.3 Unit & subunit operations
	1.2.7 Facilities		2.3.3 Other hardware maintenance		3.3.4 Megacenter operations
	1.2.8 Other	**2.4**	**Software maintenance**		
1.3	**System development**		2.4.1 Commercial off-the-shelf software		3.3.5 Phase-out contracts
	1.3.1 System design & specification		2.4.2 Application & mission software		
	1.3.2 Prototype & test site investment		2.4.3 Communication software		
1.4	**System procurement**	**2.5**	**Megacenter maintenance**		
	1.4.1 Deployment hardware	**2.6**	**Data maintenance**		
	1.4.2 System deployment software		2.6.1 Mission application data		
	1.4.3 Initial documentation		2.6.2 Standard administrative data		
	1.4.4 Logistics support equipment	**2.7**	**Site operations**		
	1.4.5 Initial spares		2.7.1 System operational personnel		
	1.4.6 Warranties		2.7.2 Utility requirement		
1.5	Outsource investment		2.7.3 Fuel		
	1.5.1 Capital investment		2.7.4 Facilities lease & maintenance		
	1.5.2 Software development		2.7.5 Communications		
	1.5.3 System user investment		2.7.6 Base operating & support		
1.6	**System implementation & fielding**		2.7.7 Recurring training		

Element 1 and subelements		Element 2 and subelements		Element 3 and subelements	
1.0	**Investment**	**2.0**	**System operations & support**	**3.0**	**Legacy system phase-out**
	1.6.1 Training		2.7.8 Miscellaneous support		
	1.6.2 Integration, test, acceptance	**2.8**	**Environmental & hazardous**		
	1.6.3 Common support equipment	**2.9**	**Contract leasing**		
	1.6.4 Site activation & facilities				
	1.6.5 Initial supplies				
	1.6.6 Engineering changes				
	1.6.7 Initial logistics support				
	1.6.8 Office furniture & furnishings				
	1.6.9 Data upload & transition				
	1.6.10 Communications				
	1.6.11 Other				
1.7	**Upgrades**				
	1.7.1 Upgrade development				
	1.7.2 Life cycle upgrades				
	1.7.3 Central mega center upgrades				
1.8	**Disposal & reuse**				
	1.8.1 Capital recoupment				
	1.8.2 Retirement				
	1.8.3 Environmental & hazardous				

Source: DOD.

This standard WBS should be tailored to fit each program. In some cases, the cost element structure contains built-in redundancies that provide flexibility in accounting for costs. For example, logistics support costs could occur in either investment or operations and support. However, it is important that the cost element structure of the automated information system not double count costs that could be included in more than one cost element. While the structure is flexible, the same rules as those of a WBS apply, in that children are assigned to only one parent. (Appendix IX contains numerous examples of standard work breakdown structures for, among others, surface, sea, and air transportation systems; military systems; communications systems; and systems for construction and utilities.)

WBS and Scheduling

The WBS should be used as the outline for the integrated master schedule, using the levels of indenture down to the work package level. Since the WBS defines the work in lower levels of detail, its framework provides the starting point for defining all activities and tasks that will be used to develop the program schedule.

The lowest level of the WBS is the work package. Within the work packages, the activities are defined and scheduled. When developing the program schedule, the WBS—in outline form—should be simply cut and pasted into the software. From there, the lower-level work packages and subsequent activities and tasks are defined.

Accordingly, the WBS provides a logical and orderly way to begin preparing the detailed schedule, determining the relationships between activities, and identifying resources required to accomplish the tasks. Therefore, high-level summary tasks and all the detailed tasks in the schedule should map directly to the WBS to ensure that the schedule encompasses the entire work effort.

WBS and EVM

By breaking the work into smaller, more manageable work elements, a WBS can be used to integrate the scheduled activities and costs for accomplishing each work package at the lowest level of the WBS. This is essential for developing the resource-loaded schedule that forms the foundation for the EVM performance measurement baseline. Thus, a WBS is an essential part of EVM cost, schedule, and technical monitoring, because it provides a consistent framework from which to measure progress. This framework can be used to monitor and control costs based on the original baseline and to track where and why there were differences. In this way, the WBS serves as the common framework for analyzing the original cost estimate and the final cost outcome.

When analysts use cost, schedule, and technical information organized by the WBS hierarchical structure, they can summarize data to provide management valuable information at any phase of the program. Furthermore, because a WBS addresses the entire program, managers at any level can assess their progress against the cost estimate plan. This helps keep program status current and visible so that risks can be managed or mitigated quickly. Without a WBS, it would be much more difficult to analyze the root cause of cost, schedule, and technical problems and to choose the optimum solution to fix them.

The WBS also provides a common thread between EVM and the integrated master schedule (IMS)—the time-phased schedule DOD and other agencies use for assessing technical performance. This link to the WBS can allow for further understanding of program cost and schedule variances. When the work is broken down into small pieces, progress can be linked to the IMS for better assessments of cost, technical, schedule, and performance issues. The WBS also enhances project control by tying the contractual work scope to the IMS, which DOD commonly uses to develop a program's technical goals and plans.

WBS and Risk Management

The WBS is also valuable for identifying and monitoring risks. During the cost estimating phase, the WBS is used to flag elements likely to encounter risks, allowing for better contingency planning. During program execution, the WBS is used to monitor risks using the EVM system, which details plans to a level that is needed to accomplish all tasks.

In scheduling the work, the WBS can help identify activities in the schedule that are at risk because resources are lacking or because too many activities are planned in parallel to one another. In addition, risk items can be mapped to activities in the schedule and the results can be examined through a schedule risk analysis (more detail is in appendix X).

WBS Benefits

Elements of a WBS may vary by phase, since different activities are required for development, production, operations, and support. Establishing a master WBS as soon as possible for the program's life cycle that details the WBS for each phase provides many program benefits:

- segregating work elements into their component parts;
- clarifying relationships between the parts, the end product, and the tasks to be completed;
- facilitating effective planning and assignment of management and technical responsibilities;
- helping track the status of technical efforts, risks, resource allocations, expenditures, and the cost and schedule of technical performance within the appropriate phases, since the work in phases frequently overlaps;
- helping ensure that contractors are not unnecessarily constrained in meeting item requirements; and
- providing a common basis and framework for the EVM system and the IMS, facilitating consistency in understanding program cost and schedule performance and assigning to the appropriate phase. Since the link between the requirements, WBS, the statement of work, IMS, and the integrated master plan provides specific insights into the relationship between cost, schedule, and performance, all items can be tracked to the same WBS elements.

As the program or system matures, engineering efforts should focus on system-level performance requirements—validating critical technologies and processes and developing top-level specifications. As the specifications are further defined, the WBS will better define the system in terms of its specifications. After the system concept has been determined, major subsystems can be identified and lower-level functions determined, so that lower-level system elements can be defined, eventually completing the total system definition. The same WBS can be used throughout, updating and revising it as the program or system development proceeds and as the work in each phase progresses. One of the outputs of each phase is an updated WBS covering the succeeding phases.

In summary, a well-developed WBS is essential to the success of all acquisition programs. A comprehensive WBS provides a consistent and visible framework that improves communication; helps in the planning and assignment of management and technical responsibilities; and facilitates tracking engineering efforts, resource allocations, cost estimates, expenditures, and cost and technical performance. Without one, a program is most likely to encounter problems, as case studies 23 and 24 illustrate.

Case Study 23: Developing Work Breakdown Structure, from *NASA*, GAO-04-642

For more than a decade, GAO had identified NASA's contract management as a high-risk area. NASA had been unable to collect, maintain, and report the full cost of its programs and projects. Because of persistent cost growth in a number of NASA programs, GAO was asked to assess 27 programs—10 in detail. GAO found that only 3 of the 10 had provided a complete breakdown of the work to be performed, despite agency guidance calling for projects to break down the work into smaller units to facilitate cost estimating and program management and to help ensure that relevant costs were not omitted.

Underestimating full life-cycle costs creates the risk that a program may be underfunded and subject to major cost overruns. It may be reduced in scope, or additional funding may have to be appropriated to meet objectives. Overestimating life-cycle costs creates the risk that a program will be thought unaffordable and it could go unfunded. Without a complete WBS, NASA's programs cannot ensure that its LCCEs capture all relevant costs, which can mean cost overruns. Inconsistent WBS estimates across programs can cause double counting or, worse, costs can be underestimated when historical program costs are used for projecting future costs for similar programs. Among its multiple recommendations, GAO recommended that NASA base its cost estimates for each program on a WBS that encompassed both in-house and contractor efforts and develop procedures that would prohibit proposed projects from proceeding through review and approval if they did not address the elements of recommended cost-estimating practices.

GAO, *NASA: Lack of Disciplined Cost-Estimating Processes Hinders Effective Program Management*, GAO-04-6426 (Washington, D.C.: May 28, 2004).

Case Study 24: Developing Work Breakdown Structure, from *Homeland Security*, GAO-06-296

The Department of Homeland Security (DHS) established U.S. Visitor and Immigrant Status Indicator Technology (US–VISIT) to collect, maintain, and share information, including biometric identifiers, on selected foreign nationals entering and exiting the United States. Having reported that the program had not followed effective cost estimating practices, GAO recommended that DHS follow effective practices for estimating future increments.

GAO then reported on the cost estimates for the latest increment in February 2006, finding US–VISIT's cost estimates still insufficient. For example, they did not include a detailed WBS and they omitted important cost elements such as system testing. The uncertainties associated with the latest system increment cost estimate were not identified. Uncertainty analysis provides the basis for adjusting estimates to reflect unknown facts and circumstances that could affect costs, and it identifies risk associated with the cost estimate.

Program officials stated that they recognized the importance of developing reliable cost estimates and initiated actions to more reliably estimate the costs of future system increments. For example, US–VISIT chartered a cost-analysis process action team to develop, document, and implement a cost-analysis policy, process, and plan for the program. Program officials had also hired additional contracting staff with cost-estimating experience.

GAO, *Homeland Security: Recommendations to Improve Management of Key Border Security Program Need to Be Implemented* (Washington, D.C.: Feb. 14, 2006).

5. Best Practices Checklist: Work Breakdown Structure

- ☐ A product-oriented WBS represents best practice.
- ☐ It reflects the program work that needs to be done. It
  - ✓ clearly outlines the end product and major work for the program;
  - ✓ contains at least 3 levels of indenture;
  - ✓ is flexible and tailored to the program.
- ☐ The 100 percent rule applies: the sum of the children equals the parent.
  - ✓ The WBS defines all work packages, which in turn includes all cost elements and deliverables.
  - ✓ In addition to hardware and software elements, the WBS contains program management and other common elements to make sure all the work is covered.
- ☐ Each system has one program WBS but may have several contract WBSs that are extended from the program WBS, depending on the number of subcontractors.
- ☐ The WBS is standardized so that cost data can be collected and used for estimating future programs. It
  - ✓ facilitates portfolio management, including lessons learned;
  - ✓ matches schedule, cost estimate, and EVM at a high level;
  - ✓ is updated as changes occur and the program becomes better defined;
  - ✓ includes functional activities within each element that are needed to support each product deliverable;
  - ✓ is the starting point for developing the program's detailed schedule;
  - ✓ provides a framework for identifying and monitoring risks and the effectiveness of contingency plans;
  - ✓ provides for a common language between the government program management office, technical specialists, prime contractors, and subcontractors.
- ☐ The WBS has a dictionary that
  - ✓ defines each element and how it relates to others in the hierarchy;
  - ✓ clearly describes what is included in each element;
  - ✓ describes resources and functional activities needed to produce the element product;
  - ✓ links each element to other relevant technical documents.

CHAPTER 9

Ground Rules and Assumptions

Cost estimates are typically based on limited information and therefore need to be bound by the constraints that make estimating possible. These constraints usually take the form of assumptions that bind the estimate's scope, establishing baseline conditions the estimate will be built from. Because of the many unknowns, cost analysts must create a series of statements that define the conditions the estimate is to be based on. These statements are usually made in the form of ground rules and assumptions (GR&A). By reviewing the technical baseline and discussing the GR&As with customers early in the cost estimating process, analysts can flush out any potential misunderstandings. GR&As

- satisfy requirements for key program decision points,
- answer detailed and probing questions from oversight groups,
- help make the estimate complete and professional,
- present a convincing picture to people who might be skeptical,
- provide useful estimating data and techniques to other cost estimators,
- provide for reconstruction of the estimate when the original estimators are no longer available, provide a basis for the cost estimate that documents areas of potential risk that can eventually be resolved.

Ground Rules

Ground rules and assumptions, often grouped together, are distinct. Ground rules represent a common set of agreed on estimating standards that provide guidance and minimize conflicts in definitions. When conditions are directed, they become the ground rules by which the team will conduct the estimate. The technical baseline requirements discussed in chapter 7 represent cost estimate ground rules. Therefore, a comprehensive technical baseline provides the analyst with all the necessary ground rules for conducting the estimate.

Assumptions

Without firm ground rules, the analyst is responsible for making assumptions that allow the estimate to proceed. In other words, assumptions are required only where no ground rules have been provided. Assumptions represent a set of judgments about past, present, or future conditions postulated as true in the absence of positive proof. The analyst must ensure that assumptions are not arbitrary, that they are founded on expert judgments rendered by experienced program and technical personnel. Many assumptions profoundly influence cost; the subsequent rejection of even a single assumption by management could invalidate many aspects of the estimate. Therefore, it is imperative that cost estimators brief management and document all assumptions well, so that management fully understands the conditions the estimate was structured on. Failing to do so can lead to overly optimistic assumptions that heavily influence the overall cost estimate, to cost overruns, and to inaccurate estimates and budgets. (See case study 25.)

Case Study 25: The Importance of Assumptions, from *Space Acquisitions*, GAO-07-96

Estimated costs for DOD's major space acquisition programs increased about $12.2 billion, nearly 44 percent, above initial estimates for fiscal years 2006 through 2011. Such growth has had a dramatic effect on DOD's overall space portfolio. To cover the added costs of poorly performing programs, DOD shifted scarce resources from other programs, creating a cascade of cost and schedule inefficiencies.

GAO's case study analyses found that program office cost estimates—specifically, assumptions they were based on—were unrealistic in eight areas, many interrelated. In some cases, such as assumptions regarding weight growth and the ability to gain leverage from legacy systems, past experiences or contrary data were ignored. In others, such as when contractors were given more program management responsibility or when growth in the commercial market was predicted, estimators assumed that promises of reduced cost and schedule would be borne out but did not have the benefit of experience to factor into their work.

GAO also identified flawed assumptions that reflected deeper flaws in acquisition strategies or development approaches. For example, five of six programs GAO reviewed assumed that technologies would be sufficiently mature when needed, even though they began without a complete understanding of how long it would take or how much it would cost to ensure that they could work as intended. In four programs, estimators assumed few delays, even though the programs adopted highly aggressive schedules while attempting to make ambitious leaps in capability. In four programs, estimators assumed funding would stay constant, even though space and weapons programs frequently experienced funding shifts and the Air Force was in the midst of starting a number of costly new space programs to replenish older ones.

GAO, *Space Acquisitions: DOD Needs to Take More Action to Address Unrealistic Initial Cost Estimates of Space Systems*, GAO-07-96 (Washington, D.C.: Nov. 17, 2006).

Global and Element-Specific Ground Rules and Assumptions

GR&As are either global or element specific. Global GR&As apply to the entire estimate; element-specific GR&As are driven by each WBS element's detailed requirements. GR&As are more pronounced for estimates in the development phase, where there are more unknowns; they become less prominent as the program moves through development into production.

While each program has a unique set of GR&As, some are general enough that each estimate should address them. For example, each estimate should at a minimum define the following global GR&As: program schedule, cost limitations (for example, unstable funding stream or staff constraints), high-level time phasing, base year, labor rates, inflation indexes, participating agency support, and government-furnished equipment.[35]

[35] Government furnished equipment can also be an assumption and is not always a ground rule.

One of the most important GR&As is to define a realistic schedule. It may be difficult to perform an in-depth schedule assessment early to uncover the frequent optimism in initial program schedules. Ideally, members from manufacturing and the technical community should be involved in developing the program schedule, but often information is insufficient and assumptions must be made. In this case, it is important that this GR&A outline the confidence the team has in the ability to achieve the schedule so that it can be documented and presented to management.

One major challenge in setting realistic schedules is that the completion date is often set by external factors outside the control of the program office before any analysis has been performed to determine whether it is feasible. Another predominant problem is that schedule risk is often ignored or not analyzed—or when it is analyzed, the analysis is biased. This can occur on the government (customer) or contractor side or both. Risk analysis conducted by a group independent of the project manager has a better chance of being unbiased than one conducted by the program manager. However, it should also be noted that many organizations are not mature enough to acknowledge or to apply program schedule or cost risk realism because of the possible repercussions. For example, a contractor may be less likely to identify schedule or cost risk if it fears negative reaction from the customer. Likewise, the customer may be unwilling to report cost or schedule risk from fear that the program could be canceled.

Sometimes, management imposes cost limitations because of budget constraints. The GR&A should then clearly explain the limitation and how it affects the estimate. Usually, cost limitations are handled by delaying program content or by a funding shortfall if program content cannot be delayed. In many cases, such actions will both delay the program and increase its final delivered cost. Either way, management needs to be fully apprised of how this GR&A affects the estimate.

Estimates are time phased because program costs usually span many years. Time phasing spreads a program's expected costs over the years in which they are anticipated to aid in developing a proper budget. Depending on the activities in the schedule for each year, some years may have more costs than others. Great peaks or valleys in annual funding should be investigated and explained, however, since staffing is difficult to manage with such variations from one year to another. Anomalies are easily discovered when the estimate is time phased. Cost limitations can also affect an estimate's time phasing, if there are budget constraints for a given fiscal year. Additionally, changes in program priority will affect funding and timing—often a program starts with high priority but that priority erodes as it proceeds, causing original plans to be modified and resulting in later delivery and higher cost to the government. These conditions should be addressed by the estimate and their effects adequately explained.

The base year is used as a constant dollar reference point to track program cost growth. Expressing an estimate in base year dollars removes the effects of economic inflation and allows for comparing separate estimates "apples to apples." Thus, a global ground rule is to define the base year dollars that the estimate will be presented in and the inflation index that will be used to convert the base year costs into then-year dollars that include inflation. At a minimum, the inflation index, source, and approval authority should be clearly explained in the estimate documentation. Escalation rates should be standardized across similar programs, since they are all conducted in the same economic environment, and priority choices between them should not hinge on different assumptions about what is essentially an economic scenario common to all programs.

Some programs result from two or more agencies joining together to achieve common program goals. When this happens, agreements should lay out each agency's area of responsibility. An agency's failing to meet its responsibility could affect the program's cost and schedule. In the GR&A section, these conditions should be highlighted to ensure that management is firmly aware that the success of the estimate depends on the participation of other agencies.

Equipment that the government agrees to provide to a contractor can range from common supply items to complex electronic components to newly developed engines for aircraft. Because the estimator cannot predict whether deliveries of such equipment will be timely, assumptions are usually made that it will be available when needed. It is important that the estimate reflect the items that it assumes government will furnish, so that the risk to the estimate if items are delayed can be modeled and presented to management. In general, schedules represent delivery of material from external sources, including the government, with date-constrained milestones. A better approach is to include the supplier's work to produce the product by a summary activity in the schedule, examine the possibility of delayed delivery, include that risk in a schedule risk analysis, and monitor the work of the supplier as the date approaches.

In addition to global GR&As, estimate-specific GR&As should be tailored for each program, including

- life-cycle phases and operations concept;
- maintenance concepts;
- acquisition strategy, including competition, single or dual sourcing, and contract or incentive type;
- industrial base viability;
- quantities for development, production, and spare and repair parts;
- use of existing facilities, including any modifications or new construction;
- savings for new ways of doing business;
- commonality or design inheritance assumptions;
- technology assumptions and new technology to be developed;
- technology refresh cycles;
- security considerations that may affect cost; and
- items specifically excluded from the estimate.

The cost estimator should work with members from the technical community to tailor these specific GR&As to the program. Information from the technical baseline and WBS dictionary help determine some of these GR&As, like quantities and technology assumptions. The element-specific GR&As carry the most risk and therefore should be checked for realism and should be well documented in order for the estimate to be considered credible.

Assumptions, Sensitivity, and Risk Analysis

Every estimate is uncertain because of the assumptions that must be made about future projections. Sensitivity analysis that examines how changes to key assumptions and inputs affect the estimate helps mitigate uncertainty. Best practice cost models incorporate the ability to perform sensitivity analyses without altering the model so that the effect of varying inputs can be quickly determined (more information is in chapters 13 and 14). For example, suppose a decision maker challenges the assumption that 5 percent of the installed equipment will be needed for spares, asking that the factor be raised to 10 percent. A sensitivity analysis would show the cost impact of this change. Because of the implications that GR&As can have when assumptions change, the cost estimator should always perform a sensitivity analysis that portrays the effects on the cost and schedule of an invalid assumption. Such analysis often provides management with an invaluable perspective on its decision making.

In addition to sensitivity analysis, factors that will affect the program's cost, schedule, or technical status should be clearly identified, including political, organizational, or business issues. Because assumptions themselves can vary, they should always be inputs to program risk analyses of cost and schedule. A typical approach to risk analysis emphasizes the breadth of factors that may be uncertain. In a risk identification exercise, the goal is to identify all potential risks stemming from a broad range of sources. A good starting point would be to examine the program's risk management database to determine which WBS elements these risks could affect. Another option would be to examine risks identified during a program's integrated baseline review—a risk based assessment of the program plan to see whether the requirements can be met within cost and schedule assumptions. Regardless of what method is used to identify risk, it is important that more than just cost, schedule, and technical risks are examined. For example, budget and funding risks, as well as risks associated with start-up activities, staffing, and organizational issues, should also be considered. Therefore, risks from all sources such as external, organizational, and even project management practices, in addition to the technical challenges, need to be addressed.

Well-supported assumptions should include documentation of an assumption's source and should discuss any weaknesses or risks. Solid assumptions are measurable and specific. For example, an assumption that states "transaction volume will average 500,000 per month and is expected to grow at an annual rate of 5 percent" is measurable and specific, while "transaction volumes will grow greatly over the next 5 years" is not as helpful. By providing more detail, cost estimators can perform risk and sensitivity analysis to quantify the effects of changes in assumptions.

Assumptions should be realistic and valid. This means that historical data should back them up to minimize uncertainty and risk. Understanding the level of certainty around an estimate is imperative to knowing whether to keep or discard an assumption. Assumptions tend to be less certain earlier in a program, and become more reliable as more information is known about them. A best practice is to place all assumptions in a single spreadsheet tab so that risk and sensitivity analysis can be performed efficiently and quickly. Explicit assumptions should be available, but assumptions are also sometimes implicit—implicit assumptions should be documented as well.

Certain ground rules should always be tested for risk. For example, the effects of the program schedule's slipping on both cost and schedule should always be modeled and the results presented to management. This is especially important if the schedule was known to be aggressive or was not assessed for realism. Too often, we have found that when schedules are compressed, for instance to satisfy a potential requirements gap, the optimism in the schedule does not hold and the result is greater costs and schedule delays. Case study 26 gives examples of what happens in such situations.

Case Study 26: Testing Ground Rules for Risk, from *Space Acquisitions*, GAO-07-96

GAO's analyses of six ongoing space programs found that original cost estimates were unrealistic in a number of areas. The six programs included the following four.

Advanced Extremely High Frequency Satellite Program. The first AEHF launch was originally scheduled for June 2006. In response to a potential gap in satellite coverage because of the launch failure of the third Milstar satellite, DOD accelerated the schedule by 18 months, aiming for December 2004. An unsolicited contractor proposal stated that it could meet this date, even though not all AEHF's requirements had been fully determined. The program office thus knew that the proposed schedule was overly optimistic, but the decision was made at high levels in DOD to award the contract. DOD did not, however, commit the funding to support the activities and manpower needed to design and build the satellites more quickly. Funding issues further hampered development efforts, increased schedule delays, and contributed to cost increases.

National Polar-orbiting Operational Environmental Satellite System. When the NPOESS estimate was developed, the system was expected to be heavier, require more power, and have more than twice as many sensors as heritage satellites. Yet the program office estimated that the new satellites would be developed, integrated, and tested in less time than heritage satellites. Independent cost estimators highlighted to the NPOESS program office that the proposed integration schedule was unrealistic, compared to historical satellite programs. Later, the CAIG cautioned the program office that the system integration assembly and test schedule were unrealistic and the assumptions used to develop the estimate were not credible.

Space Based Infrared System High Program. The SBIRS schedule proposed in 1996 did not allow enough time for geosynchronous Earth orbit system integration. And it did not anticipate the program design and workmanship flaws that eventually cost the program considerable delays. The schedule was also optimistic with regard to ground software productivity and time needed to calibrate and assess satellite health. Delivery of highly elliptical orbit sensors was delayed by almost 3 years, the launch of the first geosynchronous Earth orbit satellite by 6 years.

Wideband Gapfiller Satellites. The request for proposals specified that the available WGS budget was $750 million for three satellites and that the ground control system was to be delivered within 36 months. Competing contractors were asked to offer maximum capacity, coverage, and connectivity in a contract that would use existing commercial practices and technologies. However, greater design complexity and supplier quality issues caused the WGS schedule to stretch to 78 months for the first expected launch. DOD's history had been 55–79 months to develop satellites similar to WGS, so that while DOD's experience was within the expected range, the original 36-month schedule was unrealistic.

GAO, *Space Acquisitions: DOD Needs to Take More Action to Address Unrealistic Initial Cost Estimates of Space Systems*, GAO-07-96 (Washington, D.C.: Nov. 17, 2006).

Above and beyond the program schedule, some programs can be affected by the viability of the industrial base. Case study 27 illustrates.

Case Study 27: The Industrial Base, from *Defense Acquisition*, GAO-05-183

For the eight case study ships GAO examined, cost analysts relied on the actual cost of previously constructed ships, without adequately accounting for changes in the industrial base, ship design, or construction methods. Cost data available to Navy cost analysts were based on higher ship construction rates from the 1980s. These data were based on lower costs because of economies of scale, which did not reflect the lower procurement rates after 1989.

According to the shipbuilder, material cost increases on the CVN 76 and CVN 77 in the Nimitz class of aircraft carriers could be attributed to a declining supplier base and commodity price increases. Both carriers' material costs had been affected by more than a 15 percent increase in metals costs that in turn increased costs for associated components. Moreover, many of the materials used in the construction of aircraft carriers are highly specialized and unique—often produced by only one manufacturer. With fewer manufacturers competing in the market, the materials were highly susceptible to cost increases.

After the Seawolf submarine program was cancelled and, over a period of 6 years, submarine production had decreased from three to four submarines per year to one, many vendors left the nuclear submarine business to focus on more lucrative commercial product development. Prices for highly specialized material increased, since competition and business had diminished. For example, many vendors were reluctant to support the Virginia class submarine contract because costs associated with producing small quantities of highly specialized materials were not considered worth the investment—especially for equipment with no other military or commercial applications.

GAO, *Defense Acquisitions: Improved Management Practices Could Help Minimize Cost Growth in Navy Shipbuilding Programs*, GAO-05-183 (Washington, D.C.: Feb. 28, 2005).

Another area in which assumptions tend to be optimistic is technology maturity. Having reviewed the experiences of DOD and commercial technology development, GAO has found that programs that relied on technologies that demonstrated a high level of maturity were in a better position to succeed than those that did not. Simply put, the more mature technology is at the start of a program, the more likely it is that the program will meet its objectives. Technologies that are not fully developed represent a significant challenge and add a high degree of risk to a program's schedule and cost. Programs typically assume that the technology required will arrive on schedule and be available to support the effort. While this assumption allows the program to continue, the risk that it will prove inaccurate can greatly affect cost and schedule. Case studies 28 and 29 provide examples.

Case Study 28: Technology Maturity, from *Defense Acquisitions*, GAO-05-183

The lack of design and technology maturity led to rework, increasing the number of labor hours for most of the case study ships. For example, the design of the LPD 17, in the San Antonio class of transports, continued to evolve even as construction proceeded. When construction began on the DDG 91 and DDG 92, in the Arleigh Burke class of destroyers—the first ships to incorporate the remote mine hunting system—the technology was still being developed. As a result, workers were required to rebuild completed ship areas to accommodate design changes.

GAO, *Defense Acquisitions: Improved Management Practices Could Help Minimize Cost Growth in Navy Shipbuilding Programs*, GAO-05-183 (Washington, D.C.: Feb. 28, 2005).

Case Study 29: Technology Maturity, from *Space Acquisitions*, GAO-07-96

The Advanced Extremely High Frequency (AEHF) program of communications satellites faced several problems of technology maturity. They included developing a digital processing system that would support 10 times the capacity of Milstar's medium data rate, the predecessor satellite, without self-interference and using phased array antennas at extremely high frequencies, which had never been done before. In addition, the change from a physical process to an electronic process for crypto rekeys had not been expected at the start of AEHF. Milstar had required approximately 2,400 crypto rekeys per month and had been done physically. AEHF's proposed capability was approximately 100,000—too large for physical processing. Changing the rekeys to electronic processing was revolutionary and led to unexpected cost and schedule growth.

GAO, *Space Acquisitions: DOD Needs to Take More Action to Address Unrealistic Initial Cost Estimates of Space Systems*, GAO-07-96 (Washington, D.C.: Nov. 17, 2006).

Cost estimators and auditors should not get trapped by overly optimistic technology forecasts. It is well known that program advocates tend to underestimate the technical challenge facing the development of a new system. Estimators and auditors alike should always seek to uncover the real risk by performing an uncertainty analysis. In doing so, it is imperative that cost estimators and auditors meet with engineers familiar with the program and its new technology to discuss the level of risk associated with the technical assumptions. Only then can they realistically model risk distributions using an uncertainty analysis and analyze how the results affect the overall cost estimate.

Once the risk uncertainty and sensitivity analyses are complete, the cost estimator should formally convey the results of changing assumptions to management as early and as far up the line as possible. The estimator should also document all assumptions to help management understand the conditions the estimate was based on. When possible, the analyst should request an updated technical baseline in which the new assumptions have been incorporated as ground rules. Case study 30 illustrates an instance of management's not knowing the effects of changing assumptions.

Case Study 30: Informing Management of Changed Assumptions, from *Customs Service Modernization*, GAO/AIMD-99-41

The Automated Commercial Environment (ACE) was a major U.S. Customs Service information technology system modernization effort. In November 1997, it was estimated that ACE would cost $1.05 billion to develop, operate, and maintain between 1994 and 2008. GAO found that the agency lacked a reliable estimate of what ACE would cost to build, deploy, and maintain.

The cost estimates were understated, benefit estimates were overstated, and both were unreliable. Customs' August 1997 cost-benefit analysis estimated that ACE would produce cumulative savings of $1.9 billion over a 10-year period. The analysis identified $644 million in savings—33 percent of the total estimated savings—resulting from increased productivity. Because this estimate was driven by Customs' assumption that every minute "saved" by processing transactions or analyzing data faster using ACE rather than its predecessor system would be productively used by all workers, it was viewed as a best case upper limit on estimated productivity improvements.

Given the magnitude of the potential savings, even a small change in the assumption translated into a large reduction in benefits. For example, conservatively assuming that three-fourths of each minute saved would be used productively by three-fourths of all workers, the expected benefits would be reduced by about $282 million. Additionally, the analysis excluded costs for hardware and systems software upgrades at each port office. Using Customs' estimate for acquiring the initial suite of port office hardware and systems software, and assuming a technology refreshment cycle of every 3 to 5 years, GAO estimated this cost at $72.9 million to $171.8 million.

Because Customs did not have reliable information on ACE costs and benefits and had not analyzed viable alternatives, it did not have adequate assurance that ACE was the optimal approach. In fact, it had no assurance at all that ACE would be cost-effective. Furthermore, it had not justified the return on its investment in each ACE increment and therefore would not be able to demonstrate whether ACE would be cost-effective until it had spent hundreds of millions of dollars to acquire the entire system.

GAO recommended that Customs rigorously analyze alternative approaches to building ACE and, for each increment, use disciplined processes to prepare a robust LCCE, prepare realistic and supportable benefit expectations, and validate actual costs and benefits once an increment had been piloted.

GAO, *Customs Service Modernization: Serious Management and Technical Weaknesses Must Be Corrected*, GAO/AIMD-99-41 (Washington, D.C.: Feb. 26, 1999).

6. Best Practices Checklist: Ground Rules and Assumptions

- ☐ All ground rules and assumptions have been
  - ✓ Developed by estimators with input from the technical community.
  - ✓ Based on information in the technical baseline and WBS dictionary.
  - ✓ Vetted and approved by upper management.
  - ✓ Documented to include the rationale behind the assumptions and historical data to back up any claims.
  - ✓ Accompanied by a level of risk of the assumption's failing and its effect on the estimate.
- ☐ To mitigate risk,
  - ✓ All GR&As have been placed in a single spreadsheet tab so that risk and sensitivity analysis can be performed quickly and efficiently.
  - ✓ All potential risks including cost, schedule, technical, and programmatic (e.g., risks associated with budget and funding, start up activities, staffing, and organizational issues) have been identified and traced to specific WBS elements.
    - o A schedule risk analysis has been performed to determine the program schedule's realism.
    - o A cost risk analysis, incorporating the results of the schedule risk analysis, has been performed to determine the program's cost estimate realism.
- ☐ Budget constraints, as well as the effect of delaying program content, have been defined.
  - ✓ Peaks and valleys in time-phased budgets have been explained.
  - ✓ Inflation index, source, and approval authority have been identified.
  - ✓ Dependence on participating agencies, the availability of government-furnished equipment, and the effects if these assumptions do not hold have been identified.
  - ✓ Items excluded from the estimate have been documented and explained.
  - ✓ Technology was mature before it was included; if its maturity was assumed, the estimate addresses the effect of the assumption's failure on cost and schedule.
- ☐ Cost estimators and auditors met with technical staff to determine risk distributions for all assumptions; the distributions were used in sensitivity and uncertainty analyses of the effects of invalid assumptions. Management has been briefed, and the results have been documented.

CHAPTER 10

Data

Data are the foundation of every cost estimate. How good the data are affects the estimate's overall credibility. Depending on the data quality, an estimate can range anywhere from a mere guess to a highly defensible cost position. Credible cost estimates are rooted in historical data. Rather than starting from scratch, estimators usually develop estimates for new programs by relying on data from programs that already exist and adjusting for any differences. Thus, collecting valid and useful historical data is a key step in developing a sound cost estimate. The challenge in doing this is obtaining the most applicable historical data to ensure that the new estimate is as accurate as possible. One way of ensuring that the data are applicable is to perform checks of reasonableness to see if the results are similar. Different data sets converging toward one value provides a high degree of confidence in the data.

Performing quality checks takes time and requires access to large quantities of data. This is often the most difficult, time-consuming, and costly activity in cost estimating. It can be exacerbated by a poorly defined technical baseline or WBS. However, by gathering sufficient data, cost estimators can analyze cost trends on a variety of related programs, which gives insight into cost estimating relationships that can be used to develop parametric models.

Before collecting data, the estimator must fully understand what needs to be estimated. This understanding comes from the purpose and scope of the estimate, the technical baseline description, the WBS, and the ground rules and assumptions. Once the boundaries of the estimate are known, the next step is to establish an idea of what estimating methodology will be used. Only after these tasks have been performed should the estimator begin to develop an initial data collection plan.

Data Collection

Data collection is a lengthy process and continues throughout the development of a cost estimate and through the program execution itself. Many types of data need to be collected—technical, schedule, program, and cost data. Once collected, the data need to be normalized. Data can be collected in a variety of ways, such as from databases of past projects, engineering build-up estimating analysis, interviews, surveys, data collection instruments, and focus groups. After the estimate is complete, the data need to be well documented, protected, and stored for future use in retrievable databases. Cost estimating requires a continual influx of current and relevant cost data to remain credible. The cost data should be managed by estimating professionals who understand what the historical data are based on, can determine whether the data have value in future projections, and can make the data part of the corporate history.

Cost data should be continually supplemented with written vendor quotes, contract data, and actual cost data for each new program. Moreover, cost estimators should know the program acquisition plans, contracting processes, and marketplace conditions, all of which can affect the data. This knowledge provides the basis for credibly using, modifying, or rejecting the data in future cost estimates.

Knowing the factors that influence a program's cost is essential for capturing the right data. Examples are equivalent source lines of code, number of interfaces for software development, number of square feet for construction, and the quantity of aircraft to be produced. To properly identify cost drivers, it is imperative that cost estimators meet with the engineers and other technical experts. In addition, by studying historical data, cost estimators can determine through statistical analysis the factors that tend to influence overall cost. Furthermore, seeking input from schedule analysts can provide valuable knowledge about how aggressive a program's schedule may be.

Cost estimates must be based on realistic schedule information. Some costs such as labor, quality, supervision, rented space and equipment, and other time-related overheads depend on the duration of the activities they support. Often the cost estimators are in synch with the baseline schedule with the early estimates, but they also have to keep in touch with changes in the schedule, since schedule changes can lead to cost changes.

In addition to data for the estimate, backup data should be collected for performing cross-checks. This takes time and usually requires travel to meet with technical experts. It is important to plan ahead and schedule the time for these activities. Scheduling insufficient time can affect the estimator's ability to collect and understand the data, which can then result in a less confident cost estimate.

Common issues in data collection include inconsistent data definitions in historical programs compared to the new program. Understanding what the historical data include is vital to data reliability. For example, are the data skewed because they are for a program that followed an aggressive schedule and therefore instituted second and third shifts to complete the work faster? Or was a new manufacturing process implemented that was supposed to generate savings but resulted in more costs because of initial learning curve problems? Knowing the history behind the data will allow for its proper allocation for future estimates.

Another issue is whether the data are even available. Some agencies may not have any cost databases. Data may be accessible at higher levels but information may not be sufficient to break them down to the lower levels needed to estimate various WBS elements. Data may be incomplete. For instance, they may be available for the cost to build a component, but the cost to integrate the component may be missing. Similarly, if data are in the wrong format, they may be difficult to use. For example, if the data are only in dollars and not hours, they may not be as useful if the labor and overhead rates are not available.

Sometimes data are available, but the cost estimator cannot gain access to them. This can happen when the data are highly classified or considered competition sensitive. When this is the case, the cost estimator may have to change the estimating approach to fit the data that are available. Case study 31 gives an example.

Case Study 31: Fitting the Estimating Approach to the Data, from *Space Acquisitions*, GAO-07-96

The lack of reliable technical source data hampers cost estimating. Officials GAO spoke with believed that cost estimation data and databases on which to base cost estimates were incomplete, insufficient, and outdated. They cited the lack of reliable historical and current cost, technical, and program data and expressed concern that available cost, schedule, technical, and risk data were not similar to the systems they were developing cost estimates for. In addition, some expressed concern that relevant classified and proprietary commercial data might exist but were not usually available to the cost-estimating community working on unclassified programs. Some believed that Air Force cost estimators needed to be able to use all relevant data, including those contained in National Reconnaissance Office cost databases, since the agency builds highly complex, classified satellites in comparable time and at comparable costs per pound.

GAO, *Space Acquisitions: DOD Needs to Take More Action to Address Unrealistic Initial Cost Estimates of Space Systems*, GAO-07-96 (Washington, D.C.: Nov. 17, 2006).

Types of Data

In general, the three main types of data are cost data, schedule or program data, and technical data. Cost data generally include labor dollars (with supporting labor hours and direct costs and overhead rates), material and its overhead dollars, facilities capital cost of money, and profit associated with various activities. Program cost estimators often do not know about specific dollars, so they tend to focus mostly on hours of resources needed by skill level. These estimates of hours are often inputs to specialized databases to convert them to cost estimates in dollars.

Schedule or program data provide parameters that directly affect the overall cost. For example, lead-time schedules, start and duration of effort, delivery dates, outfitting, testing, initial operational capability dates, operating profiles, contract type, multiyear procurement, and sole source or competitive awards must all be considered in developing a cost estimate.

Technical data define the requirements for the equipment being estimated, based on physical and performance attributes, such as length, width, weight, horsepower, and size. When technical data are collected, care must be taken to relate the types of technologies and development or production methodologies to be used. These change over time and require adjustments when estimating relationships are being developed.

Cost data must often be derived from program and technical data. Moreover, program and technical data provide context for cost data, which by themselves may be meaningless. Consider the difference between these two examples:

- Operations and maintenance utilities cost $36,500.
- The Navy consumes 50,000 barrels of fuel per day per ship.

In the operations and maintenance example, the technical and program descriptors are missing, requiring follow-up questions like: What specific utilities cost $36,500? Gas or electricity or telephone? What time does this cost represent? A month or a year? and When were these costs accrued? In the current year or 5 years ago? In the Navy example, a cost estimator would need to investigate what type of ship consumes 50,000 barrels per day—aircraft carrier? destroyer?—and what type of fuel is consumed.[36]

It is essential that cost estimators plan for and gain access, where feasible, to cost and technical and program data in order to develop a complete understanding of what the data represent. Without this understanding, a cost estimator may not be able to correctly interpret the data, leading to greater risk that the data can be misapplied.

Sources of Data

Since all cost estimating methods are data-driven, analysts must know the best data sources. Table 10 lists some basic sources. Analysts should use primary data sources whenever possible. Primary data are obtained from the original source, can usually be traced to an audited document, are considered the best in quality, and are ultimately the most useful. Secondary data are derived rather than obtained directly from a primary source. Since they were derived, and thus changed, from the original data, their overall quality is lower and less useful. In many cases, secondary data are actual data that have been "sanitized" to obscure their proprietary nature. Without knowing the details, analysts will find such data of little use.

Table 10: Basic Primary and Secondary Data Sources

Data type	Primary	Secondary
Basic accounting records	x	
Data collection input forms	x	
Cost reports	x	x
Historical databases	x	x
Interviews	x	x
Program briefs	x	x
Subject matter experts	x	x
Technical databases	x	x
Other organizations	x	x
Contracts or contractor estimates		x
Cost proposals		x
Cost studies		x
Focus groups		x
Research papers		x
Surveys		x

Source: DOD and NASA.

Cost estimators must understand whether and how data were changed before deciding whether they will be useful. Furthermore, it is always better to use actual costs rather than estimates as data sources, since actual costs represent the most accurate data available.

[36] The examples and paragraph are © 2003, Society of Cost Estimating and Analysis, "Data Collection and Normalization: How to Get the Data and Ready It for Analysis."

While secondary data should not be the first choice, they may be all that is available. Therefore, the cost estimator must seek to understand how the data were normalized, what the data represent, how old they are, and whether they are complete. If these questions can be answered, the secondary data may be useful for estimating and would certainly be helpful for cross-checking the estimate for reasonableness.

Sources of historical data include business plans, catalog prices, contract performance reports, contract funds status reports, cost and software data reports, forward pricing rate agreements, historical cost databases, market research, program budget and accounting data from prior programs, supplier cost information, historical or current vendor quotes, and weight reports. In the operating and support area, common data sources include DOD's Visibility and Management of Operating and Support Costs management information system. Cost estimators should collect actual cost data from a list of similar and legacy programs. Since most new programs are improvements over existing ones, data should be available that share common characteristics with the new program.

Historical data provide the cost estimator insight into actual costs on similar programs, including any cost growth since the original estimate. As a result, historical data can be used to challenge optimistic assumptions. For example, a review of the average labor rates for similar tasks on other programs could be a powerful reality check against assumptions of skill mixes and overall effort. In addition, historical data from a variety of contractors can be used to establish generic program costs or they can be used to establish cost trends of a specific contractor across a variety of programs.

Historical data also provide contractor cost trends relative to proposal values, allowing the cost estimator to establish adjustment factors if relying on proposal data for estimating purposes. Additionally, insights can be obtained on cost accounting structures to allow an understanding of how a certain contractor charges things like other direct costs and overhead.

However, historical cost data also contain information from past technologies, so it is essential that appropriate adjustments are made to account for differences between the new system and the existing system with respect to such things as design characteristics, manufacturing processes (automation versus hands-on labor), and types of material used. This is where statistical methods, like regression, that analyze cost against time and performance characteristics can reveal the appropriate technology-based adjustment.

CPRs and cost and software data reports are excellent sources of historical cost data for DOD programs. The CPR is the primary report of cost and schedule progress on contracts containing EVM compliance requirements. It contains the time-phased budget, the actual cost, and earned value, which is the budgeted value of completed work.

By reviewing CPR data, the cost analyst can gain valuable insights into performance issues that may be relevant to future procurements. For instance, CPR data can provide information about changes to the estimate to complete (or the total expected cost of the program) and the performance measurement baseline, and it explains the reason for any variances. Before beginning any analysis of such reports, the analyst should perform a cursory assessment to ensure that the contractor has prepared them properly.

The several ways of analyzing cost data reports all use three basic elements in various combinations:

- budgeted cost for work scheduled (BCWS), or the amount of budget allocated to complete a specific amount of work at a particular time;
- budgeted cost for work performed (BCWP), also known as earned value, which represents budgeted value of work accomplished; and
- actual cost of work performed (ACWP), or actual costs incurred for work accomplished.[37]

Cost data reports are often used in estimating analogous programs, from the assumption that it is reasonable to expect similar programs at similar contractors' plants to incur similar costs. This analogy may not hold for the costs of hardware or software but may hold in the peripheral WBS areas of data, program management, or systems engineering. If the analyst can then establish costs for the major deliverables, such as hardware or software, a factor may be applied for each peripheral area of the WBS, based on historical data available from cost reports. Sometimes, the data listed in the WBS include elements that the analyst may not be using in the present estimate—spares, training, support equipment. In such cases, these elements should be removed before the data are analyzed.

Rate and factor agreements contain rates and factors agreed to by the contractor and the appropriate government negotiator. Because the contractor's business base may be fluid, with direct effect on these rates and factors, such agreements do not always exist. Information in them represents negotiated direct labor, overhead, general and administrative data, and facilities capital cost of money. These agreements could cover myriad factors, depending on each contractor's accounting and cost estimating structure. Typical factors are material scrap, material handling, quality control, sustaining tooling, and miscellaneous engineering support factors.

The scope of the estimate often dictates the need to consult with other organizations for raw data. Once government test facilities have been identified, for example, those organizations can be contacted for current cost data, support cost data, and the like. Other government agencies could also be involved with the development of similar programs and can be potential sources of data. Additionally, a number of government agencies and industry trade associations publish cost data that are useful in cost estimating.

The Defense Contract Management Agency (DCMA) and the Defense Contract Audit Agency (DCAA) help DOD cost analysts obtain validated data. Both agencies have on-site representatives at most major defense contractor facilities. Navy contractor resident supervisors of shipbuilding, for example, help obtain validated data. Before a contract is awarded, DCMA provides advice and services to help construct effective solicitations, identify potential risks, select the most capable contractors, and write contracts that meet customers' needs. In evaluating contract proposals, DCMA assists in the review of the proposal assumptions to identify how tightly scope was constrained to reduce risk premiums in the proposed cost. After a contract is awarded, DCMA monitors contractors' performance and management systems to ensure that cost, product performance, and delivery schedules comply with the contract's terms and schedule. It is common for DCMA auditors to be members of teams assembled to review elements of proposals, especially in areas of labor and overhead rates, cost, and supervision of man-hour percentages.

[37] We discuss these terms in chapters 18 and 19.

DCMA analysts often provide independent estimates at completion for programs; they are another potential source of information for cost analysts.

DCAA performs necessary contract audits for DOD. It provides accounting and advisory services for contracts and subcontracts to all DOD components responsible for procurement and contract administration. Cost analysts should establish and nurture contacts with these activities, so that a continual flow of current cost-related information can be maintained. Although civil agencies have no comparable organizations, DCMA and DCAA occasionally provide support to them.

Another area of potential cost data are contractor proposals. Analysts should remember that a contractor proposal as a source of data is a proposal—a document that represents the contractor's best estimate of cost. Proposals also tend to be influenced by the amount the customer has to spend. When this is the case, the proposal data should be viewed as suspect, and care should be taken to determine if the proposal data are supportable. Because of this, an estimate contained in a contractor's proposal should be viewed with some caution. During source selection in a competitive environment, for instance, lower proposed costs may increase the chances of receiving a contract award. This being so, it is very important to analyze the cost data for realism. A proposal can nonetheless provide much useful information and should be reviewed, when available, for the following:

- structure and content of the contractor's WBS;
- contractor's actual cost history on the same or other programs;
- negotiated bills of material;
- subcontracted items;
- government-furnished equipment compared to contractor-furnished equipment lists;
- contractor rate and factor data, based on geography and makeup of workforce;
- a self-check to ensure that all pertinent cost elements are included;
- top-level test of reasonableness;
- technological state-of-the-art assumptions; and
- estimates of management reserve and level of risk.

Because of the potential for bias in proposal data, the estimator must test the data to see whether they deviate from other similar data before deciding whether they are useful for estimating. This can be done through a plant visit, where the cost estimator visits the contractor to discuss the basis for the proposal data. As with any potential source of data, it is critical to ensure that the data apply to the estimating task and are valid for use. In the next two sections, we address how a cost estimator should perform these important activities.

Data Applicability

Because cost estimates are usually developed with data from past programs, it is important to examine whether the historical data apply to the program being estimated. Over time, modifications may have changed the historical program so that it is no longer similar to the new program. For example, it does not make sense to use data from an information system that relied on old mainframe technology when the new program will rely on server technology that can process data at much higher speeds. Having good descriptive requirements of the data is imperative in determining whether the data available apply to what is being estimated.

To determine the applicability of data to a given estimating task, the analyst must scrutinize them in light of the following issues:

- Do the data require normalization to account for differences in base years, inflation rates (contractor compared to government), or calendar year rather than fiscal year accounting systems?
- Is the work content of the current cost element consistent with the historical cost element?
- Have the data been analyzed for performance variation over time (such as technological advances)? Are there unambiguous trends between cost and performance over time?
- Do the data reflect actual costs, proposal values, or negotiated prices and has the type of contract been considered?

Proposal values are usually extremely optimistic and can lead to overly optimistic cost estimates and budgets. Furthermore, negotiated prices do not necessarily equate to less optimistic cost estimates.

- Are sufficient cost data available at the appropriate level of detail to use in statistical measurements?
- Are cost segregations clear, so that recurring data are separable from nonrecurring data and functional elements (manufacturing, engineering) are visible?
- Have risk and uncertainty for each data element been taken into account? High-risk elements usually cause optimistic cost estimates.
- Have legal or regulatory changes affected cost for the same requirement?
- When several historical values are available for the same concept, are they in close agreement or are they dispersed?

If they are in close agreement, as long as the definitions agree they should provide valuable insight. If they are different, perhaps the issues are not settled, the approaches are still at variance, and historical data may not be as useful for estimating current programs' costs.

Once these questions have been answered, the next step is to assess the validity of the data before they can be used to confidently predict future costs.

Validating and Analyzing the Data

The cost analyst must consider the limitations of cost data before using them in an estimate. Historical cost data have two predominant limitations:

- the data represent contractor marketplace circumstances that must be known if they are to have future value, and
- current cost data eventually become dated.

The first limitation is routinely handled by recording these circumstances as part of the data collection task. To accommodate the second limitation, an experienced cost estimator can either adjust the data (if applicable) or decide to collect new data. In addition, the contract type to be used in a future procurement—for example, firm fixed-price, fixed-price incentive, or cost plus award fee—may differ from that of the historical cost data. Although this does not preclude using the data, the analyst must be aware of such conditions, so that an informed data selection decision can be made. A cost analyst must attempt to address data limitations by

- ensuring that the most recent data are collected,
- evaluating cost and performance data together to identify correlation,
- ensuring a thorough knowledge of the data's background, and
- holding discussions with the data provider.

Thus, it is best practice to continuously collect new data so they can be used for making comparisons and determining and quantifying trends. This cannot be done without background knowledge of the data. This knowledge allows the estimator to confidently use the data directly, modify them to be more useful, or simply reject them.

Once the data have been collected, the next step is to create a scatter plot to see what they data looks like. Scatter plotting provides a wealth of visual information about the data, allowing the analyst to quickly determine outliers, relationships, and trends. In scatter charts, cost is typically treated as the dependent variable and is plotted on the y axis, while various independent variables are plotted on the x axis. These independent variables depend on the data collected but are typically technical—weight, lines of code, speed—or operational parameters—crew size, flying hours. These statistics provide information about the amount of dispersion in the data set, which is important for determining risk.

The cost estimator should first decide which independent variables are most likely to be cost drivers and then graph them separately. The extent to which the points are scattered will determine how likely it is that each independent variable is a cost driver. The less scattered the points are, the more likely it is that the variable is a cost driver. Eventually, the analyst will use statistical techniques to distinguish cost drivers, but using scatter charts is an excellent way to reduce their number.

The cost estimator should also examine each scatter chart in unit space to determine if a linear relationship exists. Many relationships are not linear; in such cases, the estimator can often perform a transformation to make the data linear. If the data appear to be exponential when plotted in unit space, the analyst should try plotting the natural log of the independent variable on the y axis. If the data appear to represent a power function, the analyst should try plotting the natural log of both the cost and the independent variable. In both cases, the goal is to transform the data appropriately to reveal a linear relationship, because most cost estimating relationships are based on linear regression.

After analyzing the data through a scatter plot, the estimator should calculate descriptive statistics to characterize and describe the data groups. Important statistics include sample size, mean, standard deviation, and coefficient of variation. Calculating the mean provides the estimator with the best estimate, because it is the average of the historical data. To determine the dispersion within the data set, the estimator must calculate the standard deviation. Finally, the estimator should calculate the coefficient of variation so that variances between data sets can be compared.

The coefficient of variation is calculated by dividing the standard deviation by the mean.[38] This provides a percentage that can be used to examine which data set has the least variation. Once the statistics have been derived, creating visual displays of them helps discern differences among groups. Bar charts, for example, are often useful for comparing averages. Histograms can be used to examine the distribution of different data sets in relation to their frequency. They can also be used for determining potential outliers. (Chapter 11 has more information on statistical approaches.)

Many times, estimates are not based on actual data but are derived by subjective engineering judgment. All engineering judgments should be validated before being used in a cost estimate. Validation involves cross-checking the results, in addition to analyzing the data and examining the documentation for the judgment. Graphs and scatter charts can often help validate an engineering judgment, because they can quickly point out any outliers.

It is never a good idea to discard an outlier without first understanding why a data point is outside the normal range. An outlier is a data point that is typically defined as falling outside the expected range of three standard deviations. Statistically speaking, outliers are rare, occurring only 0.3 percent of the time. If a data point is truly an outlier, it should be removed from the data set, because it can skew the results. However, an outlier should not be removed simply because it appears too high or too low compared to the rest of the data set. Doing so is naïve. Instead, a cost estimator should provide adequate documentation as to why an outlier was removed and this documentation should include comparisons to historical data that show the outlier is in fact an anomaly. If possible, the documentation should describe why the outlier exists; for example, there might have been a strike, a program restructuring, or a natural disaster that skewed the data. If the historical data show the outlier is just an extreme case, the cost estimator should retain the data point; otherwise, it will appear that the estimator was trying to manipulate the data. This should never be done, since all available historical data are necessary for capturing the natural variation within programs.

EVM Data Reliability

In chapter 3, we discussed top-level EVM data reliability tasks such as

- requesting a copy of the EVM system compliance letter showing the contractor's ability to satisfy the 32 guidelines;
- requesting a copy of the IBR documentation and final briefing to see what risks were identified and what weaknesses, if any, were found;
- determining whether EVM surveillance is being done by qualified and independent staff; and
- determining the financial accounting status of the contractor's EVM system to see whether any adverse opinions would call into question the reliability of the accounting data.

In addition to these tasks, auditors should perform a sanity check to see if the data even make sense. For example, the auditor should review all WBS elements in the CPR to determine whether there are any data anomalies such as

[38] The coefficient of variation is a useful descriptive statistic for comparing the degree of variation from various data sets, even if the means are very different.

- negative values for BCWS, BCWP, ACWP, estimate at completion (EAC), or budget at completion (BAC);
- large month-to-month performance swings (BCWP) not attributable to technical or schedule problems (may indicate cost collection issues);
- BCWS and BCWP data with no corresponding ACWP;
- BCWP with no BCWS or ACWP;
- ACWP with no BCWS or BCWP;
- large and continuing unexplained variances between ACWP and BCWP;
- inconsistencies between EAC and BAC (for example, EAC with no BAC or BAC with no EAC);
- ACWP greater than EAC;
- BCWP or BCWS exceed the BAC.

Despite the fact that these anomalies should be rare and fully explained in the variance analysis portion of the report, unfortunately we have found programs that submit CPRs with these types of errors. Case study 32 highlights this issue.

Case Study 32: Data Anomalies, from ***Cooperative Threat Reduction*****, GAO-06-692**

The EVM system the contractor was using to record, predict, and monitor progress contained flawed and unreliable data. GAO found serious discrepancies in the data, such as improper calculations and accounting errors. For example, from September 2005 through January 2006 the contractor's EVM reports had not captured almost $29 million in actual costs for the chemical weapons destruction facility project. EVM current period data were not accurate because of historical data corruption, numerous mistakes in accounting accruals, and manual budget adjustments. The mistakes underestimated the true cost of the project by ignoring cost variances that had already occurred.

For example, the Moscow project management task had been budgeted at a cost of $100,000. According to the January 2006 EVM report, the work was complete, but the actual cost was $2.6 million—an overrun of approximately $2.5 million that the EVM report failed to capture. Such data were misleading and skewed the project's overall performance. Unreliable EVM data limited DOD's efforts to accurately measure progress on the Shchuch'ye project and estimate its final completion date and cost.

GAO recommended that the Secretary of Defense direct the Defense Threat Reduction Agency, in conjunction with the U.S. Army Corps of Engineers, to ensure that the contractor's EVM system contain valid, reliable data and that the system reflect actual cost and schedule conditions; withhold a portion of the contractor's award fee until the EVM system produced reliable data; and require the contractor to perform an IBR after awarding the contract for completing Building 101.

GAO, *Cooperative Threat Reduction: DOD Needs More Reliable Data to Better Estimate the Cost and Schedule of the Shchuch'ye Facility*, GAO-06-692 (Washington, D.C.: May 31, 2006).

Data Normalization

The purpose of data normalization (or cleansing) is to make a given data set consistent with and comparable to other data used in the estimate. Since data can be gathered from a variety of sources, they are often in many different forms and need to be adjusted before being used for comparison analysis or as a basis for projecting future costs. Cost data are adjusted in a process called normalization, stripping out the effect of certain external influences. The objective of data normalization is to improve data consistency, so that comparisons and projections are more valid and other data can be used to increase the number of data points. Data are normalized in several ways.

Cost Units

Cost units primarily adjust for inflation. Because the cost of an item has a time value, it is important to know the year in which funds were spent. For example, an item that cost $100 in 1990 is more expensive than an item that cost $100 in 2005 because of the effects of inflation over the 15 years that would make the 1990 item more expensive when converted to a 2005 equivalent cost. Costs may also be adjusted for currency conversions.

In addition to inflation, the cost estimator needs to understand what the cost represents. For example, does it represent only direct labor or does it include overhead and the contractor's profit? Finally, cost data have to be converted to equivalent units before being used in a data set. That is, costs expressed in thousands, millions, or billions of dollars must be converted to one format—for example, all costs expressed in millions of dollars.

Sizing Units

Sizing units normalize data to common units—for example, cost per foot, cost per pound, dollars per software line of code. When normalizing data for unit size, it is very important to define exactly what the unit represents: What constitutes a software line of code? Does it include carriage returns or comments? The main point is to clearly define what the sizing metric is so that the data can be converted to a common standard before being used in the estimate.

Key Groupings

Key groupings normalize data by similar missions, characteristics, or operating environments by cost type or work content. Products with similar mission applications have similar characteristics and traits, as do products with similar operating environments. For example, space systems exhibit characteristics different from those of submarines, but the space shuttle has characteristics distinct from those of a satellite even though they may share common features. Costs should also be grouped by type. For example, costs should be broken out between recurring and nonrecurring or fixed and variable costs.

Technology Maturity

Technology maturity normalizes data for where a program is in its life cycle; it also considers learning and rate effects. The first unit of something would be expected to cost more than the 1,000th unit, just as a system procured at one unit per year would be expected to cost more per unit than the same system procured at 1,000 units per year. Technology normalization is the process of adjusting cost data for productivity improvements resulting from technological advancements that occur over time.

In effect, technology normalization is the recognition that technology continually improves, so a cost estimator must make a subjective attempt to measure the effect of this improvement on historical program costs. For instance, an item developed 10 years ago may have been considered state of the art and the costs would be higher than normal. Today, that item may be available off the shelf and therefore the costs would be considerably less.

Therefore, technology normalization is the ability to forecast technology by predicting the timing and degree of change of technological parameters associated with the design, production, and use of devices. Being able to adjust the cost data to reflect where the item is in its life cycle, however, is very subjective, because it requires identifying the relative state of technology at different points in time.

Homogeneous Groups

Using homogeneous groups normalizes for differences between historical and new program WBS elements in order to achieve content consistency. To do this type of normalization, a cost estimator needs to gather cost data that can be formatted to match the desired WBS element definition. This may require adding and deleting certain items to get an apples-to-apples comparison. A properly defined WBS dictionary is necessary to avoid inconsistencies.

Recurring and Nonrecurring Costs

Embedded within cost data are recurring and nonrecurring costs. These are usually estimated separately to keep one-time nonrecurring costs from skewing the costs for recurring production units. For this reason, it is important to segregate cost data into nonrecurring and recurring categories.

Nonrecurring Costs

SCEA defines nonrecurring costs as the elements of development and investment costs that generally occur only once in a system's life cycle. They include all the effort required to develop and qualify an item, such as defining its requirements and its allocation, design, analysis, development, qualification, and verification. Costs for the following are generally nonrecurring:

- manufacturing and testing development units, both breadboard and engineering, for hardware, as well as qualification and life-test units;
- retrofitting and refurbishing development hardware for requalification;
- developing and testing virtually all software before beginning routine system operation; nonrecurring integration and test efforts usually end when qualification tests are complete;
- providing services and some hardware, such as engineering, before and during critical design review;
- developing, acquiring, producing, and checking all tooling, ground handling, software, and support equipment and test equipment.

Recurring Costs

As defined by SCEA, recurring costs are incurred for each item produced or each service performed. For example, the costs associated with producing hardware—that is, manufacturing and testing, providing engineering support for production, and supporting that hardware with spare units or parts—are recurring costs. Recurring integration and testing, including the integration and acceptance testing of production units at all WBS levels, also represent recurring costs. In addition, refurbishing hardware for operational or spare units is a recurring cost, as is maintaining test equipment and production support software. In contrast, maintaining system operational software, although recurring in nature, is often considered part of operating and support costs, which might also have nonrecurring components.

Similar to nonrecurring and recurring costs are fixed and variable costs. Fixed costs are static, regardless of the number of quantities to be produced. An example of a fixed cost is the cost to rent a facility. A variable cost is directly affected by the number of units produced and includes such things as the cost of electricity or overtime pay. Knowing what the data represent is important for understanding anomalies that can occur as the result of production unit cuts.

The most important reason for differentiating recurring from nonrecurring costs is in their application to learning curves. Simply put, learning curve theory applies only to recurring costs. Cost improvement or learning is generally associated with repetitive actions or processes, such as those directly tied to producing an item again and again. Categorizing as recurring or variable costs that are affected by the quantity of units being produced adds more clarity to the data. An analyst who knows only the total cost of something does not know how much of that cost is affected by learning.

Inflation Adjustments

In the development of an estimate, cost data must be expressed in like terms. This is usually accomplished by inflating or deflating cost data to express them in a base year that will serve as a point of reference for a fixed price level. Applying inflation is an important step in cost estimating. If a mistake is made or the inflation amount is not correct, cost overruns can result, as case study 33 illustrates.

Case Study 33: Inflation, from *Defense Acquisitions*, GAO-05-183

Inflation rates can significantly affect ship budgets. Office of the Secretary of Defense (OSD) and OMB inflation indexes are based on a forecast of the implicit price deflator for the gross domestic product. Until recently, the Navy had used OSD and OMB inflation rates; shipbuilding industry rates were Historically higher. As a result, contracts were signed and executed using industry-specific inflation rates while budgets were based on the lower inflation rates, creating a risk of cost growth from the outset. For the ships reviewed, this difference in inflation rates explained 30 percent of the $2.1 billion cost growth. The Navy had changed its inflation policy in February 2004, directing program offices to budget with what the Navy believed were more realistic inflation indexes, anticipating that this would help curtail requests for prior-year completion funds.

GAO, *Defense Acquisitions: Improved Management Practices Could Help Minimize Cost Growth in Navy Shipbuilding Programs* (Washington, D.C.: Feb. 28, 2005).

Applying inflation correctly is necessary if the cost estimate is to be credible. In simple terms, inflation reflects the fact that the cost of an item usually continues to rise over time. Inflation rates are used to convert a cost from its current year into a constant base year so that the effects of inflation are removed. When cost estimates are stated in base-year dollars, the implicit assumption is that the purchasing power of the dollar has remained unchanged over the period of the program being estimated. Cost estimates are normally prepared in constant dollars to eliminate the distortion that would otherwise be caused by price-level changes. This requires the transformation of historical or actual cost data into constant dollars.

For budgeting purposes, however, the estimate must be expressed in then-year dollars to reflect the program's projected annual costs by appropriation. This requires applying inflation to convert from base-year to then-year dollars. Cost estimators must make assumptions about what inflation indexes to use, since any future inflation index is uncertain. In cases in which inflation decreases over time, applying the wrong inflation rate will result in a higher cost estimate. Worse is the situation in which the inflation is higher than projected, resulting in costs that are not sufficient to keep pace with inflation, as illustrated in case study 33. Thus, it is imperative that inflation assumptions be well documented and that the cost estimator always perform uncertainty and sensitivity analysis to study the effects of changes on the assumed rates.

Selecting the Proper Indexes

The cost estimator will not have to construct an index to apply inflation but will select one to apply to cost data. Often, the index is directed by higher authority, such as OMB. In this way, all programs can be compared and aggregated with the same escalation rate, since they are all being executed in the same economic circumstances. This doesn't mean that the forward escalation rates are correct—in fact, escalation rates are difficult to forecast—but that program comparisons will at least not be confused by different assumptions about escalation. When the index is not directed, a few general guidelines can help the cost estimator select the correct index. Because all inflation indexes measure the average rate of inflation for a particular market basket of goods, the objective in making a choice is to select the one whose market basket most closely matches the program to be estimated. The key is to use common sense and objective judgment. For example, the consumer price index would be a poor indicator of inflation for a new fighter aircraft, because the market baskets obviously do not match. Labor escalation would be affected by different factors than, say, fuel or steel costs. Although the selected index will never exactly match the market basket of costs, the closer the match, the better the estimate.

Weighted indexes are used to convert constant, base-year, dollars to then-year dollars and vice versa. Raw indexes are used to change the economic base of constant dollars from one base year to another. Contract prices are stated in then-year dollars, and weighted indexes are appropriate for converting them to base-year dollars. Published historical cost data are frequently, but not always, normalized to a common base year, and raw indexes are appropriate for changing the base year to match that of the program being estimated. It is important that the cost estimator determine what year dollars cost data are expressed in, so that normalization for inflation can be done properly.

Schedule risk can affect the magnitude of escalation in a cost estimate. The escalation dollars are often estimated by applying a monthly escalation rate (computed so that compounding monthly values equates to the forecasted annual rate) to dollars forecasted to be spent in each month. If the schedule is delayed, a dollar that would have been escalated by, say, 30 months might now be escalated for 36 months. Even if the cost estimate in today's dollars is an accurate estimate, a schedule slip would affect the amount of escalation.

In addition, the question of escalating the contingency reserve arises. Some cost estimating systems calculate the contingency on base-year dollars but do not escalate the contingency, perhaps because they do not have a way to determine when the dollars will be spent. In a cost risk analysis, in contrast, the contingency reserve is computed during the simulation using the risk in the line-item costs. If the simulated line-item costs are then subjected to escalation during the same simulation, the process effectively escalates the contingency. This is appropriate, since contingency money is just more money needed to be spent on the statement of work, and it should be affected by escalation as is any other money spent.

Data Documentation

After the data have been collected, analyzed, and normalized, they must be documented and stored for future use. One way to keep a large amount of historical data viable is to continually supplement them with every new system's actual return costs and with every written vendor quote or new contract. Although data have many sources, the predominant sources are the manufacturers who make the item or similar items. It can take years for a cost estimator to develop an understanding of these sources and to earn the trust of manufacturers regarding the use of their proprietary and business-sensitive data. Once trust has been established and maintained for some time, the cost estimator can normally expect a continual flow of useful data.

All data collection activities must be documented as to source, work product content, time, units, and assessment of accuracy and reliability. Comprehensive documentation during data collection greatly improves quality and reduces subsequent effort in developing and documenting the estimate. The data collection format should serve two purposes. First, the format should provide for the full documentation and capture of information to support the analysis. Second, it should provide for standards that will aid in mapping other forms of cost data.

Previously documented cost estimates may provide useful data for a current estimate. Relying on previous estimates can save the cost estimator valuable time by eliminating the need to research and conduct statistical analyses that have already been conducted. For example, a documented program estimate may provide the results of research on contractor data, identification of significant cost drivers, or actual costs, all of which are valuable to the cost estimator. Properly documented estimates describe the data used to estimate each WBS element, and this information can be used as a good starting point for the new estimate. Moreover, relying on other program estimates can be valuable in understanding various contractors and providing cross-checks for reasonableness.

Because many cost documents are secondary sources of information, the cost estimator should be cautious. When using information from documented cost estimates, the analyst should fully understand the data. For example, if a factor was constructed from CPRs, the cost estimator should ask the following questions to see if the data are valid for the new program:

- What was the base used in the ratio?
- Are the WBS elements consistent with those of the system being estimated—for example, is data management included in the data or the systems engineering and program management element?
- Was the factor computed from the ACWP or the EAC?
- What percentage complete is the contract?

Thus, previous estimates can provide the cost estimator with valuable data and can also save time, since they provide a structure from which to develop the new cost estimate. They also help avoid reinventing the wheel, since the estimator can leverage off the work of others. However, the cost estimator will still have to perform follow-on work before fully relying on these data.

7. Best Practices Checklist: Data

- ☐ As the foundation of an estimate, data
  - ✓ Have been gathered from historical actual cost, schedule and program, and technical sources;
  - ✓ Apply to the program being estimated;
  - ✓ Have been analyzed for cost drivers;
  - ✓ Have been collected from primary sources, if possible, and secondary sources as the next best option, especially for cross-checking results;
  - ✓ Have been adequately documented as to source, content, time, units, assessment of accuracy and reliability, and circumstances affecting the data;
  - ✓ Have been continually collected, protected, and stored for future use;
  - ✓ Were assembled as early as possible, so analysts can participate in site visits to understand the program and question data providers.
- ☐ Before being used in a cost estimate, the data were
  - ✓ Fully reviewed to understand their limitations and risks;
  - ✓ Segregated into nonrecurring and recurring costs;
  - ✓ Validated, using historical data as a benchmark for reasonableness;
  - ✓ Current and found applicable to the program being estimated;
  - ✓ Analyzed with a scatter plot to determine trends and outliers;
  - ✓ Analyzed with descriptive statistics;
  - ✓ Normalized to account for cost and sizing units, mission or application, technology maturity, and content so they are consistent for comparisons;
  - ✓ Normalized to constant base-year dollars to remove the effects of inflation, and the inflation index was documented and explained.

CHAPTER 11

Developing a Point Estimate

In this chapter, we discuss step 7 in the high-quality estimating process. Step 7 pulls all the information together to develop the point estimate—the best guess at the cost estimate, given the underlying data. High-quality cost estimates usually fall within a range of possible costs, the point estimate being between the best and worst case extremes. (We explain in chapter 14 how to develop this range of costs using risk and uncertainty analysis.) The cost estimator must perform several activities to develop a point estimate:

- develop the cost model by estimating each WBS element, using the best methodology, from the data collected;
- include all estimating assumptions in the cost model;
- express costs in constant-year dollars;
- time-phase the results by spreading costs in the years they are expected to occur, based on the program schedule; and
- add the WBS elements to develop the overall point estimate.

Having developed the overall point estimate, the cost estimator must then

- validate the estimate by looking for errors like double counting and omitted costs and ensuring that estimates are comprehensive, accurate, well-documented, and credible (more information on validation is in chapter 15);
- compare the estimate against the independent cost estimate and examine where and why there are differences;
- perform cross-checks on cost drivers to see if results are similar; and
- update the model as more data become available or as changes occur and compare the results against previous estimates.

We have already discussed how to develop a WBS and GR&As, collect and normalize the data into constant base-year dollars, and time-phase the results. Once all the data have been collected, analyzed, and validated, the cost estimator must select a method for developing the cost estimate.

Cost Estimating Methods

The three commonly used methods for estimating costs are analogy, engineering build-up, and parametric. An analogy uses the cost of a similar program to estimate the new program and adjusts for differences. The engineering build-up method develops the cost estimate at the lowest level of the WBS, one piece at a time, and the sum of the pieces becomes the estimate. The parametric method relates cost to one or more technical, performance, cost, or program parameters, using a statistical relationship.

Which method to select depends on where the program is in its life cycle. Early in the program, definition is limited and costs may not have accrued. Once a program is in production, cost and technical data from the development phase can be used to estimate the remainder of the program. Table 11 gives an overview of the strengths, weaknesses, and applications of the three methods.

Table 11: Three Cost Estimating Methods Compared

Method	Strength	Weakness	Application
Analogy	▪ Requires few data ▪ Based on actual data ▪ Reasonably quick ▪ Good audit trail	▪ Subjective adjustments ▪ Accuracy depends on similarity of items ▪ Difficult to assess effect of design change ▪ Blind to cost drivers	▪ When few data are available ▪ Rough-order-of-magnitude estimate ▪ Cross-check
Engineering build-up	▪ Easily audited ▪ Sensitive to labor rates ▪ Tracks vendor quotes ▪ Time honored	▪ Requires detailed design ▪ Slow and laborious ▪ Cumbersome	▪ Production estimating ▪ Software development ▪ Negotiations
Parametric	▪ Reasonably quick ▪ Encourages discipline ▪ Good audit trail ▪ Objective, little bias ▪ Cost driver visibility ▪ Incorporates real-world effects (funding, technical, risk)	▪ Lacks detail ▪ Model investment ▪ Cultural barriers ▪ Need to understand model's behavior	▪ Budgetary estimates ▪ Design-to-cost trade studies ▪ Cross-check ▪ Baseline estimate ▪ Cost goal allocations

Source: © 2003, MCR, LLC, "Cost Estimating: The Starting Point of EVM."

Other cost estimating methods include

- expert opinion, which relies on subject matter experts to give their opinion on what an element should cost;[39]
- extrapolating, which uses actual costs and data from prototypes to predict the cost of future elements; and
- learning curves, which is a common form of extrapolating from actual costs.

In the sections below, we describe these methods and their advantages and disadvantages. Finally, we discuss how to pull all the methods together to develop the point estimate.

Analogy Cost Estimating Method

An analogy takes into consideration that no new program, no matter how state of the art it may be technologically, represents a totally new system. Most new programs evolve from programs already fielded that have had new features added on or that simply represent a new combination of existing components. The analogy method uses this concept for estimating new components, subsystems, or total programs. That is, an analogy uses actual costs from a similar program with adjustments to account for differences

[39] Expert opinion, also known as engineering judgment, is commonly applied to fill gaps in a relatively detailed WBS when one or more experts are the only qualified source of information, particularly in matters of specific scientific technology.

between the requirements of the existing and new systems. A cost estimator typically uses this method early in a program's life cycle, when insufficient actual cost data are available but the technical and program definition is good enough to make the necessary adjustments.

Adjustments should be made as objectively as possible, by using factors (sometimes scaling parameters) that represent differences in size, performance, technology, or complexity. The cost estimator should identify the important cost drivers, determine how the old item relates to the new item, and decide how each cost driver affects the overall cost. All estimates based on the analogy method, however, must pass the "reasonable person" test—that is, the sources of the analogy and any adjustments must be logical, credible, and acceptable to a reasonable person. In addition, since analogies are one-to-one comparisons, the historical and new systems should have a strong parallel.

Analogy relies a great deal on expert opinion to modify the existing system data to approximate the new system. If possible, the adjustments should be quantitative rather than qualitative, avoiding subjective judgments as much as possible. An analogy is often used as a cross-check for other methods. Even when an analyst is using a more detailed cost estimating technique, an analogy can provide a useful sanity check. Table 12 shows how an analogy works.

Table 12: An Example of the Analogy Cost Estimating Method

Parameter	Existing system	New system	Cost of new system (assuming a linear relationship)
Engine	F-100	F-200	
Thrust	12,000 lbs	16,000 lbs	
Cost	$5.2 million	X	(16,000/12,000) x $5.2 million = $6.9 million

Source: © 2003, Society of Cost Estimating and Analysis (SCEA), "Costing Techniques."

The equation in table 12 implicitly assumes a linear relationship between engine cost and amount of thrust. However, there should be a compelling scientific or engineering reason why an engine's cost is directly proportional to its thrust. Without more data (or an expert on engine costs), it is hard to know what parameters are the true drivers of cost. Therefore, when using the analogy method, it is important that the estimator research and discuss with program experts the reasonableness of technical program drivers to determine whether they are significant cost drivers.

The analogy method has several advantages:

- It can be used before detailed program requirements are known.
- If the analogy is strong, the estimate will be defensible.
- An analogy can be developed quickly and at minimum cost.
- The tie to historical data is simple enough to be readily understood.

Analogies also have some disadvantages:

- An analogy relies on a single data point.
- It is often difficult to find the detailed cost, technical, and program data required for analogies.
- There is a tendency to be too subjective about the technical parameter adjustment factors.

The last disadvantage can be best explained with an example. If a cost estimator assumes that a new component will be 20 percent more complex but cannot explain why, this adjustment factor is unacceptable. The complexity must be related to the system's parameters, such as that the new system will have 20 percent more data processing capacity or will weigh 20 percent more. Case study 34 highlights what can happen when technical parameter assumptions are too optimistic.

Case Study 34: Cost Estimating Methods, from *Space Acquisitions*, GAO-07-96

In 2004, Advanced Extremely High Frequency (AEHF) satellite program decision makers relied on the program office cost estimate rather than the independent estimate the CAIG developed to support the production decision. The program office estimated that the system would cost about $6 billion, on the assumption that AEHF would have 10 times more capacity than Milstar, the predecessor satellite, at half the cost and weight. However, the CAIG concluded that the program could not deliver more data capacity at half the weight, given the state of the technology. In fact, the CAIG believed that to get the desired increase in data rate, the weight would have to increase proportionally. As a result, the CAIG estimated that AEHF would cost $8.7 billion and predicted a $2.7 billion cost overrun.

The CAIG relied on weight data from historical satellites to estimate the program's cost, because it considered weight to be the best cost predictor for military satellite communications. The historical data from the AEHF contractor showed that the weight had more than doubled since the program began and that the majority of the weight growth was in the payload. The Air Force also used weight as a cost predictor but attributed the weight growth to structural components rather than the more costly payload portion of the satellite. The CAIG stated that major cost growth was inevitable from the program start because historical data showed that it was possible to achieve a weight reduction or an increase in data capacity but not both at the same time.

GAO, *Space Acquisitions: DOD Needs to Take More Action to Address Unrealistic Initial Cost Estimates of Space Systems*, GAO-07-96 (Washington, D.C.: Nov. 17, 2006).

Engineering Build-Up Cost Estimating Method

The engineering build-up cost estimating method builds the overall cost estimate by summing or "rolling-up" detailed estimates done at lower levels of the WBS. Because the lower-level estimating associated with the build-up method uses industrial engineering principles, it is often referred to as engineering build-up and is sometimes referred to as a grass-roots or bottom-up estimate.

An engineering build-up estimate is done at the lowest level of detail and consists of labor and materials costs that have overhead and fee added to them. In addition to labor hours, a detailed parts list is required. Once in hand, the material parts are allocated to the lowest WBS level, based on how the work will be accomplished. In addition, quantity and schedule have to be considered in order to capture the effects of learning. Typically, cost estimators work with engineers to develop the detailed estimates. The cost estimator's focus is to get detailed information from the engineer in a way that is reasonable, complete, and consistent with the program's ground rules and assumptions. The cost estimator must find additional data to validate the engineer's estimates.

An engineering build-up method is normally used during the program's production, because the program's configuration has to be stabilized, and actual cost data are required to complete the estimate. The underlying assumption of this method is that historical costs are good predictors of future costs. The premise is that data from the development phase can be used to estimate the cost for production. As illustrated in table 13, the build-up method is used when an analyst has enough detailed information about building an item—such as number of hours and number of parts—and the manufacturing process to be used.

Table 13: An Example of the Engineering Build-Up Cost Estimating Method

Problem	Similar aircraft	Solution	Result
Estimate sheet metal cost of the inlet nacelle for a new aircraft	F/A-18 inlet nacelle	Apply historical F/A-18 variance for touch labor effort and apply support labor factor to adjust estimated touch labor hours	2,000 hours x 1.2 = 2,400 touch labor hours and 2,400 labor hours x 1.48 = 3,522 labor hours (touch labor plus support labor) estimate for new aircraft
Standard hours to produce a new nacelle are estimated at 2,000 for touch labor; adjust to reflect experience of similar aircraft and support labor effort	F/A-18 inlet nacelle experienced a 20% variance in touch labor effort above the industrial engineering standard. In addition, F/A-18 support labor was equal to 48% of the touch labor hours		Average labor rates would then be used to convert these total labor hours into costs

Source: © 2003, Society of Cost Estimating and Analysis (SCEA), "Costing Techniques."

Because of the high level of detail, each step of the work flow should be identified, measured, and tracked, and the results for each outcome should be summed to make the point estimate.

The several advantages to the build-up technique include

- the estimator's ability to determine exactly what the estimate includes and whether anything was overlooked,
- its unique application to the specific program and manufacturer,
- that it gives good insight into major cost contributors, and
- easy transfer of results to other programs.

Some disadvantages of the engineering build-up method are that

- it can be expensive to implement and it is time consuming,
- it is not flexible enough to answer what-if questions,
- new estimates must be built for each alternative,
- the product specification must be well known and stable,
- all product and process changes must be reflected in the estimate,

- small errors can grow into larger errors during the summation, and
- some elements can be omitted by accident.

Parametric Cost Estimating Method

In the parametric method, a statistical relationship is developed between historical costs and program, physical, and performance characteristics. The method is sometimes referred to as a top-down approach. Types of physical characteristics used for parametric estimating are weight, power, and lines of code. Other program and performance characteristics include site deployment plans for information technology installations, maintenance plans, test and evaluation schedules, technical performance measures, and crew size. These are just some examples of what could be a cost driver for a particular program.

Sources for these cost drivers are often found in the technical baseline, cost analysis requirements document or cost analysis data requirement. The important thing is that the attributes used in a parametric estimate should be cost drivers of the program. The assumption driving the parametric approach is that the same factors that affected cost in the past will continue to affect future costs. This method is often used when little is known about a program except for a few key characteristics like weight or volume.

Using a parametric method requires access to historical data, which may be difficult to obtain. If the data are available, they can be used to determine the cost drivers and to provide statistical results and can be adjusted to meet the requirements of the new program. Unlike an analogy, parametric estimating relies on data from many programs and covers a broader range. Confidence in a parametric estimate's results depends on how valid the relationships are between cost and the physical attributes or performance characteristics. Using this method, the cost estimator must always present the related statistics, assumptions, and sources for the data.

The goal of parametric estimating is to create a statistically valid cost estimating relationship using historical data. The parametric CER can then be used to estimate the cost of the new program by entering its specific characteristics into the parametric model. CERs established early in a program's life cycle should be continually revisited to make sure they are current and the input range still applies to the new program. In addition, parametric CERs should be well documented, because serious estimating errors could occur if the CER is improperly used.

Parametric techniques can be used in a wide variety of situations, ranging from early planning estimates to detailed contract negotiations. It is always essential to have an adequate number of relevant data points, and care must be taken to normalize the dataset so that it is consistent and complete. In software, the development environment—that is, the extent to which the requirements are understood and the strength of the programmers' skill and experience—is usually the major cost driver. Because parametric relationships are often used early in a program, when the design is not well defined, they can easily be reflected in the estimate as the design changes simply by adjusting the values of the input parameters.

It is important to make sure that the program attributes being estimated fall within (or, at least, not far outside) the CER dataset. For example, if a new software program was expected to contain 1 million software lines of code and the data points for a software CER were based on programs with lines of code ranging from 10,000 to 250,000, it would be inappropriate to use the CER to estimate the new program.

To develop a parametric CER, cost estimators must determine the cost drivers that most influence cost. After studying the technical baseline and analyzing the data through scatter charts and other methods, the cost estimator should verify the selected cost drivers by discussing them with engineers. The CER can then be developed with a mathematical expression, which can range from a simple rule of thumb (for example, dollars per pound) to a complex regression equation.

The more simplified CERs include rates, factors, and ratios. A rate uses a parameter to predict cost, using a multiplicative relationship. Since rate is defined to be cost as a function of a parameter, the units for rate are always dollars per something. The rate most commonly used in cost estimating is the labor rate, expressed in dollars per hour.

A factor uses the cost of another element to estimate a new cost using a multiplier. Since a factor is defined to be cost as a function of another cost, it is often expressed as a percentage. For example, travel costs may be estimated as 5 percent of program management costs.

A ratio is a function of another parameter and is often used to estimate effort. For example, the cost to build a component could be based on the industry standard of 20 hours per subcomponent.

Rates, factors, and ratios are often the result of simple calculations (like averages) and many times do not include statistics. Table 14 contains a parametric cost estimating example.

Table 14: An Example of the Parametric Cost Estimating Method

Program attribute	Calculation
A cost estimating relationship (CER) for site activation (SA) is a function of the number of workstations (NW)	SA = $82,800 + ($26,500 x NW)
Data range for the CER	7 – 47 workstations based on 11 data points
Cost to site activate a program with 40 workstations	$82,800 + ($26,500 x 40) = $1,142,800

Source: © 2003, Society of Cost Estimating and Analysis (SCEA), “Costing Techniques.”

In table 14, the number of workstations is the cost driver. The equation is linear but has both a fixed component (that is, $82,800) and a variable component (that is, $26,500 x NW).

In addition, the range of the data is from 7 to 47 workstations, so it would be inappropriate to use this CER for estimating the activation cost of a site with as few as 2 or as many as 200 workstations.

In fact, at one extreme, the CER estimates a cost of $82,800 for no workstation installations, which is not logical. Although we do not show any CER statistics for this example, the CERs should always be presented with their statistics. The reason for this is to enable the cost estimator to understand the level of variation within the data and model its effect with uncertainty analysis.

CERs should be developed using regression techniques, so that statistical inferences may be drawn. To perform a regression analysis, the first step is to determine what relationship exists between cost (dependent variable) and its various drivers (independent variables). This relationship is determined by developing a scatter chart of the data. If the data are linear, they can be fit by a linear regression. If they are not linear and transformation of the data does not produce a linear fit, nonlinear regression can be used. The independent variables should have a high correlation with cost and should be logical.

For example, software complexity can be considered a valid driver of the cost of developing software. The ultimate goal is to create a fit with the least variation between the data and the regression line. This process helps minimize the statistical error or uncertainty brought on by the regression equation.

The purpose of the regression is to predict with known accuracy the next real-world occurrence of the dependent variable (or the cost), based on knowledge of the independent variable (or some physical, operational, or program variable). Once the regression is developed, the statistics associated with the relationship must be examined to see if the CER is a strong enough predictor to be used in the estimate. Most statistics can be easily generated with the regression analysis function of spreadsheet software. Among important regression statistics are

- R-squared,
- statistical significance,
- the F statistic, and
- the t statistic.

R-squared

The R-squared (R^2) value measures the strength of the association between the independent and dependent (or cost) variables. The R^2 value ranges between 0 and 1, where 0 indicates that there is no relationship between cost and its independent variable, and 1 means that there is a perfect relationship between them. Thus, the higher R^2 is the better. An R^2 of 91 percent in the example in table 14, for example, would mean that the number of workstations (NW) would explain 91 percent of the variation in site activation costs, indicating that it is a very good cost driver.

Statistical Significance

Statistical significance is the most important factor for deciding whether a statistical relationship is valid. An independent variable can be considered statistically significant if there is small probability that its corresponding coefficient is equal to zero, because a coefficient of zero would indicate that the independent variable has no relationship to cost. Thus, it is desirable that the probability that the coefficient is equal to zero be as small as possible. How small is denoted by a predetermined value called the significance level. For example, a significance level of .05 would mean there was a 5 percent probability that a variable was not statistically significant. Statistical significance is determined by both the regression as a whole and each regression variable.

F Statistic

The F statistic is used to judge whether the CER as a whole is statistically significant by testing to see whether any of the variables' coefficients are equal to zero. The F statistic is defined as the ratio of the equation's mean squares of the regression to its mean squared error, also called the residual. The higher the F statistic is, the better the regression, but it is the level of significance that is important.

t Statistic

The t statistic is used to judge whether individual coefficients in the equation are statistically significant. It is defined as the ratio of the coefficient's estimated value to its standard deviation. As with the F statistic, the higher the t statistic is, the better, but it is the level of significance that is important.

The Parametric Method: Further Considerations

The four statistics described above are just some of the statistical analyses that can be used to validate a CER. (For more information on statistics or hardware cost estimating, a good reference is the Parametric Estimating Handbook.[40]) Once the statistics have been evaluated, the cost estimator picks the best CER—that is, the one with the least variation and the highest correlation to cost.

The final step in developing the CER is to validate the results, using a data set different from the one used to generate the equation, to see if the results are similar. Again, it is important to use a CER developed from programs whose variables are within the same data range as those used to develop the CER. Deviating from the CER variable input range could invalidate the relationship and skew the results. We note several other pitfalls associated with CERs.

Always question the source of the data underlying the CER. Some CERs may be based on data that are biased by unusual events like a strike, hurricane, or major technical problems that required a lot of rework. To mitigate this risk, it is essential to understand the data the CER is based on and, if possible, to use other historical data to check the validity of the results.

All equations should be checked for common sense to see if the relationship described by the CER is reasonable. This helps avoid the mistake that the relationship adequately describes one system but does not apply to the one being estimated.

Normalizing the data to make them consistent is imperative to good results. All cost data should be converted to constant base years. In addition, labor and material costs should be broken out separately, since they may require different inflation factors to convert them to constant dollars. Moreover, independent variables should be converted into like units for various physical characteristics such as weight, speed, and length.

Historical cost data may have to be adjusted to reflect similar accounting categories, which might be expressed differently from one company to another.

It is important to fully understand all CER modeling assumptions and to examine the reliability of the dataset, including its sources, to see if they are reasonable.

Among the several advantages to parametric cost estimating are its

- Versatility: If the data are available, parametric relationships can be derived at any level, whether system or subsystem component. And as the design changes, CERs can be quickly modified and used to answer what-if questions about design alternatives.
- Sensitivity: Simply varying input parameters and recording the resulting changes in cost can produce a sensitivity analysis.
- Statistical output: Parametric relationships derived from statistical analysis generally have both objective measures of validity (statistical significance of each estimated coefficient and of the model

[40] See International Society of Parametric Analysts, *Parametric Estimating Handbook*©, 4th ed. (Vienna, Va.: ISPA/SCEA Joint Office, 2008). www.ispa-cost.org/newbook.htm. The handbook and its appendixes detail, and give examples of, how to develop, test, and evaluate CERs.

as a whole) and a calculated standard error that can be used in risk analysis. This information can be used to provide a confidence level for the estimate, based on the CER's predictive capability.

- Objectivity: CERs rely on historical data that provide objective results. This increases the estimate's defensibility.

Disadvantages to parametric estimating include

- Database requirements: The underlying database must be consistent and reliable. It may be time-consuming to normalize the data or to ensure that the data were normalized correctly, especially if someone outside the estimator's team developed the CER. Without understanding how the data were normalized, the analyst has to accept the database on faith—sometimes called the black-box syndrome, in which the analyst simply plugs in numbers and unquestioningly accepts the results. Using a CER in this manner can increase the estimate's risk.
- Currency: CERs must represent the state of the art; that is, they must be updated to capture the most current cost, technical, and program data.
- Relevance: Using data outside the CER range may cause errors, because the CER loses its predictive ability for data outside the development range.
- Complexity: Complicated CERs (such as nonlinear CERs) may make it difficult for others to readily understand the relationship between cost and its independent variables.

Parametric Cost Models

Many cost estimating models are based on parametric methods. They may estimate hardware or software costs. Depending on the model, the database may contain cost, technical, and programmatic data at the system, component, and subcomponent level. Parametric models typically consist of several interrelated CERs and are often computerized. They may involve extensive use of cost-to-noncost CERs, multiple independent variables related to a single cost effect, or independent variables defined in terms of weapon system performance or design characteristics rather than more discrete material requirements or production processes. Information technology databases and computer modeling may be used in these types of parametric cost estimating systems.

When using parametric models, many times the underlying data are proprietary, so access to the raw data may not be available. When the inputs to the parametric models are qualitative, as often happens, they should be objectively assessed. In addition, many parameters should be selected to tailor the model to the specific hardware or software product that is being estimated. Therefore, it is also important to calibrate the parametric model to best reflect the particular situation or environment in which the product will be developed. Finally, the model should be validated using historical data to determine how well it predicts costs.

Parametric models are always useful for cross-checking the reasonableness of a cost estimate that is derived by other means. As a primary estimating method, parametric models are most appropriate during the engineering concept phase when requirements are still somewhat unclear and no bill of materials exists. When this is the situation, it is imperative that the parametric model is based on historical cost data and that the model is calibrated to those data. To ensure that the model is a good predictor of costs, it should demonstrate that it actually reflects or replicates known data to a reasonable degree of accuracy. In addition, the model should demonstrate that the cost-to-noncost estimating relationships are logical and that the data used for the parametric model can be verified and traced back to source documentation.

Using parametric cost models has several advantages:

- They can be adjusted to best fit the hardware or software being estimated.
- Cost estimates are based on a database of historical data.
- They can be calibrated to match a specific development environment.

Their disadvantages are that

- their results depend on the quality of the underlying database,
- they require many inputs that may be subjective, and
- accurate calibration is required for valid results.

Expert Opinion

Expert opinion is generally considered too subjective but can be useful in the absence of data. It is possible to alleviate this concern by probing further into the experts' opinions to determine if real data back them up. If so, the analyst should attempt to obtain the data and document the source.

The cost estimator's interviewing skills are also important for capturing the experts' knowledge so that the information can be used properly. However, cost estimators should never ask experts to estimate the costs for anything outside the bounds of their expertise, and they should always validate experts' credentials before relying on their opinions.

The advantages of using an expert's opinion are that

- it can be used when no historical data are available;
- it takes minimal time and is easy to implement, once experts are assembled;
- an expert may give a different perspective or identify facets not previously considered, leading to a better understanding of the program;
- it can help in cross-checking for CERs that require data significantly beyond the data range;
- it can be blended with other estimation techniques within the same WBS element; and
- it can be applied in all acquisition phases.

Disadvantages associated with using an expert's opinion include

- its lack of objectivity,
- the risk that one expert will try to dominate a discussion to sway the group or that the group will succumb to the urge to agree, and
- it is not very accurate or valid as a primary estimating method.

The bottom line is that because of its subjectivity and lack of supporting documentation, expert opinion should be used sparingly and only as a sanity check. Case study 35 shows how relying on expert opinion as a main source for a cost estimate is unwise.

Case Study 35: Expert Opinion, from *Customs Service Modernization*, GAO/AIMD-99-41

The U.S. Customs Service Automated Commercial Environment (ACE), a major information technology systems modernization effort, was estimated in November 1997 to cost $1.05 billion to develop, operate, and maintain between 1994 and 2008. GAO's 1999 review found that the agency lacked a reliable estimate of what ACE would cost to build, deploy, and maintain. Instead of using a cost model, Customs had used an unsophisticated spreadsheet to extrapolate the cost of each ACE software increment.

Further, Customs' approach to determining software size and reuse was not well supported or convincing and had not been documented. For example, Customs had estimated the size of each ACE software increment—most increments had still been undefined—by extrapolating from the estimated size of the first increment, based on individuals' undocumented best judgments about functionality and complexity.

Last, Customs did not have any historical project cost data when it developed the $1.05 billion estimate, and it had not accounted for relevant, measured, and normalized differences in the increments. For instance, it had not accounted for the change in ACE's architecture from a mainframe system that had been written in COBOL and C++ to a combined mainframe and Internet-based system that was to be written in C++ and Java. Such a fundamental change would clearly have a dramatic effect on system costs and should have been explicitly addressed in Customs' cost estimates.

GAO, *Customs Service Modernization: Serious Management and Technical Weaknesses Must Be Corrected*, GAO/AIMD-99-41 (Washington, D.C.: Feb. 26, 1999).

Other Estimating Methods: Extrapolation from Actual Costs

Extrapolation uses the actual past or current costs of an item to estimate its future costs. The several variants of extrapolation include

- averages, the most basic variant, a method that uses simple or moving averages to determine the average actual costs of units that have been produced to predict the cost of future units;
- learning curves, which account for cost improvement and are the most common variant; and
- estimates at completion, which use actual cost and schedule data to develop estimates of costs at completion with EVM techniques; EACs can be calculated with various EVM forecast techniques to take into account factors such as current performance.

Extrapolation is best suited for estimating follow-on units of the same item when there are actual data from current or past production lots. This method is valid when the product design or manufacturing process has changed little. If major changes have occurred, careful adjustments will have to be made or another method will have to be used. When using extrapolation techniques, it is essential to have accurate data at the appropriate level of detail, and the cost estimator must ensure that the data have been validated and properly normalized. When such data exist, they form the best basis for cost estimates. Advantages associated with extrapolating from actual costs include their

- reliance on historical costs to predict future costs,
- great credibility and reliability for estimating costs, and

- ability to be applied at whatever level of data—labor hours, material dollars, total costs.

The disadvantages associated with extrapolating from actual costs are that

- changes in the accounting of actual costs can affect the results,
- obtaining access to actual costs can be difficult,
- results will be invalid if the production process or configuration is not stable, and
- it should not be used for items outside the actual cost data range.

Other Estimating Methods: Learning Curves

Using the cost estimating methods discussed in this chapter can generate the cost of a single item. However, a cost estimator needs to determine whether that cost is for the first unit, the average unit, or every unit. And given the cost for one unit, how should a cost estimator determine the appropriate costs for other units? The answer is in the use of learning curves. Sometimes called progress or improvement curves, learning curve theory is based on the premise that people and organizations learn to do things better and more efficiently when they perform repetitive tasks. A continuous reduction in labor hours from repetitive performance in producing an item often results from more efficient use of resources, employee learning, new equipment and facilities, or improved flow of materials. This improvement can be modeled with a mathematical CER that assumes that as the quantity of units to be produced doubles, the amount of effort declines by a constant percentage.

Workers gain efficiencies in a number of areas as items are repeatedly produced. The most commonly recognized area of improvement is worker learning. Improvement occurs because as a process is repeated, workers tend to become physically and mentally more adept at it. Supervisors, in addition to realizing these gains, become more efficient in using their people, as they learn their strengths and weaknesses. Improvements in the work environment also translate into worker and supervisory improvement: Studies show that changes in climate, lighting, and general working conditions motivate people to improve.

Cost improvement also results from changes to the production process that optimize placement of tools and material and simplify tasks. In the same vein, organizational changes can lead to lower recurring costs, such as instituting a just-in-time inventory or centralizing tasks (heat and chemical treatment processes, tool bins, and the like). Another example of organizational change is a manufacturer's agreeing to give a vendor preferred status if it is able to limit defective parts to some percentage. The reduction in defective parts can translate into savings in scrap rates, quality control hours, and recurring manufacturing labor, all of which can result in valuable time savings. In general, it appears that more complex manufacturing tasks tend to improve faster than simpler tasks. The more steps in a process, the more opportunity there is to learn how to do them better and faster.

Another reason for contractor improvement is that in competitive business environments, market forces require suppliers to improve efficiency to survive. As a result, some suppliers may competitively price their initial product release at a loss, with the expectation that future cost improvements will make up the difference. This strategy can also discourage competitors from entering new markets. For the strategy to work, however, the assumed improvements must materialize or the supplier may cease to exist because of high losses.

In observing production data (for example, manufacturing labor hours), early analysts noted that labor hours per unit decreased over time. This observation led to the formulation of the learning curve equation $Y = AX^b$ and the concept of a constant learning curve slope (b) that captures the change in Y given a change in X.[41] The unit formulation states that "as the number of units doubles, the cost decreases by a constant percent." In other words, every time the total quantity doubles, the cost decreases by some fixed percentage. Figure 13 illustrates how a learning curve works.

Figure 13: A Learning Curve

Source: © 1994, R. Max Wideman, FCSCE, "A Pragmatic Approach to Using Resource Loading, Production and Learning Curves on Construction Projects."

Figure 13 shows how an item's cost gets cheaper as its quantities increase. For example, if the learning curve slope is 90 percent and it takes 1,000 hours to produce the first unit, then it will take 900 hours to produce the second unit. Every time the quantity doubles—for example, from 2 to 4, 4 to 8, 8 to 16—the resource requirements will reduce according to the learning curve slope.

Determining the learning curve slope is an important effort and requires analyzing historical data. If several production lots of an item have been produced, the slope can be derived from the trend in the data. Another way to determine the slope would be to look at company history for similar efforts and calculate it from those efforts. Or the slope could be derived from an analogous program. The analyst could look at slopes for a particular industry—aircraft, electronics, shipbuilding—sometimes reported in organizational studies, research reports, or estimating handbooks. Slopes can be specific to functional areas such as manufacturing, tooling, and engineering, or they may be composite slopes calculated at the system level, such as aircraft, radar, tank, or missiles.

The first unit cost might be arrived at by analogy, engineering build-up, a cost estimating relationship, fitting the actual data, or another method. In some cases, the first unit cost is not available. Sometimes

[41] $b = \log(\text{slope}) / \log(2)$.

work measurement standards might provide the hours for the 5th unit, or a cost estimating relationship might predict the 100th unit cost. This is not a problem as long as the cost estimator understands the point on the learning curve that the unit cost is from and what learning curve slope applies. With this information, the cost estimator can easily solve for the 1st unit cost using the standard learning curve formula $Y = AX^b$.

Because learning can reduce the cost of an item over time, cost estimators should be aware that if multiple units are to be bought from one contractor as part of the program's acquisition strategy, reduced costs can be anticipated. Thus, knowledge of the acquisition plan is paramount in deciding if learning curve theory can be applied. If so, careful consideration must be given to determining the appropriate learning curve slope for both labor hours and material costs. In addition, learning curves are based on recurring costs, so cost estimators need to separate recurring from nonrecurring costs if the results are not to be skewed. Finally, these circumstances should be satisfied before deciding to use learning curves:

- much manual labor is required to produce the item;
- the production of items is continuous and, if not, then adjustments are made;
- the items to be produced require complex processes;
- technological change is minimal between production lots;
- the contractor's business process is being continually improved;[42] and
- the government program office culture (or environment) is sufficiently known.

Particular care should be taken for early contracts, in which the cost estimator may not yet be familiar enough with program office habits to address the risk accurately (for example, high staff turnover, propensity for scope creep, or excessive schedule delays).

Production Rate Effects on Learning

It is reasonable to expect that unit costs decrease not only as more units are produced but also as the production rate increases. This theory accounts for cost reductions that are achieved through economies of scale. Some examples are quantity discounts and reduced ordering, processing, shipping, receiving, and inspection costs. Conversely, if the number of quantities to be produced decreases, then unit costs can be expected to increase, because certain fixed costs have to be spread over fewer items. At times, an increase in production rate does not result in reduced costs, as when a manufacturer's nominal capacity is exceeded. In such cases, unit costs increase because of such factors as overtime, capital purchases, hiring actions, and training costs.

Another aspect of improvement is the continuity of the production line. Production breaks may occur because of program delays (budgetary or technical), time lapses between initial and follow-on orders, or labor disputes. They may occur as a result of design changes that may require a production line to shut down so it can be modified with new tools and equipment or a new configuration. Production lines can also shut down for unexpected recalls that require repairs for previously produced items. How much learning is lost depends on how long the production line is shut down.

[42] Appendix XI has more detail on learning and learning curves.

To determine the effect of a production break on the unit cost two questions need answering:

1. How much learning has been lost (or forgotten) because of the break in production?
2. How will this loss of learning affect the costs of future production items?

The cost estimator should always consider the effect of a production break on the cost estimate. (See case study 36.)

Case Study 36: Production Rate, from *Defense Acquisitions*, GAO-05-183

Costs on the CVN 76 and CVN 77 Nimitz aircraft carriers grew because of additional labor hours required to construct the ships. At delivery, CVN 76 had required 8 million additional labor hours to construct; CVN, 77, 4 million. As the number of hours increased, total labor costs grew because the shipbuilder was paying for additional wages and overhead costs. Increases in labor hours stemmed in part from underestimating the labor hours. The shipbuilder had negotiated CVN 76 for approximately 39 million labor hours—only 2.7 million more labor hours than the previous ship—CVN 75. However, CVN 75 had been constructed more efficiently, because it was the fourth ship of two concurrent ship procurements. CVN 76 and CVN 77, in contrast, were procured as single ships.

Single ship procurements have Historically been less efficient than two-ship procurements. The last time the Navy procured a carrier as a single-ship procurement, 7.9 million more hours were required—almost 3 times the number estimated for CVN 76 (2.7 million more hours). In addition, a 4-month strike in 1999, during the construction of CVN 76, had led to employee shortages in key trades and learning losses, because many employees were not returning to the shipyard. According to Navy officials, the shipbuilder was given $51 million to offset the strike's effect.

GAO, *Defense Acquisitions: Improved Management Practices Could Help Minimize Cost Growth in Navy Shipbuilding Programs*, GAO-05-183 (Washington, D.C.: Feb. 28, 2005).

Pulling the Point Estimate Together

After each WBS element has been estimated with one of the methods discussed in this chapter, the elements should be added together to arrive at the total point estimate. The cost estimator should validate the estimate by looking for errors like double-counting and omitted costs. The cost estimator should also perform, as a best practice, cross-checks on various cost drivers to see if similar results can be produced. This helps validate the estimate. The cost estimator should also compare the estimate to an independent cost estimate. The estimate and the independent cost estimate should also be reconciled at this time. (Chapter 15 discusses validating the estimate.)

DOD's major defense acquisition programs are required to develop independent cost estimates for major program milestones; other agencies may not require this practice. An independent cost estimate gives an objective measure of whether the point estimate is reasonable. Differences between them should be examined and discussed to achieve understanding of overall program risk and to adjust risk around the point estimate.

Finally, as the program matures through its life cycle, as more data become available, or as changes occur, the cost estimator should update the point estimate. The updated point estimate should be compared against previous estimates, and lessons learned should be documented. (More detail is in chapter 20.)

8. Best Practices Checklist: Developing a Point Estimate

- ☐ The cost estimator considered various cost estimating methods:
  - ✓ Analogy, early in the life cycle, when little was known about the system being developed:
    - o Adjustments were based on program information, physical and performance characteristics, contract type.
  - ✓ Expert opinion, very early in the life cycle, if an estimate could be derived no other way.
  - ✓ The build-up method later, in acquisition, when the scope of work was well defined and a complete WBS could be determined.
  - ✓ Parametrics were used if a database of sufficient size, quality, and homogeneity was available for developing valid CERs and the data were normalized correctly.
    - o Parametric models were calibrated and validated using historical data.
  - ✓ Extrapolating from actual cost data, at the start of production.
- ☐ Cost estimating relationships were considered:
  - ✓ Statistical techniques were used to develop CERs:
    - o Higher R-squared;
  - ✓ Statistical significance, for determining the validity of statistical relationships;
    - o Significance levels of F and t statistics.
  - ✓ Before using a CER, the cost estimator
    - o Examined the underlying data set to understand anomalies;
    - o Checked equations to ensure logical relationships;
    - o Normalized the data;
    - o Ensured that CER inputs were within the valid dataset range;
    - o Checked modeling assumptions to ensure they applied to the program.
  - ✓ Learning curve theory was applied if
    - o Much manual labor was required for production;
    - o Production was continuous or adjustments had to be made;
    - o Items to be produced required complex processes;
    - o Technological change was minimal between production lots;
    - o The contractor's business process was being continually improved.
- ☐ Production rate and breaks in production were considered.
- ☐ The point estimate was developed by aggregating the WBS element cost estimates by one of the cost estimating methods.
  - ✓ Results were checked for accuracy, double-counting, and omissions and were validated with cross-checks and independent cost estimates.

CHAPTER 12

Estimating Software Costs

Software is a key component in almost all major systems the federal government acquires. Estimating software development, however, can be difficult and complex. To illustrate, consider some statistics: a Standish Group International 2000 report showed that 31 percent of software programs were canceled, more than 50 percent overran original cost estimates by almost 90 percent, and schedule delays averaged almost 240 percent.[43] Moreover, the Standish Group reported that the number of software development projects that are completed successfully on time and on budget, with all features and functions as originally specified, rose only from 16 percent in 1994 to 28 percent in 2000. [44]

Most often, creating an estimate based on an unachievable schedule causes software cost estimates to be far off target. Playing into this problem is an overwhelming optimism about how quickly software can be developed. This optimism stems from a lack of understanding of how staffing, schedule, software complexity, and technology all interrelate. Furthermore, optimism about how much savings new technology can offer and the amount of reuse that can be leveraged from existing programs also cause software estimates to be underestimated. Case study 37 gives an example.

Case Study 37: Underestimating Software, from *Space Acquisitions*, GAO-07-96

The original estimate for the Space Based Infrared System for nonrecurring engineering, based on actual experience in legacy sensor development and assumed software reuse, was significantly underestimated. Nonrecurring costs should have been two to three times higher, according to historical data and independent cost estimators. Program officials also planned on savings from simply rehosting existing legacy software, but those savings were not realized because all the software was eventually rewritten. It took 2 years longer than planned to complete the first increment of software.

GAO, *Space Acquisitions: DOD Needs to Take More Action to Address Unrealistic Initial Cost Estimates of Space Systems*, GAO-07-96 (Washington, D.C.: Nov. 17, 2006).

Our work has also shown that the ability of government program offices to estimate software costs and develop critical software is often immature. Therefore, we highlight software estimation as a special case of cost estimation because of its significance and complexity in acquiring major systems. This chapter

[43] Daniel D. Galorath, *Software Projects on Time and Within Budget—Galorath: The Power of Parametrics*, PowerPoint presentation, El Segundo, California, n.d., p. 3. http://www.galorath.com/wp/software-project-failure-costs-billions-better-estimation-planning-can-help.php.

[44] Jim Johnson and others, "Collaboration: Development and Management—Collaborating on Project Success," *Software Magazine*, Sponsored Supplement, February–March 2001, p. 2.

supplements the steps in cost estimating with what is unique in the software development environment, so that auditors can better understand the factors that can lead to software cost overruns and failure to deliver required functionality on time. Auditors should remember that all the steps of cost estimating have to be performed for software just as they have to be performed for hardware.

The 12 steps of cost estimating described in chapter 1 and summarized in table 15 also apply to software. That is, the purpose of the estimate and the estimating plan should be defined in steps 1 and 2, software requirements should be defined in step 3, the effort to develop the software should be defined in step 4, GR&As should be established in step 5, relevant technical and cost data should be collected in step 6, and a method for estimating the cost for software development and maintenance should be part of the point estimate in step 7. Moreover, sensitivity in step 8, risk and uncertainty analysis in step 9, documenting the estimate in step 10, presenting results to management in step 11, and updating estimates with actual costs in step 12 are all relevant for software cost estimates.

Table 15: The Twelve Steps of High-Quality Cost Estimating Summarized

Step	Summary
1	Define the estimate's purpose
2	Develop the estimating plan
3	Define the program characteristics, the technical baseline
4	Determine the estimating structure, the WBS
5	Identify ground rules and assumptions
6	Obtain the data
7	Develop the point estimate and compare it to an independent cost estimate
8	Conduct sensitivity analysis
9	Conduct a risk and uncertainty analysis
10	Document the estimate
11	Present the estimate to management for approval
12	Update the estimate to reflect actual costs and changes

Source: GAO.

In this chapter, we discuss some of the best practices for developing reliable and credible software cost estimates and fully understanding typical cost drivers and risk elements associated with software development.

Unique Components of Software Estimation

Since software is not tangible like hardware; it can be more ambiguous and difficult to comprehend. In addition, software is built only once, whereas hardware is often mass produced, once design and testing are complete. Unlike hardware, for which the industry changes more slowly, software changes constantly, making it difficult to collect good data for cost estimating. Despite these differences, software estimating is otherwise similar to hardware estimating in that it follows the same basic development process.[45] For instance, both use the same types of estimating methods—analogy, engineering build-up, parametric.

[45] A source for more information on hardware cost estimating is the International Society of Parametric Analysts, *Parametric Estimating Handbook*, 4th ed.

Size and complexity are cost drivers for both. Finally, how quickly hardware and software can be produced depends on the developer's capability, available resources, and familiarity with the environment.

Software is mainly labor intensive, and all the tasks associated with developing it are nonrecurring—there is no production phase. That is, once the software is developed, it is simple to produce a copy of it. How much effort is required to develop software depends on its size and complexity. Thus, estimating software costs has two basic elements—the software to be developed and the development effort to accomplish it.

Estimating Software Size

Cost estimators begin a software estimate by predicting the sizes of the deliverables that must be constructed. Software sizing is the process of determining how big the application being developed will be. The size depends on many factors. For example, software programs that are more complex, perform many functions, have safety-of-life requirements, and require high reliability are typically bigger than simpler programs.

Estimating software size is not easy and depends on having a detailed knowledge about a program's functions in terms of scope, complexity, and interactions. Not only is it hard to generate a size estimate for an application that has not yet been developed, but the software process also often experiences requirements growth and scope creep that can significantly affect size and the resulting cost and schedule estimates.

Programs that do not track and control these trends typically overrun their costs and experience schedule delays. Methods for measuring size data include COSMIC (Common Software Measurement International Consortium) Functional Sizing Method, function point analysis, object point analysis, source lines of code, and use case (described in table 16).

Table 16: Sizing Metrics and Commonly Associated Issues

Metric	Advantages	Disadvantages
COSMIC functional sizing		
Measures the size of software based on functional user requirements; sizes software independently of the technology to be used to implement it, focusing on practices and procedures the software must follow to meet user needs. COSMIC points are based on four different data movements: entry, exit, read, and write. Each one constitutes a COSMIC function point. The method can be used to determine the software size of various applications including business, real-time (telecommunications, process control), embedded software (cellular phones, electronics), and infrastructure software (operating system software)	Sizing is easily understood and simplified because all data movements have the same value; sizing does not depend on data attributes; It applies to real-time and embedded systems and allows for end-user and developer viewpoints; standards exist for counting	Recently developed, so benchmarking data are limited; not accurate for counting highly algorithmic software; detailed information about data movements takes time to collect; automated counting does not exist

Metric	Advantages	Disadvantages
Function point analysis		
Considers how many functions a program does rather than how many instructions it contains; functions typically include user inputs (add, change, delete), outputs (reports), data files to be updated by the application, interfaces with other applications, and inquiries (searches or retrievals). Each function is weighted for complexity and total count is adjusted for the effect of 14 characteristics such as data communications, transaction rate, installation ease, and whether there are multiple sites. Accurate counting requires in-depth knowledge of standards, experience, and, preferably, function point certification. Function point analysis is linked directly to system requirements and functionality, so size analysis is measured in terms users can understand. The size estimates (and resulting cost and schedule estimates) can be based on quantifiable analysis through the project life cycle as requirements change. Function points are particularly useful in many development environments that might use unified modeling language, commercial off-the-shelf components, or object-oriented approaches to software development and implementation	Many types of data sources can be used throughout development: user or estimator interviews, requirements and design documents, data dictionaries and models, end user guides, screen captures; not dependent on language or technology; count is unaffected by language or tools used to develop the software; counts are available early in development from requirements and design specifications; nontechnical users can understand what function points are measuring; function points can be used to determine requirements (or scope) creep; counts are fully documented and auditable; standards are established and reviewed often by the International Function Point Users Group; counting can be quick and efficient	Counting involves subjectivity; difficult to derive requirements from top-level specifications; does not capture technical and design constraints; untrained or inexperienced people can develop inconsistent function point counts; definitions can be confusing; automated function point analysis counting does not exist; database is not as big as for source line of code counts; counts tend to underestimate algorithmic intensive systems
Object point analysis		
Uses integrated computer-aided software engineering tools (CASE) to count number of screens, reports, and third-generation modules for basic sizing; CASE tools take over the job of manually writing software code by using graphical user interface generators, libraries of reusable components, and other design tools. Object points focus on actors involved in the solution and any actions they must take. One benefit of using objects (i.e., actors) is that similar behaviors can be grouped into classes, allowing for behaviors from upper classes (parent) to be inherited by lower classes (children). Inheritance results in reduced coding effort; each count is weighted for complexity, summed to a total count, and adjusted for reuse	Relies on a graphical user interface; automates manual activities; objective measures; easier calculations; accounts for reuse through inheritance	Counts occur at the end of design; no standards for counting; and not widely used and therefore validated productivity metrics are not available

Metric	Advantages	Disadvantages
Reports, interfaces, conversions, extensions, and forms/workflows (RICEF/W)		
Commonly used to size the effort associated with implementing Enterprise Resource Planning (ERP) systems; identifies changes that need to be made to configure the ERP system so that it satisfies user needs and fits within the target operating environment. Can be used to add functionality through custom development. RICEF/W needs to be adjusted for complexity	Represents ERP modifications and enhancements that do not require custom development	Specific to ERP systems; no standards for counting; does not capture costs for integrating bolt-on functionality
Source lines of code (SLOC)		
Considers the volume of code required to develop the software; includes executable instructions and data declarations and normally excludes comments and blanks. Estimation is by analogy, engineering expertise, or automated code counters. SLOC sizing is particularly appropriate for projects preceded by similar ones (e.g., same language, developers, type of application); helps ensure that experience is aligned to future development. When developing lines of code counts, it is critical to define what is and is not included. When developing databases or relying on software cost models, consistency in defining what the lines of code include is key	Widely used for many years; can be used to estimate real time systems easily counted, manually or by automated code counter; objective; large databases of historical program sizes are available; can obtain precise counts of existing software using the USC Code Counter	No standard definition of what should be counted as lines of code (e.g., physical line vs. logical statement); different lines of code count for the same function, depending on language and programmer's style; hard to capture lines of code for commercial off-the-shelf systems; hard to translate lines of code counts between other programming languages such as object oriented code; variations in definition make it hard to compare studies using SLOC; hard to estimate program SLOC early; emphasizes coding effort, which is small compared to overall software development effort
Use cases and use case points		
Defines interactions between external users and the system to achieve a goal (e.g., capture fingerprint or facial biometric to enroll applicants). A use case model describes a system's functional requirements, consists of all users and use cases (tasks performed by the end user of a system that has a useful outcome), and identifies reuse by use case inclusions and extensions. Sizing count is arrived at by categorizing use cases as small, medium, or large and applying an average "use case points per category." Adding a complexity factor to the sizing count based on number and types of users and transactions improves the count accuracy	Applies to interactive end-user applications and devices users interact with; intuitive to stakeholders and development team; identifies opportunities for software reuse; traceable to development team's plans and output; increasingly applied to real-time systems; can be mapped to test cases and business scenarios, which helps in staggered deployment	Often yields an inaccurate final estimate if the system engineering process is immature and historical data are lacking; no standards for counting; developer must be using object oriented design techniques so required documentation is available; estimate cannot be done until design document with the defined use case is available; requires a design team with a great deal of experience with object oriented design

Source: DOD, NASA, SCEA, and industry.

While software sizing can be approached in many ways, none are accurate because the "size" of software is an abstract concept. Moreover, with the exception of COSMIC and function points, none of the methods table 16 describes have a controlling body for internationally standardizing the counting rules. In the absence of a universal counting convention, different places may take one of the source definitions for the basic approach and then "standardize" the rules internally. This can result in different counts. Therefore, it is critical that the sizing method used is consistent. The test of a good sizing method is that two separate individuals can apply the same rules to the same problem and yield almost the same result. Before choosing a sizing approach, one must consider the following questions of maturity and applicability:

- Are the rules for the sizing technique rigorously defined in a widely accepted format?
- Are they under the control of a recognized, independent controlling body?
- Are they updated from time to time by the recognized, independent controlling body?
- Does the controlling body certify the competency (and, hence, consistency) of counters who use their rules?
- Are statistical data available to support claims for the consistency of counting by certified counters?
- How long have the rules been stable?

Auditors should know a few things about software sizing. The first is that reused and autogenerated software source lines of code should be differentiated from the total count. Reused software (code used verbatim with no modifications), adapted software (code that needs to be redesigned, may need to be converted, and may need some code added), and autogenerated software provide the developer with code that can be used in a new program, but none of these comes for free, and additional effort is usually associated with incorporating them into a new program. For instance, the effort associated with reused code depends on whether significant integration, reverse engineering, and additional design, validation, and testing are required. But if the effort to incorporate reused software is too great, it may be cheaper to write the code from scratch. As a result, the size of the software should reflect the amount of effort expected with incorporating code from another source. This can be accomplished by calculating the equivalent source lines of code, which adjusts the software size count to reflect the fact that some effort is required.

Software porting is a special case of software reuse that is getting increasing visibility in cost estimation with respect to specific technologies, such as communications systems (waveforms). Porting represents hidden pitfalls, depending on the amount of capability to be transferred from special purpose processors (such as field-programmable gate arrays). Also, the quality of software commenting and documentation and the modularity of the initial code's design and implementation greatly affect the porting of standard code in general purpose processors. Therefore, assumptions regarding savings (for example, assume less effort is required and no testing is necessary) from reused, adapted, and autogenerated software code should be looked at skeptically because of the additional work to research the code and provide necessary quality checks. As a minimum, regression testing will be required before integrating the software with the hardware for this type of code.

Second, while function points generate counts for real-time software, like missile systems, they are not optimal in capturing the complexity associated with high levels of algorithmic software. Therefore, for programs that require high levels of complex processing like operating systems, telephone switching systems, navigation systems, and process control systems, estimators should base the count on COSMIC points or SLOC rather than function points to adequately capture the additional effort associated with developing algorithmic software.

Finally, choosing a sizing metric depends on the software application (purpose of the software and level of reliability needed) and the information that is available. Since no one way is best, cost estimators should work with software engineers to determine which metric is most appropriate. Since SLOCs have been used widely for years as a software sizing metric, many organizations have databases of historical SLOC counts for various completed programs. Thus, source lines of code tend to be the most predominant method for sizing software. If the decision is made to use historical source lines of code for estimating software size, however, the cost estimator needs to make sure that the program being estimated is similar in size, language, and application to the historical data. For programs for which no analogous data are available but detailed requirements and specifications have been developed, function point counting is appropriate, as long as the software does not contain many algorithms; if it does, then COSMIC points or SLOC should be used. And, if computer-assisted software engineering tools are being used to develop the software, then object point analysis is appropriate. No matter which metric is chosen, however, the actual results can vary widely from the estimate, so that any point estimate should be accompanied by an estimated range of probability. (We discuss software and other cost estimating risk and uncertainty analyses in chapter 14.)

When completing a software size estimate, it is preferable to use two different methodologies, if available, rather than relying on a single approach. Software estimates based on several different approaches that are compared and merge toward a consensus is the best practice. In addition, it is extremely important to include the expected growth in software size from requirements growth or underestimation (that is, optimism). Adjusting the software size to reflect expected growth from requirements being refined, changed, or added or initial size estimates being too optimistic, and less reuse than expected is a best practice. This growth adjustment should be made before performing an uncertainty analysis (discussed in chapter 14). Understanding that software will usually grow, and accounting for it by using historical data, will result in more accurate software sizing estimates. Moreover, no matter what sizing convention is used, it is a best practice to continually update the size estimate as data become available so that growth can be monitored and accounted for.

Estimating Software Development Effort

Once the initial software sizing is complete, it can be converted into software development effort—that is, an estimate of the human resources needed for the software's development. It is important to note whether the effort accounts only for the WBS elements associated with the actual development of the software or also includes all the other nondevelopment activities.

Table 53 in appendix IX, for example, shows a typical WBS for ground software development. The table shows that many other activities outside the actual coding of software are part of a typical software acquisition. These activities should also be estimated as part of the development effort. In particular, software management and control, software systems engineering, test-bed development, system integration and testing, quality assurance, and training are all activities that should be performed in a customized software solution acquisition.

The level of effort required for each activity depends on the type of system being developed. For example, military and systems software programs require more effort than Web programs of the same size. Since variations in activities can affect overall costs, schedules, and productivity rates by significant amounts, it is critical to appropriately match activities to the type of software project being estimated. For example, safety critical software applications composed of complex mathematical algorithms require higher levels of effort because stringent quality and certification testing must be satisfied. Moreover, operating systems that must reflect real time updates and great reliability will need more careful design, development, and testing than software systems that rely on simple calculations.

To convert software size into software development effort, the size is usually divided by a productivity factor like number of source lines of code, or function points, developed per labor work month. The productivity factor depends on several aspects, like the language used; whether the code is new, reused, or autogenerated; the developer's capability; and the development tools used. It is best to use historical data from a similar program to develop the productivity factor, so that it best represents the development environment. If historical productivity factors are not available, an estimator can use a factor based on industry averages, but this will add more uncertainty to the estimate. It is important to note, however, that a productivity factor—based on the coding phase only—cannot be used to estimate the entire software development effort. When a productivity factor is used, all parameters associated with its computation need to be considered. Once the productivity factor has been selected, the corresponding labor hours can be generated.

Some considerations in converting labor hours to cost are, first, that a cost estimator needs to determine how many productive hours are being assumed in a typical developer's work day. This is important because assuming 8 hours of productive coding is unrealistic: staff meetings and training classes cut into valuable programming time, so that the number of effective work hours per day is typically 6 hours rather than 8. Further, the number of work days per year is not the same from company to company because of differences in vacation and sick leave offered and the country the developers live in. In the United States, fewer vacation days tend to be provided than in countries in Europe, but in other countries like Japan less time is provided. All these issues need to be considered and calibrated to the program being estimated. In fact, multiple studies on the impact of overtime have shown that except for a short increase in effort over the first 1 or 2 months, overtime does not have a significant impact on the life of the program.

The sizing value usually represents only the actual software development effort, so the cost estimator needs to use other methods to estimate all the other activities related to developing the software. Sometimes factors (such as percentage of development effort) are available for estimating these additional costs. Software cost estimating models often provide estimates for these activities. If a model is not used or not available, then the cost estimator must account for the cost of the other labor as well as nonlabor costs, such as hardware and licenses. Accurately estimating all these tasks is challenging, because they are affected by a number of risks. (Some of are identified in table 17; appendix XV contains a more comprehensive list of risks.)

Table 17: Common Software Risks That Affect Cost and Schedule

Risk	Typical cost and schedule element
Sizing and technology	▪ Overly optimistic software engineers tending to underestimate the amount of code needed ▪ Poor assumptions on the use of reused code (requiring no modification) or adapted code (requiring some redesign, recoding, and retesting) ▪ Vague or incomplete requirements, leading to uncertain size counts ▪ Not planning for additional effort associated with commercial off-the-shelf software (e.g., systems engineering, performance testing, developing glue code)
Complexity	▪ Programming language: the amount of design, coding, and testing (e.g., object-oriented languages require more up-front design but result in less coding and testing) ▪ Applications: software purpose and reliability (e.g., criticality of failure, loss of life) ▪ Hardware limitations with respect to the need for more efficient code ▪ Number of modules affecting integration effort ▪ Amount of new code to be developed ▪ Higher quality requiring more development and testing but resulting in less and easier-to-perform maintenance ▪ Safety critical software requires more design, coding, and testing
Capability	▪ Developers with better skill can deliver more effective software with fewer defects, allowing for faster software delivery ▪ Optimistic assumption that a new development tool will increase productivity ▪ Optimistic assumption about developer's productivity, leading to cost growth, even if sizing is accurate ▪ Geographically dispersed development locations, making communication and coordination more difficult
Management and executive oversight	▪ Management's dictating an unrealistic schedule ▪ A decision to concurrently develop hardware and software, increasing risk ▪ Incorporating a new method, language, tool, or process for the first time ▪ Incomplete or inaccurate definition of system requirements ▪ Not handling creeping requirements proactively ▪ Inadequate quality control, causing delays in fixing unexpected defects ▪ Unanticipated risks associated with commercial off-the-shelf software upgrades and lack of support

Source: SCEA and industry.

Scheduling Software Development

The schedule for getting the work accomplished should also be estimated. Too often, software development programs tend to run late because of requirements creep or poor quality control. Other times, the schedule is driven by some arbitrary date dictated by management or the customer. Optimism may be based on management's thinking that if more people are added to the development team, the product can be developed faster. Unfortunately, the opposite usually happens: the larger the development team, the less its members are able to communicate with one another or work effectively. In addition, the more complex the software development effort is, the harder it will be to find the right staff for the job.

Scheduling is complicated and is affected by many factors. A cost estimator should understand the intricate interdependencies that affect the schedule:

- staff availability;
- an activity's dependence on prior tasks;

- the concurrence of scheduled activities;
- the activities that make up the critical path;
- the number of shifts working and effective work hours per shift;
- available budget;
- whether overtime can be authorized;
- downtime from meetings, travel, sickness;
- geographic location of workers, including time zones.

Significantly large software development efforts frequently experience cost and schedule growth. This is because of the complexities inherent in managing configuration, communications, and design assumptions that typically hinder software development productivity. In addition, increased software schedule has a ripple effect on other collateral support efforts such as program management and systems engineering. Hardware programs experience the same problems.

Management pressure on software developers to keep to an unrealistic schedule presents other problems. For example, to meet schedule constraints, the developer may minimize the time for requirements analysis, which can affect the quality of the software developed. In addition, developers may skip documentation, which could result in higher software maintenance costs. Moreover, developers may decide to build more components in parallel, defer functionality, postpone rework, or minimize functional testing, all to reduce schedule time. While these actions may save some time up front, they result in additional time, effort, and risk for the program.

Rework should be included in every software development schedule because it is unwise to assume that software can be delivered without any defects. Therefore, if rework is not accounted for in the schedule, it will have to be accounted for when it occurs, which will cause problems in the sequencing of remaining tasks. It should be noted that if a software schedule does not include effort for rework, then the schedule will be unexecutable, and the maturity of the developing organization is questionable for assuming that all requirements will pass testing the very first time. Rework effort should include the time and resources associated with diagnosing the problem, designing and coding the fix, and then retesting until the problem is resolved. To adequately account for rework, the schedule should anticipate a certain number of defects based on historical experience, and time and effort should be allocated for fixing them.

We discuss scheduling more thoroughly in chapter 18, including how to account for these risks so that schedule is realistic.

Software Maintenance

Once the software has been developed, tested, and installed in its intended location, it must be maintained, just like hardware. Often called the operational phase for software, its costs must be accounted for in the LCCE. During this phase, software is maintained by fixing any defects not discovered in testing (known as corrective maintenance), modifying the software to work with any changes to its physical environment (adaptive maintenance), and adding new functionality (perfective maintenance). When adding capability, the effort is similar to a minidevelopment effort and the cost drivers are the same as in development. Software maintenance may also be driven by technology upgrades (adaptive maintenance) and users requesting enhancements (perfective maintenance). In addition to providing help desk support to users of the software, perfective maintenance often makes up the bulk of the software maintenance effort.

The level of maintenance required depends on several factors. How complex the software is will determine how much maintenance is needed. In addition, if requirements from development were deferred until the software was in maintenance mode, or the requirements were too vague and not well understood, then additional perfective maintenance will be necessary. The quality of the developed software will also affect maintenance. If the software was rigorously tested, then less corrective maintenance will be needed. In addition, software that is well documented will be easier to de-bug and will provide maintainers a better understanding of how the software was designed, making modifications more streamlined.

In addition to the need to maintain the software code, costs are associated with help desk support that need to be included in the software's operation and support phase. Effort will be spent on trouble calls and generating defect tickets for software maintenance and should be included as part of the software cost estimate.

Parametric Software Estimation

Software development cost estimating tools—or parametric tools—can be used to estimate the cost to develop and maintain software. Parametric tools are based on historical data collected from hundreds of actual projects that can generate cost, schedule, effort, and risk estimates based on inputs provided by the tool user. Among other things, these inputs generally include the size of the software, personnel capabilities, experience, development environment, amount of code reuse, programming language, and labor rates. Once the data have been input, the tool relies on cost estimating relationships and analogies to past projects to calculate the software cost and schedule estimates. When these data are not available to the cost estimator, most tools have default values that can be used instead.

Parametric tools should be used throughout the development life cycle of the software. They are especially beneficial in the early stages of the software life cycle, when requirement specifications and design are still vague. For example, these tools provide flexibility by accepting multiple sizing metrics, so that estimators can apply different sizing methods and examine the results. Additionally, parametric-based estimates can be used to understand tradeoffs by analyzing the relative effects of different development scenarios, determine risk areas that can be managed, and provide the information necessary for monitoring and control of the program.

The tools allow estimators to manipulate various inputs to gauge the overall sensitivity to parameter assumptions and then assess the overall risk, based on the certainty of those inputs. Developers who use tools in development can discover potential problems early enough to mitigate their impact.

As the project matures and actual data become available, the precision of the cost estimates produced by a parametric tool are likely to improve. For this to happen, the tool must be calibrated with actual data from completed programs so it can be adjusted to reflect the actual development environment. Since most models are built on industry averages, simply using default values in the tool may lead to skewed results. Calibration avoids this by using known inputs and outcomes to adjust the relationships in the model. Therefore, calibration is necessary for ensuring more accurate estimates.

When a parametric tool is used, it is essential to ensure that the estimators are trained and experienced in applying it and interpreting the results. Simply using a tool does not enhance the estimate's validity. Using a tool correctly by calibrating it to the specific program is necessary for developing a reliable estimate. In addition, the following issues should be well understood before unquestioningly accepting the results of a parametric tool:

- Ensure that autogenerated code is properly captured by the model, in terms of increased productivity and the effort required to design, develop, document, and produce the code.
- Output from the tool may include different cost and effort estimates or activities and phases that would have to be mapped or deleted to conform to the specific program. Not understanding what is in the output could lead to overestimating or underestimating the program.
- Some models limit the size of the development program for which they can forecast the effort. Sizes outside of the tool range may not fit the program being estimated.
- Data are often proprietary so the models are only as accurate as their underlying data allow them to be. Therefore, results from the model should be cross-checked.
- Each model has different sensitivities to certain parameters and "opinions" on desirable staff levels. Therefore, various models offer different schedule duration results. For particularly small or large software programs, a schedule predicted by commercial parametric model needs to be cross-checked.
- Where a detailed build structure or spiral development is to be modeled, the commercial model implementation and results should be closely monitored. The same is true for significant integration of commercial off-the-shelf software (COTS) or government off-the-shelf software (GOTS) with development software (or hardware).

In addition to these issues, it is important to note that many models do not address the costs associated with database development. If databases will be required as part of the software solution, and the model used to estimate the software does not account for the cost of database development, then this cost must be estimated separately. The cost for database development will depend on the size and complexity of the source data. Cost drivers for database development include the number of feeder systems, data elements, and users as well as the software to be used to develop the new database.

Commercial Off-The-Shelf Software

Using commercial off-the-shelf software has advantages and disadvantages, and auditors need to understand the risks that come with relying on it. One advantage is that development time can be faster. The software can provide more user functionality than custom software and may be flexible enough to accommodate multiple hardware and operating environments. Also, help desk support can be purchased with the commercial license, which can help reduce software maintenance costs.

Among the drawbacks to off-the-shelf software is the learning curve associated with its use, as well as integrating it into the new program's environment. In addition, most commercial software is developed for a broad spectrum of users, so it tends to address only general functions. More specific functions must be customized and added, and glue-code may be required to enable the software to interact with other applications. And, because the source code is usually not provided to customers of commercial off-the-shelf software, it can be hard to support the software in-house. When upgrades occur, the software may have to be reintegrated with existing custom code. Thus, it can be wrong to think that commercial software will necessarily be an inexpensive solution.

Estimators tend to underestimate the effort that comes before and after implementing off-the-shelf software. For example, requirements definition, design, and testing of the overall system must still be conducted. Poorly defined requirements can result in less than optimal software selection, necessitating the development of new code to satisfy all requirements. This unexpected effort will raise costs and cause program delays. In addition, adequate training and access to detailed documentation are important for effectively using the software.

Furthermore, since commercial software is subject to intense market forces, upgrades can be released with minimal testing, causing unpredictable problems, such as defects and systems incompatibilities. When this happens, additional time is needed to analyze the cause of failures and fix them. Finally, interfaces between the software and other applications may need to be rewritten every time the software is upgraded. While software developers can address all these issues, they take some time to accomplish. Therefore, adequate planning should be identified and estimated by the cost estimator to ensure that enough time and resources are available to perform them.

Enterprise Resource Planning Software

Enterprise resource planning (ERP) refers to the implementation of an administrative software system based on commercial off-the-shelf software throughout an organization. ERP's objective is to integrate information and business processes—including human resources, finance, manufacturing, and sales—to allow information entered once into the system to be shared throughout an organization. ERP systems force business process reengineering, allowing for improved operations that can lead to savings down the road. To achieve savings requires an extensive knowledge of business processes so that users will optimize automation, programming skills, and change management in the new work processes. Although an ERP system is configured commercial software and should be treated as such, we highlight this type of effort because of the unique difficulty of estimating its implementation costs and duration.

Organizations implementing ERP systems risk cost overruns and missed deadlines. According to a Gartner report, "For 40 percent of enterprises deploying ERP systems through 2009, the actual time and money spent on these implementations will exceed original estimates by at least 50 percent (0.7 probability)."[46]

At the heart of an ERP system are thousands of packages—built from database tables—that need to be configured to match end business processes. Each table has a decision switch that opens a specific decision path. By confining themselves to only one way to do a task, stove-piped units become integrated under one system. Deciding which switches in the tables to choose requires a deep understanding of the existing business operating processes. Thus, as table switches are picked, these business processes become reengineered to conform to the ERP's way of doing business. As a result, change management and buy-in from the end users are crucial to the ERP system's ultimate success.

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[46] Pat Phelan, *Estimating the Time and Cost of ERP Implementation Projects Is a 10-Step Process* (Stamford, Conn.: Gartner Inc., Apr. 10, 2006), p. 3.

Cost estimators and auditors need to be aware of the additional risks associated with ERP implementation. Table 18 describes some of these risks and best practices for avoiding them.

Table 18: Best Practices Associated with Risks in Implementing ERP

Risk	Best practice
Training	Staff are trained in the new ERP system's software and the new processes; agencies teach workers how the ERP system will affect their business processes, developing their own training programs if necessary; providing mentoring and support for the first year of implementation eases the transition to the new system; obtaining user buy-in can be accomplished by communicating and marketing the benefits and new capabilities the ERP system will offer
Integrating and testing software links	Agencies build and test links from their established software to the new ERP system or buy add-ons that are already integrated with the new system; they estimate and budget costs carefully, planning either way to test ERP integration from a process-oriented perspective
Interfacing with legacy systems	Since interfacing the ERP's system software with legacy systems can be very expensive, carefully determining early on how both systems will pass data is paramount; preparing a business case to evaluate whether to maintain the legacy system is worth the added costs
Customizing	Customizing core ERP software can be costly, especially since the ERP system's elements are linked; perhaps use commercial add-ons if the software cannot handle at least one business process
Converting and analyzing data	Cost estimators look at the agency's data conversion and analysis needs to see whether, for example, the cost of converting data to a new client server setup is accounted for, data from the ERP system and external systems have to be combined for analysis, the ERP budget should include data warehouse costs, or programming has to be customized
Following up installation	Agencies plan for follow-up activities after installation, building them into their budget, keeping the team who implemented the ERP system onboard to keep the agency informed of its progress, and providing management with knowledge of the ERP project's benefits

Source: GAO, DOD, and Derek Slater, "The Hidden Costs of Enterprise Software," *CIO Enterprise Magazine*, Jan. 15, 1998.

Other costs associated with ERP system implementations include costs for adding "bolt-ons," which are separate supplemental software packages that deliver capability not offered by the ERP system. Bolt-ons connect to the ERP system using standard application programming interfaces or extensible markup language schema, which allow for data to pass between both systems. Costs for interfacing the bolt-on with the ERP system need to be identified and estimated. In addition, the number of bolt-ons that need to be integrated, as well as the type and size of the bolt-on functionality, will drive the cost of the interface.

Experts agree that the ERP postimplementation stabilization period tends to be underestimated, because people tend to be too optimistic about how long training and the transition period will last. As a result, there is a risk for cost growth if management does not do a good job of selling the benefits of ERP. To successfully implement an ERP system, management has to be committed to freeing up resources to get the job done. This means that seasoned staff will need to be pulled away from their day jobs to focus on the effort to be fully effective. In addition, training tends to be underestimated terms of both length and timing. To better plan for this effort, management needs to create a sense of urgency for change and provide early communication and adequate training in order to ensure successful implementation.

Software Costs Must also Account for Information Technology Infrastructure and Services

Studies have shown that information technology (IT) services outside software development and maintenance (for example, hardware cost, help desk, upgrade installation, training) can make up a majority of total ownership costs. In fact, OMB reports that 77 percent of the overall IT budget for fiscal year 2009 will support steady state IT operations while only 23 percent will be used for development, modernization, and enhancement.

Even systems such as ships, aircraft, and mission control centers have major IT infrastructure and services components to them. In fact, some IT systems encounter over 90 percent of their costs in the infrastructure and services required to support and run them. Yet when we read of costs, successes, failures, and challenges in IT systems, the vast majority of the systems typically refer to the software portions only, ignoring the IT services and infrastructure components. Making matters more difficult for those estimating IT systems are the numerous definitions of IT infrastructure. One useful definition is that it consists of the equipment, systems, software, and services used in common across an organization, regardless of mission, program, or project. IT infrastructure also serves as the foundation on which mission, program, or project-specific systems and capabilities are built.

While we have already discussed software development and maintenance, we discuss in this section estimating the information technology services, hardware systems, and facilities required to support software and systems.

Unique Components of IT Estimation

Unlike software, IT estimation is in some ways simpler than software development estimation, since IT infrastructure and services are more tangible. However, IT estimation is fraught with issues such as

- What is the cost of the system engineering to define the IT system?
- How much computing power is needed to support a system?
- How many help desk personnel are needed to support X users?
- How can costs be contained while still achieving innovation?
- How can the value of the IT investment be quantified against its costs?
- How do buy and lease decisions affect expenses and profitability?
- How can we make tradeoffs between technology and costs?
- What kind of application initiatives are needed to support the business?
- How many vendors and how much vendor interface is required to run the IT operation?
- How many sites does the IT infrastructure support?
- How many and how clearly defined or stable are the requirements for the IT to align itself with the business goals?

Simply getting a quote from a vendor for an IT system is rarely sufficient for IT cost estimation. While quotes often do not include many important cost elements, the cost estimator will still need to consider these elements. They include

- help desk support services supplied internally for applications and equipment;
- facilities costs;
- costs of on-going installation, maintenance, repair, and trouble shooting;
- employee training, both formal training and self-training.

To further complicate the effort, many vendors offer IT infrastructure either as a "software as a service" platform or as just "cloud computing."[47] Vendor-operated IT infrastructure hardware can be viable if issues such as loss of control, security, and potential resource sharing are acceptable. However, such vendor-operated infrastructure does not usually eliminate the costs of ongoing IT services to provide users help desk support, local computing, setup training, and other infrastructure services. The cost estimator must be aware that these costs should be considered, whether the infrastructure is to be owned by the government, leased, or owned and operated by vendors under contract with the government.

Major Cost Drivers Associated with IT Estimation

Many factors that affect IT costs need to be considered when developing an IT cost estimate. Various examples of cost drivers, organized by physical attributes of the IT infrastructure, are listed next, along with performance and complexity requirements and economic considerations.

1. Physical attributes that drive IT costs:
   - Application software, system software, and database storage size;
   - End user hardware list (e.g., laptops, CPU, printers);
   - Facility requirements (power, cooling);
   - Infrastructure hardware list (UNIX Servers, Windows servers, WAN/LAN equipment);
   - Number of application software, system software, and database items;
   - Number of application software, system software, and database users (concurrent, causal);
   - Number of inbound and outbound application software and database interfaces;
   - Number of unique platforms supported;
   - Operating locations;
   - Physical and organizational entities.
2. Performance and complexity attributes:
   - Business requirements;
   - Complexity of infrastructure environment (e.g., disparate platforms, loose vs. tight coupling);

[47] Cloud computing refers to information that resides in servers on the Internet and is downloaded temporarily onto various hardware devices such as desktop and notebook computers, entertainment centers, and handheld telephones.

- User type (professional, concurrent, casual);
- Criticality and reliability of systems;
- Expected service level (system administration, database administration, help desk Tier I, Help Desk Tier II, Help Desk Tier III);
- Experience with systems;
- Infrastructure hardware complexity (small, medium, large);
- IT project type (ERP, SOA, Web application, data mart);
- Number of transactions per second;
- Number of vendors;
- Process experience and rigor;
- Security requirements;
- System complexity (hardware or software);
- Usage patterns (transaction rates).

3. Economic factors and considerations:
   - Acquisition strategy;
   - Hardware leasing and purchasing agreements;
   - Labor rates;
   - Sourcing strategy;
   - Replacement and upgrade policies;
   - Software leasing and purchasing agreements (enterprise, user based);
   - Test plan;
   - Training strategy;
   - Years of operating.

Common Risks for IT Infrastructure

Many of the risks that affect software cost estimating apply to IT infrastructure. For example, in estimating the costs of any effort, a consideration should be made whether the risks of the investment justify the inclusion of an independent verification and validation contractor. In situations where the risks are very high, such as potential loss of life, the overall schedule may need to be extended to accommodate the additional reviews and testing required. For IT infrastructure, the set of risks in table 19 should be considered.

Table 19: Common IT Infrastructure Risks

Risks	Technical, management, and logistic requirements that increase costs
Financial	Cost overruns
	Funding cuts and delays
Logistics and equipment	Contingency equipment availability
	Physical storage of equipment on arrival and security
	Supply availability
Schedule	Unscheduled changes and delays
	Nonconformance, not starting, and failures
	Reliance on external subcontractors and organizations
Personnel	Changes of personnel among customer or vendor
	Lack of skills or knowledge
	Not aware of policy or procedures or inadequate personnel to support help desk and deployment
	Time lost for end user training, trouble shooting, and down time
Project management	No quality control or management process built into plan
	Absence of issue, change request, or configuration management logs
	Inconsistent project documentation or lack of IT process model
	Information security
	Lack of detailed site information
	Lack of issue identification or trends
	Lack of reporting
	Poor planning
	Requirements not well defined
	Role confusion
	Unaware of customer site requirements
Technical	Adequate capacity
	Additional hardware or software requirements to fully support system
	Compatibility or whether data in the relevant process flow from end to end
	Disasters
	Hardware or software failure
	Incorrect images or version loaded
	Integration with existing systems
	New design not working
	Unplanned or unapproved changes
	Version control problems
User	Confusion about customer and vendor responsibilities
	Inability to perform core or noncore business activities
	Loss of data
	Not aware of vendor schedule or activities
	User expectations

Source: GAO.

Estimating Labor and Material Costs Associated with IT Infrastructure

Labor and material nonrecurring and recurring efforts are associated with IT infrastructure. For estimating the nonrecurring effort, staff loading of the IT infrastructure is similar to software development during early architecture and design. Once the design is complete, the recurring effort associated with actual implementation and deployment can be accomplished, based on a distribution of organizational demand for IT.

IT recurring operations costs include costs similar to the maintenance of general fixed facilities. For example, facilities costs such as power, security, and general facilities support apply to IT infrastructure recurring operations. Furthermore, costs for purchased software licenses, training, technical refreshment, and various service level agreements also need to be considered. Finally, since the cost of hardware changes daily as does the requirement for computing power in items like servers, designing with a 50 percent reserve in capacity is prudent since systems tend to grow. Many labor services categories need to be considered when developing an IT infrastructure labor cost estimate. Table 20 describes typical labor categories.[48]

Table 20: Common Labor Categories Described

Category	Description	Common titles
Project stakeholder	A person invested in the project's success while not participating in its execution or implementation; includes end users, managers, and external clients whose success is somehow tied to the project's success. Stakeholders work with the product management team to ensure that the solution developed meets the project's original needs. Stakeholder participation and availability are vital to the success of any project	
Management	Performs project planning, staffing, and tracking; is involved with daily operational activities, ensuring that resources are used effectively and services are delivered	Configuration manager, database manager, IT manager, project manager
Analyst	Generally involved in planning and defining needs and requirements for IT projects and related support systems and in ongoing systems support, often bridging the user or customer and the technical team. Generally has domain or specialty knowledge of a certain type of system, technology, or discipline used to apply technology to address business and user requirements	Business process, requirements, or system analyst; network or telecommunications analyst; support analyst; operations analyst; database analyst; UI analyst; security analyst
Architect	Develops high-level system design plans to meet the organization's needs and comply with its policies; can help formulate policies and plans that support the organization, particularly as they pertain to technologies used to carry out policies and procedures	Systems architect or engineer; IT or data architect; network architect; storage architect

[48] Appendix IX contains a sample IT infrastructure and IT services WBS; it is a supplement to the automated information system configuration, customization, development, and maintenance WBS discussed in chapter 8.

Category	Description	Common titles
Technician	Involved primarily in the physical setup, support, and maintenance of systems according to well defined plans and procedures, including system setup, installation, upgrades, and troubleshooting	Desktop or PC technician; network engineer or technician; hardware technician; telecommunications technician
Test/QA	Primarily verifies the integrity and performance of systems being deployed and operated; develops test plans and procedures, collecting and tracking defect data and problem reports and serves an auditing function to ensure compliance with policies and procedures	IT auditor, QA analyst, application tester, call center agent
Documentation	Prepares or maintains documentation pertaining to programming, systems operation, and user documentation, including user manuals and online help screens	Technical or report writer; online help publisher; content developer; documentation specialist
Training	Prepares and updates courseware and training materials and conducts training classes or events	Instructor, training developer, instructional designer, end user
Administrator	Generally involved with the ongoing administration, maintenance, and support of specific systems to ensure they operate properly and effectively; associated with a specific system or type of system such as a platform, database, network, or enterprise application	Network, system, or enterprise application administrator; system administrator; Web or telecommunications administrator; database administrator; security administrator; storage administrator; help desk specialist (tier I, tier II, tier III)
Computer operator	Computer operators not included in support of IT infrastructure and IT services	
Indirect support	Secretarial, reception, and other labor in support of IT services and infrastructure personnel and systems	
Contract labor	Vendors that provide services under contract to support IT infrastructure	

Source: GAO.

9. Best Practices Checklist: Estimating Software Costs

- ☐ The software cost estimate followed the 12-step estimating process:
  - ✓ Software was sized with detailed knowledge of program scope, complexity, and interactions, and the cost estimators worked with software engineers to determine the appropriate sizing metric.
  - ✓ It was sized with source lines of code, function, object, feature point, or other counts.
- ☐ The software sizing method was appropriate:
  - ✓ Source lines of code were used if requirements were well defined and if there was a historical database of code counts for similar programs and a standard definition for a line of code.
  - ✓ Function points were used if detailed requirements and specifications were available, software did not contain many algorithmic functions, and an experienced and certified function point counter was available.
  - ✓ COSMIC points were used if functional user requirements are known and the application is for business, real-time, embedded, or infrastructure software.
  - ✓ Object points were used if computer-aided software engineering tools were used to develop the software.
  - ✓ Reports, interfaces, conversions, extensions and forms / workflow were used for ERP programs.
  - ✓ Use cases and use case points were used if system and user interactions were defined.
  - ✓ Autogenerated and reused source lines of code were identified separately from new and modified code to account for pre- and postimplementation efforts.
  - ✓ Several methods were used to size the software to increase the accuracy of the sizing estimate.
  - ✓ The final software size was adjusted for growth based on historical data, and growth is continually monitored over time.
- ☐ Software cost estimates included
  - ✓ Development labor costs for coding and testing, other labor supporting software development, and nonlabor costs like purchasing hardware and licenses.
  - ✓ Productivity factors for converting software size into labor effort, based on historical data and calibrated to match program size and development environment.
  - ✓ If no historical data were available, industry average productivity factors and risk ranges were used.
  - ✓ Assumptions about productive labor hours in a day and work days in a year.
  - ✓ Development schedules accounting for staff availability, prior task dependencies, concurrent and critical path activities, number and length of shifts, overtime allowance, down time, and worker locations.

- ✓ Costs for help desk support, database development, and corrective, adaptive, and preventive maintenance as part of the software's life cycle cost.
- ✓ Time and effort associated with rework to fix defects.
- ✓ Cost estimators were trained to calibrate parametric tools to match the program and model results were cross-checked for accuracy.
- ✓ Estimators accounted for integrating commercial off-the-shelf software into the system, including developing custom software and glue-code.
- ✓ Impact of risks facing ERP system implementations as outlined in table 18.
- ✓ Costs associated with interfacing bolt-on applications for ERP systems.

☐ IT infrastructure and services components of the software cost estimate included

- ✓ Costs associated with the physical attributes of the IT infrastructure, the performance and complexity requirements, and economic considerations.
- ✓ Impact of risks affecting IT infrastructure, as outlined in table 19.
- ✓ Costs associated with labor and material nonrecurring and recurring efforts.

CHAPTER 13

Sensitivity Analysis

As a best practice, sensitivity analysis should be included in all cost estimates because it examines the effects of changing assumptions and ground rules. Since uncertainty cannot be avoided, it is necessary to identify what cost elements represent the most risk and, if possible, cost estimators should quantify the risk. This can be done through both a sensitivity analysis and an uncertainty analysis (discussed in the next chapter).

Sensitivity analysis helps decision makers choose the alternative. For example, it could allow a program manager to determine how sensitive a program is to changes in gasoline prices and at what gasoline price a program alternative is no longer attractive. By using information from a sensitivity analysis, a program manager can take certain risk mitigation steps, such as assigning someone to monitor gasoline price changes, deploying more vehicles with smaller payloads, or decreasing the number of patrols.

For a sensitivity analysis to be useful in making informed decisions, however, carefully assessing the underlying risks and supporting data is necessary. In addition, the sources of the variation should be well documented and traceable. Simply varying the cost drivers by applying a subjective plus or minus percentage is not useful and does not constitute a valid sensitivity analysis. This is the case when the subjective percentage does not have a valid basis or is not based on historical data.

In order for sensitivity analysis to reveal how the cost estimate is affected by a change in a single assumption, the cost estimator must examine the effect of changing one assumption or cost driver at a time while holding all other variables constant. By doing so, it is easier to understand which variable most affects the cost estimate. In some cases, a sensitivity analysis can be conducted to examine the effect of multiple assumptions changing in relation to a specific scenario.

Regardless of whether the analysis is performed on only one cost driver or several within a single scenario, the difference between sensitivity analysis and risk or uncertainty analysis is that sensitivity analysis tries to isolate the effects of changing one variable at a time, while risk or uncertainty analysis examines the effects of many variables changing all at once.

Typically performed on high-cost elements, sensitivity analysis examines how the cost estimate is affected by a change in a cost driver's value. For example, it might evaluate how the number of maintenance staff varies with different assumptions about system reliability values or how system manufacturing labor and material costs vary in response to additional system weight growth.

Sensitivity analysis involves recalculating the cost estimate with different quantitative values for selected input values, or parameters, in order to compare the results with the original estimate. If a small change in the value of a cost element's parameter or assumption yields a large change in the overall cost estimate, the results are considered sensitive to that parameter or assumption. Therefore, a sensitivity analysis can provide helpful information for the system designer because it highlights elements that are cost sensitive. In this way, sensitivity analysis can be useful for identifying areas where more design research could result in less production cost or where increased performance could be implemented without substantially increasing cost. This type of analysis is typically called a what-if analysis and is often used for optimizing cost estimate parameters.

Sensitivity Factors

Uncertainty about the values of some, if not most, of the technical parameters is common early in a program's design and development. Many assumptions made at the start of a program turn out to be inaccurate. Therefore, once the point estimate has been developed, it is important to determine how sensitive the total cost estimate is to changes in the cost drivers.

Some factors that are often varied in a sensitivity analysis are

- a shorter or longer economic life;
- the volume, mix, or pattern of workload;
- potential requirements changes;
- configuration changes in hardware, software, or facilities;
- alternative assumptions about program operations, fielding strategy, inflation rate, technology heritage savings, and development time;
- higher or lower learning curves;
- changes in performance characteristics;
- testing requirements;
- acquisition strategy, whether multiyear procurement, dual sourcing, or the like;
- labor rates;
- growth in software size or amount of software reuse; and
- down-scoping the program.

These are just some examples of potential cost drivers. Many factors that should be tested are determined by the assumptions and performance characteristics outlined in the technical baseline description and GR&As. Therefore, auditors should look for a link between the technical baseline parameters and the GR&As to see if the cost estimator examined those that had the greatest effect on the overall sensitivity of the cost estimate.

In addition, the cost estimator should always include in a sensitivity analysis the assumptions that are most likely to change, such as an assumption that was made for lack of knowledge or one that is outside the control of the program office. Case study 38 shows some assumptions that can affect the cost of building a ship.

Case Study 38: Sensitivity Analysis, from *Defense Acquisitions*, GAO-05-183

Given the uncertainties inherent in ship acquisitions, such as introducing new technologies and volatile overhead rates over time, cost analysts face a significant challenge in developing credible initial cost estimates. The Navy must develop cost estimates as long as 10 years before ship construction begins, before many program details are known. Cost analysts therefore have to make a number of assumptions about ship parameters like weight, performance, and software and about market conditions, such as inflation rates, workforce attrition, and supplier base.

In the 8 case study ships we examined, other unknowns led to uncertain estimates. Labor hour and material costs were based on data from previous ships and on unproven efficiencies in ship construction. GAO found that analysts often factored in savings based on expected efficiencies that never materialized. For example, they anticipated savings from implementing computer-assisted design and computer-assisted manufacturing for the San Antonio class transport LPD 17, but the contractor had not made the requisite research investments to achieve the proposed savings. Similar unproven or unsupported efficiencies were estimated for the Arleigh Burke class destroyer DDG 92 and Nimitz class aircraft carrier CVN 76. Changes in the shipbuilders' supplier base also created uncertainties in their overhead costs.

Despite these uncertainties, the Navy did not test the validity of the cost analysts' assumptions in estimating construction costs for the eight case study ships and did not identify a confidence level for estimates.

GAO, *Defense Acquisitions: Improved Management Practices Could Help Minimize Cost Growth in Navy Shipbuilding Programs*, GAO-05-183 (Washington, D.C.: Feb. 28, 2005).

Steps in Performing a Sensitivity Analysis

A sensitivity analysis addresses some of the estimating uncertainty by testing discrete cases of assumptions and other factors that could change. By examining each assumption or factor independently, while holding all others constant, the cost estimator can evaluate the results to discover which assumptions or factors most influence the estimate. A sensitivity analysis also requires estimating the high and low uncertainty ranges for significant cost driver input factors. To determine what the key cost drivers are, a cost estimator needs to determine the percentage of total cost that each cost element represents. The major contributing variables within the highest percentage cost elements are the key cost drivers that should be varied in a sensitivity analysis. A credible sensitivity analysis typically has five steps:

1. identify key cost drivers, ground rules, and assumptions for sensitivity testing;
2. reestimate the total cost by choosing one of these cost drivers to vary between two set amounts—for example, maximum and minimum or performance thresholds;[49]
3. document the results;
4. repeat 2 and 3 until all factors identified in step 1 have been tested independently;
5. evaluate the results to determine which drivers affect the cost estimate most.

[49] The ranges should be documented during data collection and cost estimating (steps 6 and 7).

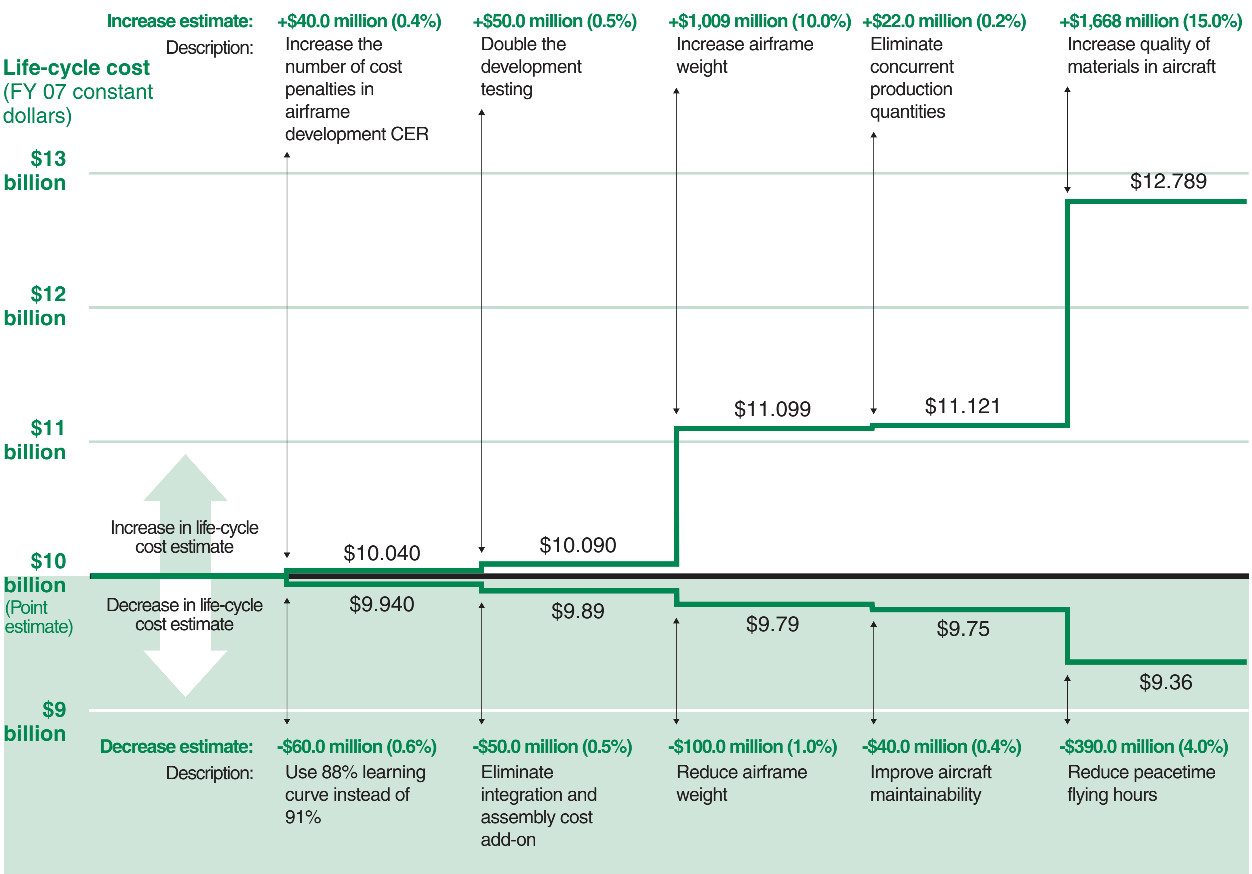
Sensitivity analysis also provides important information for economic analyses that can end in the choice of a different alternative from the original recommendation. This can happen because, like a cost estimate, an economic analysis is based on assumptions and constraints that may change. Thus, before choosing an alternative, it is essential to test how sensitive the ranking of alternatives is to changes in assumptions. In an economic analysis, sensitivity is determined by how much an assumption must change to result in an alternative that differs from the one recommended. For example, an assumption is considered sensitive if a 10–50 percent change yields a different alternative, very sensitive if the change is less than 10 percent.

Assumptions and cost drivers that have the most effect on the cost estimate warrant further study to ensure that the best possible value is used for that parameter. If the cost estimate is found to be sensitive to several parameters, all the GR&As should be reviewed, to assure decision makers that sensitive parameters have been carefully investigated and the best possible values have been used in the final point estimate.

Sensitivity Analysis Benefits

A sensitivity analysis provides a range of costs that span a best and worst case spread. In general, it is better for decision makers to know the range of potential costs that surround a point estimate and the reasons behind what drives that range than to just have a point estimate to make a decision from. Sensitivity analysis can provide a clear picture of both the high and low costs that can be expected, with discrete reasons for what drives them. Figure 14 shows how sensitivity can provide insight to decision makers.

Figure 14: A Sensitivity Analysis That Creates a Range around a Point Estimate



Source: GAO.

In figure 14, it is very apparent how certain assumptions affect the estimate. For example, increasing the quality of materials in the aircraft has the biggest effect on the highest cost estimate—adding $1,668 million to the point estimate—while reducing the number of flying hours is the biggest driver for reducing the cost estimate—reducing the flying hours saves $390 million. Using visuals like this can quickly display what-if analyses that can help management make informed decisions.

A sensitivity analysis also reveals critical assumptions and program cost drivers that most affect the results and can sometimes yield surprises. Therefore, the value of sensitivity analysis to decision makers lies in the additional information and understanding it brings to the final decision. Sensitivity analysis can also make for a more traceable estimate by providing ranges around the point estimate, accompanied by specific reasons for why the estimate could vary. This insight allows the cost estimator and program manager to further examine potential sources of risk and develop ways to mitigate them early. Sensitivity analysis permits decisions that influence the design, production, and operation of a system to focus on the elements that have the greatest effect on cost.

The Limitations of Sensitivity Analysis

Sensitivity analysis examines only the effect of changing one assumption or factor at a time. But the risk of several assumptions or factors varying simultaneously, and its effect on the overall point estimate, should be understood.[50] In the next chapter, we discuss risks and uncertainty analyses.

10. Best Practices Checklist: Sensitivity Analysis

- ☐ The cost estimate was accompanied by a sensitivity analysis that identified the effects of changing key cost driver assumption and factors.
  - ✓ Well-documented sources supported the assumption or factor ranges.
  - ✓ The sensitivity analysis was part of a quantitative risk assessment and not based on arbitrary plus or minus percentages.
  - ✓ Cost-sensitive assumptions and factors were further examined to see whether design changes should be implemented to mitigate risk.
  - ✓ Sensitivity analysis was used to create a range of best and worst case costs.
  - ✓ Assumptions and performance characteristics listed in the technical baseline description and GR&As were tested for sensitivity, especially those least understood or at risk of changing.
  - ✓ Results were well documented and presented to management for decisions.
- ☐ The following steps were taken during the sensitivity analysis:
  - ✓ Key cost drivers were identified.
  - ✓ Cost elements representing the highest percentage of cost were determined and their parameters and assumptions were examined.
  - ✓ The total cost was reestimated by varying each parameter between its minimum and maximum range.
  - ✓ Results were documented and the reestimate was repeated for each parameter that was a key cost driver.
  - ✓ Outcomes were evaluated for parameters most sensitive to change.
- ☐ The sensitivity analysis provided a range of possible costs, a point estimate, and a method for performing what-if analysis.

[50] DOD has a tool that is intended to do cost sensitivity analyses, in addition to other tools, that can be downloaded for free at www.hq.usace.army.mil/cemp/e/ec/econ/econ.htm.

CHAPTER 14

Cost Risk and Uncertainty

In chapter 13, we discussed sensitivity analysis and how it is useful for performing what-if analysis, determining how sensitive the point estimate is to changes in the cost drivers, and developing ranges of potential costs. A drawback of sensitivity analysis is that it looks only at the effects of changing one parameter at a time. In reality, many parameters can change at the same time. Therefore, in addition to a sensitivity analysis, an uncertainty analysis should be performed to capture the cumulative effect of additional risks.

Because cost estimates predict future program costs, uncertainty is always associated with them. For example, data from the past may not always be relevant in the future, because new manufacturing processes may change a learning curve slope or new composite materials may change the relationship between weight and cost. Moreover, a cost estimate is usually composed of many lower-level WBS elements, each of which comes with its own source of error. Once these elements are added together, the resulting cost estimate can contain a great deal of uncertainty.

The Difference Between Risk and Uncertainty

Risk and uncertainty refer to the fact that because a cost estimate is a forecast, there is always a chance that the actual cost will differ from the estimate. Moreover, lack of knowledge about the future is only one possible reason for the difference. Another equally important reason is the error resulting from historical data inconsistencies, assumptions, cost estimating equations, and factors typically used to develop an estimate.

In addition, biases are often found in estimating program costs and developing program schedules. The biases may be cognitive—often based on estimators' inexperience—or motivational, where management intentionally reduces the estimate or shortens the schedule to make the project look good to stakeholders. Recognizing the potential for error and deciding how best to quantify it is the purpose of risk and uncertainty analysis.[51]

It is inaccurate to add up the most likely WBS elements to derive a program cost estimate, since their sum is not usually the most likely estimate for the total program, even if they are estimated without bias.[52] Yet summing costs estimated at the detailed level to derive a point estimate is the most common approach to

[51] Many good references outline the cost risk and uncertainty modeling process. The Air Force Cost Analysis Agency's recent *Cost Risk and Analysis Handbook* is one example (see Alfred Smith and others, *Air Force Cost Analysis Agency (AFCAA) Cost Risk Analysis Handbook (CRH)*, prepared for Stephen Tracy, Air Force Cost Analysis Agency (Goleta, Calif.: Tecolote Research, Inc., October 2006).

[52] See Stephen A. Book, "Do Not Sum 'Most Likely' Costs," presentation to American Society of Military Comptrollers, Los Angeles, Calif., April 30, 2002.

estimating a total program. Simulation of program risks is a better way to estimate total program cost, as we discuss below.

Quantifying risk and uncertainty is a cost estimating best practice addressed in many guides and references. DOD specifically directs that uncertainty be identified and quantified. The Clinger-Cohen Act requires agencies to assess and manage the risks of major information systems, including the application of the risk-adjusted return on investment criterion in deciding whether to undertake particular investments.[53]

While risk and uncertainty are often used interchangeably, in statistics their definitions are distinct:

> Risk is the chance of loss or injury. In a situation that includes favorable and unfavorable events, risk is the probability that an unfavorable event will occur.
>
> Uncertainty is the indefiniteness about the outcome of a situation. It is assessed in cost estimate models to estimate the risk (or probability) that a specific funding level will be exceeded.[54]

Therefore, while both risk and uncertainty can affect a program's cost estimate, enough data will never be available in most situations to develop a known frequency distribution. Cost estimating is analyzed more often for uncertainty than risk, although many textbooks use both terms to describe the effort.

Point Estimates Alone Are Insufficient for Good Decisions

Since cost estimates are uncertain, making good predictions about how much funding a program needs to be successful is difficult. In a program's early phases, knowledge about how well technology will perform, whether the estimates are unbiased, and how external events may affect the program is imperfect. For management to make good decisions, the program estimate must reflect the degree of uncertainty, so that a level of confidence can be given about the estimate.

Quantitative risk and uncertainty analysis provide a way to assess the variability in the point estimate. Using this type of analysis, a cost estimator can model such effects as schedules slipping, missions changing, and proposed solutions not meeting user needs, allowing for a known range of potential costs. Having a range of costs around a point estimate is more useful to decision makers, because it conveys the level of confidence in achieving the most likely cost and also informs them on cost, schedule, and technical risks.

Point estimates are more uncertain at the beginning of a program, because less is known about its detailed requirements and opportunity for change is greater. In addition, early in a program's life cycle, only general statements can be made. As a program matures, general statements translate into clearer and more refined requirements that reduce the unknowns. However, more refined requirements often translate into additional costs, causing the distribution of potential costs to move further to the right, as illustrated in figure 15.

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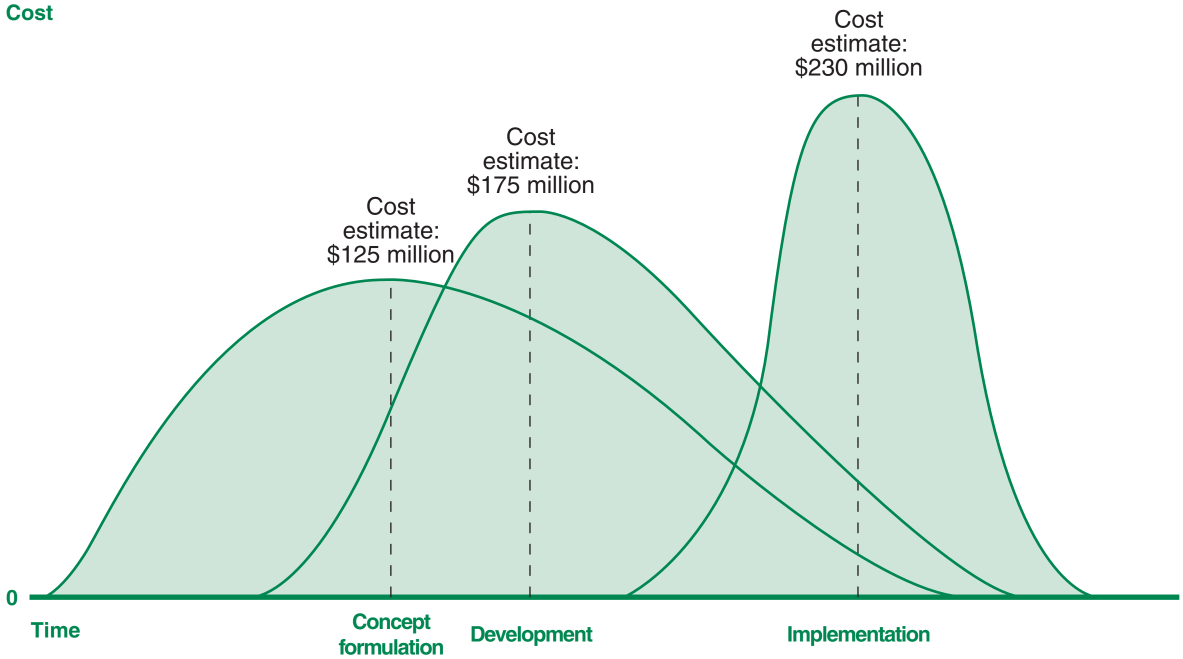
[53] 40 U.S.C. § 11312 (Supp. IV 2004).

[54] © 2000 From Probability Methods for Cost Uncertainty Analysis by Paul Garvey. Reproduced by permission of Taylor and Francis Group, LLC, a division of Informa PLC.

Figure 15: Changes in Cost Uncertainty across the Acquisition Life Cycle



Source: GAO.

While the point estimate increases in figure 15, the uncertainty range around it decreases. More is learned as the project matures. First, a better understanding of the risks is achieved, and some risk is either retired or some form of risk handling lessens the potential cost or effect on schedule. Second, the program is understood better and, most probably, more requirements are added or overlooked as elements are added, which has a tendency to increase costs along with reducing the variance. Thus, a point estimate, by itself, provides no information about the underlying uncertainty other than that it is the value chosen as most likely.

A confidence interval, in contrast, provides a range of possible costs, based on a specified probability level. For example, a program with a point estimate of $10 million could range in cost from $5 million to $15 million at the 95 percent confidence level. In addition, the probability distribution, usually in the form of a cumulative distribution or S curve (described below) can provide the decision maker with an estimate of the probability that the program's cost will actually be at some value or lower. Conversely, 1.0 minus this probability is the probability that the project will overrun that value.

Using an uncertainty analysis, a cost estimator can easily inform decision makers about a program's potential range of costs. Management, in turn, can use these data to decide whether the program fits within the overall risk range of the agency's portfolio.

Budgeting to a Realistic Point Estimate

Over the years, GAO has reported that many programs overrun their budgets because original point estimates are unrealistic. Case studies 39 and 40 are examples.

Case Study 39: Point Estimates, from *Space Acquisitions*, GAO-07-96

Estimated costs for DOD's major space acquisitions increased about $12.2 billion, or nearly 44 percent, above initial estimates for fiscal year 2006 through fiscal year 2011. GAO identified a variety of reasons for this. The most notable are that weapons programs have incentives to produce and use optimistic cost and schedule estimates to compete successfully for funding and that DOD starts its space programs before it has assurance that the capabilities it is pursuing can be achieved within its resource and time constraints.

At the same time, the cost growth resulted partly from DOD's using low cost estimates to establish program budgets, finding it necessary later to make funding shifts with costly, reverberating effects. In 2003, a DOD study found that the space acquisitions system was strongly biased to produce unrealistically low cost estimates throughout the process. The study found that most programs at contract initiation had a predictable cost growth of 50 percent to 100 percent. It found that the unrealistically low projections of program cost and the lack of provisions for management reserve seriously distorted management decisions and program content, increased risks to mission success, and virtually guaranteed program delays. GAO found most of these conditions in many DOD programs.

GAO, *Space Acquisitions: DOD Needs to Take More Action to Address Unrealistic Initial Cost Estimates of Space Systems*, GAO-07-96 (Washington, D.C.: Nov. 17, 2006).

Case Study 40: Point Estimates, from *Defense Acquisitions*, GAO-05-183

For several case study ships, the costs of materials increased dramatically above the shipbuilder's initial plan. Materials cost was the most significant component of cost growth for the CVN 76 in the Nimitz class of aircraft carriers, the LPD 17 in the San Antonio class of transports, and the SSN 775 in the Virginia class of submarines. The growth in materials costs resulted, in part, from Navy and shipbuilders underbudgeting for these costs.

For example, the materials budget for the first four Virginia class submarines was $132 million less than quotes received from vendors and subcontractors. The shipbuilder agreed to take on the challenge of achieving lower costs in exchange for providing in the contract that the shipbuilder would be reimbursed for cost growth in high-value, specialized materials.

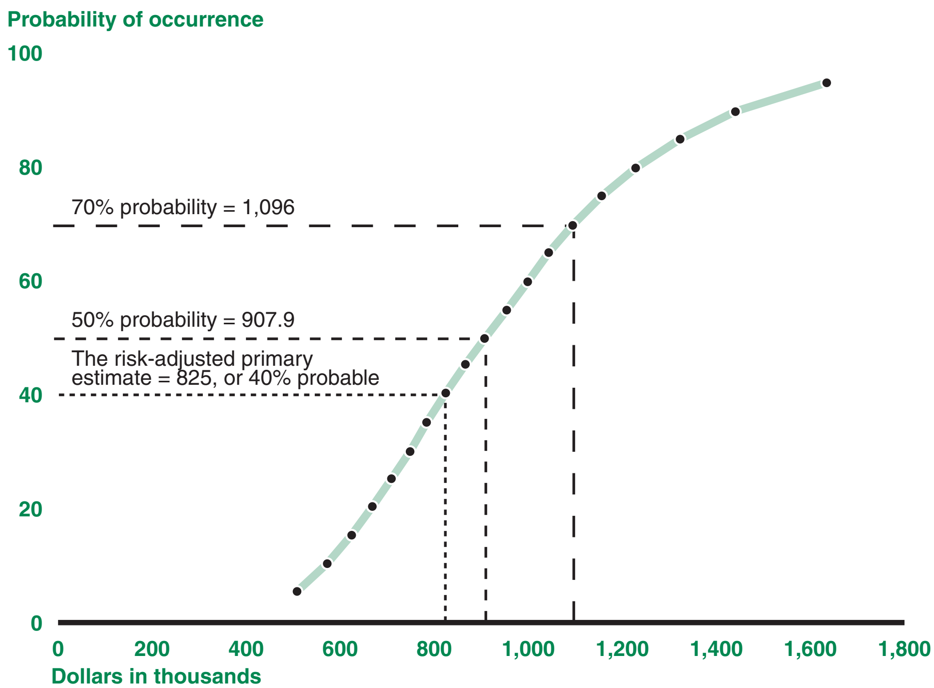
In addition, the materials budget for the CVN 76 and CVN 77 was based on an incomplete list of materials needed to construct the ships, leading to especially sharp increases in estimated materials costs. In this case, the Defense Contract Audit Agency criticized the shipbuilder's estimating system, particularly the system for materials and subcontract costs, stating that the resulting estimates "do not provide an acceptable basis for negotiation of a fair and reasonable price." Underbudgeting of materials contributed to cost growth, recognized in the fiscal year 2006 budget.

GAO, *Defense Acquisitions: Improved Management Practices Could Help Minimize Cost Growth in Navy Shipbuilding Programs*, GAO-05-183 (Washington, D.C.: Feb. 28, 2005).

We have found that budgeting programs to a risk-adjusted estimate that reflects a program's risks is critical to its successfully achieving its objectives. However, programs have developed optimistic estimates for many reasons. Cost estimators may have ignored program risk, underestimated data outliers, relied on historical data that may be misleading for a new technology, or assumed better productivity than the historical data supported, causing narrow uncertainty ranges. Decision makers may add their own bias for political or budgetary reasons. For example, they may make optimistic assumptions by assuming that a new program will perform much better than its predecessor in order to justify a preconceived notion, to fit the program within unrealistic budgetary parameters, or just to sell the program.

One way to determine whether a program is realistically budgeted is to perform an uncertainty analysis, so that the probability associated with achieving its point estimate can be determined. A cumulative probability distribution, more commonly known as an S curve—usually derived from a simulation such as Monte Carlo—can be particularly useful in portraying the uncertainty implications of various cost estimates. Figure 16 shows an example of a cumulative probability distribution with various cost estimates mapped to a certain probability level.

Figure 16: A Cumulative Probability Distribution, or S Curve



Source: GAO and NASA.

In figure 16, one can readily see that given what is known about program risks and uncertainties, the least this hypothetical program could cost is about $500,000, at about 5 percent probability; the most, $1,700,000 or less, at about 95 percent probability. Using an S curve, decision makers can easily understand what the likelihood of different funding alternatives will imply.[55]

For example, according to the S curve in figure 16, the point estimate has up to a 40 percent chance of being met, meaning there is a 60 percent chance that costs will be greater than $825,000. On the basis

[55] The simulation quantifies the imperfectly understood risks in the program after any agreed-on mitigation has been incorporated. Unknown unknowns, risks that are not known when the analysis is done, may require periodic risk analysis leading to improvement of the estimate of uncertainty.

of this information, management could decide to add $82,900 to the point estimate to increase the probability to 50 percent or $271,000 to increase the confidence level to 70 percent. The important thing to note, however, is the large cost increase between the 70 percent and 95 percent confidence levels—about $600,000—indicating that a substantial investment would be necessary to reach a higher level of certainty.

Management can use the data in an S curve to choose a defensible level of contingency reserves. While no specific confidence level is considered a best practice, experts agree that program cost estimates should be budgeted to at least the 50 percent confidence level, but budgeting to a higher level (for example, 70 percent to 80 percent, or the mean) is now common practice. Moreover, they stress that contingency reserves are necessary to cover increased costs resulting from unexpected design complexity, incomplete requirements, technology uncertainty, and industrial base concerns, to name a few uncertainties that can affect programs.

How much contingency reserve should be allocated to a program beyond the 50 percent confidence level depends on the program cost growth an agency is willing to risk. Some organizations adopt other levels like the 70th or 80th percentile (refer to the S curve above) to

1. reduce their anxiety about success within budget,
2. make some provision for risks unknown at the time but likely to appear as the project progresses, and
3. reduce the probability that they will have to explain overruns or rebaseline because they ran out of reserve budget.

The amount of contingency reserve should be based on the level of confidence with which management chooses to fund a program, based on the probabilities reported in the S curve. In figure 16, management might choose to award a contract for $907,900 but fund the program at $1,096,000. This alternative would provide an additional $188,000 in contingency reserve at the 70 percent confidence level. The result would be only a 30 percent chance that the program would need additional funding, given the identification and quantification of the risks at the time of the analysis.

Another benefit of using an S curve is that management can proactively monitor a program's costs, because it knows the probability for incurring overruns. By understanding which input variables have a significant effect on a program's final costs, management can devote resources to acquire better knowledge about them so that risks can be minimized. Finally, knowing early what the potential risks are enables management to prepare contingencies to monitor and mitigate them using an EVM system once the program is under contract.

The bottom line is that management needs a risk-adjusted point estimate based on an estimate of the range of confidence to make wise decisions. Using information from an S curve with a realistic probability distribution, management can quantify the level of confidence in achieving a program within a certain funding level. It can also determine a defensible amount of contingency reserve to quickly mitigate risk.

Developing A Credible S Curve of Potential Program Costs

Since an S curve is vital to knowing how much confidence management can have in a given point estimate, it is important to know the activities in developing one. Seven steps are associated with developing a justifiable S curve:

1. determine the program cost drivers and associated risks;
2. develop probability distributions to model various types of uncertainty (for example, program, technical, external, organizational, program management including cost estimating and scheduling);
3. account for correlation between cost elements to properly capture risk;
4. perform the uncertainty analysis using a Monte Carlo simulation model;
5. identify the probability level associated with the point estimate;
6. recommend sufficient contingency reserves to achieve levels of confidence acceptable to the organization; and
7. allocate, phase, and convert a risk-adjusted cost estimate to then-year dollars and identify high-risk elements to help in risk mitigation efforts.

To take these steps, the cost estimator must work with the program office and technical experts to collect the proper information. Short-changing or merely guessing at the first two steps does not lead to a credible S curve and can give management a false sense of confidence in the information.

Step 1: Determine Program Cost Drivers and Associated Risks

In chapter 13, we noted that one of the benefits of a sensitivity analysis is a list of the program cost drivers. Since numerous risks can influence the estimate, they should be examined for their sources of uncertainty and potential effect, and they should be modeled to determine how they can affect the uncertainty of the cost estimate. For example, undefined or unknown technical information, uncertain economic conditions, unexpected schedule problems, requirements growth, security level changes, and political issues are often encountered during a program's acquisition. Each of these risks can negatively or positively affect a program's cost. This means that uncertainty can cause the actual cost or schedule to differ from any current plan in either a positive or beneficial direction or in a negative or harmful direction. In addition, new technologies may be proposed that can fail outright, causing rework and unexpected cost growth.

Risks are also associated with the estimating process itself. For instance, historical data from which to make a credible estimate can be lacking. When this happens, a cost estimator has no choice but to extrapolate with existing methods or develop a new estimating approach. No matter the method, some error will be introduced into the estimate.

Accounting for all possible risks is necessary to adequately capture the uncertainty associated with a program's point estimate. Far from exhaustive, table 21 describes some of the many sources of risk. It is only a starting point, since each program is unique.

Table 21: Potential Sources of Program Cost Estimate Uncertainty

Uncertainty	Definition	Example
Business or economic	Variations from change in business or economic assumptions	Changes in labor rate assumptions—e.g., wages, overhead, general and administrative cost—supplier viability, inflation indexes, multiyear savings assumptions, market conditions, and competitive environment for future procurements
Cost estimating	Variations in the cost estimate despite a fixed configuration baseline	Errors in historical data and cost estimating relationships, variation associated with input parameters, errors with analogies and data limitations, data extrapolation errors, optimistic learning and rate curve assumptions, using the wrong estimating technique, omission or lack of data, misinterpretation of data, incorrect escalation factors, overoptimism in contractor capabilities, optimistic savings associated with new ways of doing business, inadequate time to develop a cost estimate
Program	Risks outside the program office control	Program decisions made at higher levels of authority, indirect events that adversely affect a program, directed funding cuts, multiple contractor teams, conflicting schedules and workload, lack of resources, organizational interface issues, lack of user input when developing requirements, personnel management issues, organization's ability to accept change, other program dependencies
Requirements	Variations in the cost estimate caused by change in the configuration baseline from unforeseen design shifts	Changes in system architecture (especially for system of systems programs), specifications, hardware and software requirements, deployment strategy, critical assumptions, program threat levels, procurement quantities, network security, data confidentiality
Schedule	Any event that changes the schedule: stretching it out may increase funding requirements, delay delivery, and reduce mission benefits	Amount of concurrent development, changes in configuration, delayed milestone approval, testing failures requiring rework, infeasible schedule with no margin, overly optimistic task durations, unnecessary activities, omission of critical reviews
Software	Cost growth from overly optimistic assumptions about software development	Underestimated software sizing, overly optimistic software productivity, optimistic savings associated with using commercial off-the-shelf software, underestimated integration effort, lack of commercial software documentation, underestimating the amount of glue code needed, configuration changes required to support commercial software upgrades, changes in licensing fees, lack of support for older software versions, lack of interface specification, lack of software metrics, low staff capability with development language and platform, underestimating software defects
Technology	Variations from problems associated with technology maturity or availability	Uncertainty associated with unproven technology, obsolete parts, optimistic hardware or software heritage assumptions, feasibility of producing large technology leaps, relying on lower reliability components, design errors or omissions

Source: DOD, DHS, DOE, NASA, OMB, SCEA, and industry.

Collecting high-quality risk data is key to a successful analysis of risk. Often there are no historical data from which to derive the information needed as inputs to a risk analysis of cost or schedule. Usually most risk data are derived from in-depth interviews or in risk workshops. In other words, the data used in program risk analyses are often based on individuals' expert judgment, which depends on the experience of the interviewees and may be biased. The success of data collection depends also on the risk maturity of the organization's culture. It is difficult to collect useful risk analysis data when the organization is indifferent or even hostile to expressing risk in the program. Obtaining risk information from staff outside the acquisition program office can help balance potential optimism.

After identifying all possible risks, a cost estimator needs to define each one in a way that facilitates determining the probability of each risk occurring, along with the cost effect. To do this, the estimator needs to identify a range of values and their respective probabilities— based either on specific statistics or expressed as best case, worst case, and most likely—and the rationale for choosing the variability discussed. While the best practice is to rely on historical data, if these data are not available, how qualitative judgment was applied should be explained (e.g., not planning for first time success in testing). Because the quality and availability of the data affect the cost estimate's uncertainty, these should be well documented and understood. For example, a cost estimate based on detailed actual data in significant quantities will yield a more confident estimate than one based on an analogy using only a few data points.

Since collecting all this information can be formidable, it should be done when the data are collected to develop the estimate. Interviews with experts familiar with the program are good sources of how varied the risks are for a particular cost element. However, experts do not always think in extremes. They tend instead to estimate probability ranges that represent only 60 percent to 85 percent of the possible outcomes, so adjustments may have to be made to consider a wider universe of risks. In addition, the technical baseline description should address the minimum and maximum range, as well as the most likely value for critical program parameters.

Several approaches, ranging from subjective judgment to complex statistical techniques, are available for dealing with uncertainty. Here we describe different ways of determining the uncertainty of a cost estimate.

Cost Growth Factor

Using the cost growth factor, the cost estimator reflects on assumptions and judgments from the development of the cost estimate and then makes a final adjustment to the estimate. This is usually a percentage increase, based on historical data from similar programs, or an adjustment solicited from expert opinion and based on experience. This yields a revised cost estimate that explicitly recognizes the existence of uncertainty. It can be applied at the total program level or for one or more WBS elements. The advantages of this approach are that it is easy to implement, takes little time to perform, and requires minimal detail. Its several problems are that it requires access to a credible historical database, the selection of comparative projects and adjustment factors that can be subjective, and new technologies or lessons learned that may cause historical data to be less relevant.

Expert Opinion

An independent panel of experts can be gathered to review, understand, and discuss the system and its costs, in order to quantify the estimate's uncertainty and adjust the point estimate. This approach is often used in conjunction with the Delphi technique, in which several experts provide opinions independently and anonymously. The results are summarized and returned to the experts, who are then given the opportunity to change or modify their opinions, based on the opinions of the group as a whole. If successful, after several such iterations, the expert opinions converge.

The strengths of this approach are directly related to the diversity and experience of the panel members. The major weaknesses are that it can be time consuming and experts can present biased opinions. For example, some of the largest risks facing a program may stem from a new technology for which there is little previous experience. If the risk distributions rest on the beliefs of the same experts who may be stakeholders, it could be difficult to truly capture the program risks. A typical rule of thumb is that lower and upper bounds estimated by experts should be interpreted as representing the 15 percent and 85 percent levels, respectively of all possible outcomes. Therefore, the cost estimator will need to adjust the distribution bounds to account for skew (see Step 2 for more on this issue). Cost estimators can also mitigate bias by avoiding leading questions and by questioning all assumptions to see if they are backed by historical data.

The analytic hierarchy process, like the Delphi technique, is another approach to making the best of expert opinion. It can be applied to the opinion of either an individual or a panel of experts and mitigates the problems of bias that result from group think or dominating personalities. The analytic hierarchy process provides a structured way to address complicated decisions: it relies on a framework for quantifying decision elements and evaluating various alternatives. This process allows for effective decision making because it captures both subjective and objective evaluation parameters which can lead to less bias and help determine the best overall decision. The approach relies on mathematics to organize pair-wise comparisons of decision components and prioritizes the results to arrive at a stable outcome.

Mathematical Approaches

Mathematical approaches rely on statistics to describe the variance associated with an analogy or a cost estimating relationship. The most common approach is to collect data on the optimistic, most likely, and pessimistic range (the "3-point estimate") for the risk or the cost element schedule activity duration. Statistics like the standard error of the estimate and confidence intervals are more difficult to collect from program participants and are not commonly used. Some distributions use more exotic inputs such as "shape parameters" that are often difficult to collect, even in the most in-depth interviews. Therefore, the 3-point estimate and an idea about the distribution shape can be used to define the probability distribution to be used in a simulation. Probability distributions are used either to characterize risks that are assigned to cost elements or activity durations or as estimates of uncertainty in costs or durations that may be affected by several risks. With either of these approaches, in the simulation the lower-level WBS element cost probabilities are combined to develop an overall program cost estimate probability distribution.

A benefit of this approach is that it complements the decomposition approach to cost estimating. In addition, the emergence of commercial software models means that Monte Carlo simulation can be implemented quickly and easily, once all the data have been collected. Some drawbacks to the approach include the variety of input distributions, correlation between cost elements needs to be included, and decision makers may not always accept the output. In addition, high-quality risk data are sometimes difficult and may be expensive to collect.

Technology Readiness Levels

NASA and the Air Force Space Command, among other organizations, address uncertainty by applying readiness levels, which capture the risk associated with developing state-of-the-art technology. They have historically developed technology readiness levels to indicate how close a given technology is to being available. Technology readiness levels are rated on a scale from 1 to 9, with 1 representing paper studies of a technology's feasibility and 9 representing technology completely integrated into a finished product. In appendix XII, we list and describe nine technology readiness levels.

Knowing a technology's readiness level allows a cost estimator to judge the risk inherent in assuming it will be available for a given program. For example, GAO has determined that level 7—demonstration of a prototype in an operational environment—is the level of technological maturity that constitutes low risk for starting a product development program. One needs to be cautious, since programs can inflate the level. There should be specific evidence that a program has achieved the claimed technology readiness level, such as physical and functional interfaces are clearly defined, raw materials are available, and manufacturing procedures are set up and undergoing testing for proof of concept before accepting a claim as true.

Software Engineering Institute Maturity Models

SEI has developed a variety of models that provide a logical framework for assessing whether an organization has the necessary process discipline to repeat earlier successes on similar projects. Organizations that do not satisfy the requirements for the "repeatable" level are by default judged to be at the initial level of maturity—meaning that their processes are ad hoc, sometimes even chaotic, with few of the processes defined and success dependent mainly on the heroic efforts of individuals. The lower the maturity, the higher the risk that a program will incur cost overruns.

In addition to evaluating software risks, SEI's risk evaluation method can be tailored to address hardware and organizational risks with a program. This method includes identifying and quantifying risk using a repeatable process for eliciting risks from experts. Furthermore, using SEI's taxonomy, the risk evaluation method provides a consistent framework for employing risk management methods and mitigation techniques.

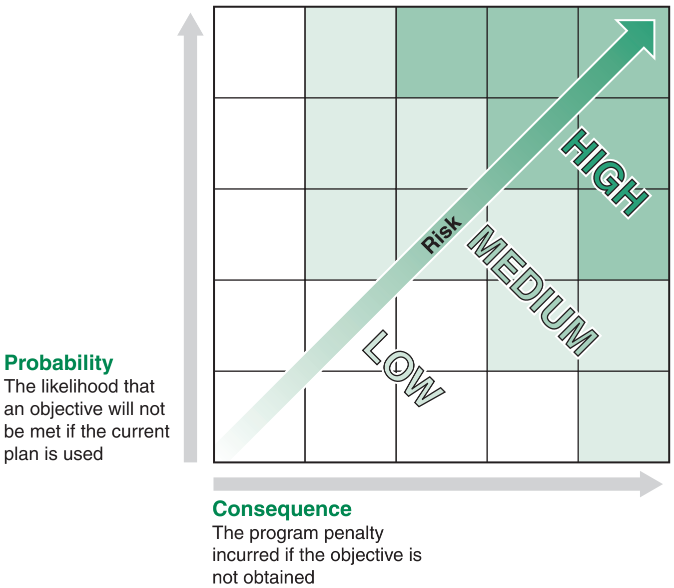
Schedule Risk Analysis

Schedule risk analysis captures the risk that schedule durations may increase from technical challenges, lack of qualified personnel, and too few staff to do the work. Schedule risk analysis examines the effect of activities and events slipping on a program's critical path or the longest path through the network schedule. A program schedule delay will have cost effects for all aspects of a program, including systems engineering and program management. It also analyzes how various activities affect one another because of precedence relationships—activity C cannot begin until activities A and B are finished—and how a slip in one activity affects the duration of other activities when concurrence is high among tasks. By applying probabilistic distributions to capture the uncertainty with traditional early start–late start and early finish–late finish schedule durations, using optimistic, pessimistic, and most likely values, a cost estimator can draw a better picture of the true critical path and any cost effects to the program. In addition, this analysis addresses the feasibility of the program plan as well as the effect of not meeting the anticipated finish date.

Risk Cube (Probability Impact Matrix) Method

The risk cube method prioritizes uncertainties that could jeopardize program cost, schedule, performance, and quality objectives in terms of probability of occurrence and cost effect. Subject matter experts, typically engineers and others familiar with the program, define the risk factors, probabilities, and cost effect for each identified risk. Using these data, the cost estimator develops the expected cost overrun by multiplying the cost impact by each risk factor's probability of occurrence. A common technique for engaging those knowledgeable about the program is creating a two-dimensional matrix like the one in figure 17.

Figure 17: A Risk Cube Two-Dimensional Matrix



Source: GAO.

In the risk cube (P-I matrix) method, risks are mapped onto the matrix, based on the severity of the consequence—ranging from low risk = 1 to high risk = 5—and the likelihood of their occurring—ranging from low likelihood = 1 to high = 5. Risks that fall in the upper right quadrant are the most likely to occur and have the greatest consequences for the program, compared to risks that fall into the lower left quadrant.

When risks are plotted together, management can quickly determine which ones have top priority. For a risk cube (P-I matrix) analysis to be accurate, complete lists of all risks are needed, as well as accurate probabilities of occurrence and cost impacts. Determining the cost impact will vary by program and WBS element, but a cost impact could, for example, be categorized as "60 percent more funding is required to resolve a technical shortfall that has no acceptable workarounds." Once the cost impacts are identified, they are mapped to the appropriate WBS elements to help identify risk mitigation steps that would be most beneficial.

The advantages of using this approach are that those knowledgeable about the program can readily understand and relate to risks presented in this manner and that decision makers can understand the link between specific risks and consequences. A disadvantage is that engineers may not always know the cost impacts and may not account for the full spectrum of possible outcomes. Moreover, this method can underestimate total risk by omitting the correlation between technical risk and level of effort in activities like program management.

Risk Scoring

Risk scoring quantifies and translates risks into cost impacts. Risk scoring is used to determine the amount of risk, preferably using an objective method in which the intervals between a score have meaning—a score of 1 = low risk, a score of 5 = medium risk, and a score of 10 = high risk. This method is used most often to determine technical risk associated with hardware and software. The following categories are used for hardware: technology advancement (level of maturity), engineering development (current stage of development), reliability (operating time without failure), producibility (ease to manufacture), alternative item (availability of back-up item), and schedule (amount of aggressiveness). Table 22 is an example of the hardware risk scoring matrix.[56]

Table 22: A Hardware Risk Scoring Matrix

	Risk score: 0 = low, 5 = medium, 10 = high				
Risk category	**0**	**1–2**	**3–5**	**6–8**	**9–10**
1. Technology advancement	Completed, state of the art	Minimum advancement required	Modest advancement required	Significant advancement required	New technology
2. Engineering development	Completed, fully tested	Prototype	Hardware and software development	Detailed design	Concept defined
3. Reliability	Historically high for same system	Historically high on similar systems	Modest problems known	Serious problems known	Unknown
4. Producibility	Production and yield shown on same system	Production and yield shown on similar system	Production and yield feasible	Production feasible and yield problems	No known production experience
5. Alternative item	Exists or availability on other items not important	Exists or availability on other items somewhat important	Potential alternative in development	Potential alternative in design	Alternative does not exist and is required
6. Schedule	Easily achieved	Achievable	Somewhat challenging	Challenging	Very challenging

Source: © 2003, Society of Cost Estimating and Analysis (SCEA), "Cost Risk Analysis."

In addition to hardware, categories for software include technology approach (level of innovation), design engineering (current stage of development), coding (code maturity), integrated software (based on the source lines of code count), testing (amount completed), alternatives (availability of back-up code), and schedule (amount of aggressiveness). A software risk scoring matrix is shown in table 23.

[56] The original approach to this impact-only assessment was Floyd Maxwell's of the Aerospace Corporation. Since he used it for many years at Aerospace, it was originally called the "Maxwell Matrix."

Table 23: A Software Risk Scoring Matrix

Risk category	Risk score: 0 = low, 5 = medium, 10 = high				
	0	**1–2**	**3–5**	**6–8**	**9–10**
1. Technology advancement	Proven conventional analytic approach, standard methods	Undemonstrated conventional approach, standard methods	Emerging approaches, new applications	Unconventional approach, concept in development	Unconventional approach, concept unproven
2. Design engineering	Design complete and validated	Specifications defined and validated	Specifications defined	Requirements defined	Requirements partly defined
3. Coding	Fully integrated code available and validated	Fully integrated code available	Modules integrated	Modules exist but not integrated	Wholly new design, no modules exist
4. Integrated software	Thousands of instructions	Tens of thousands of instructions	Hundreds of thousands of instructions	Millions of instructions	Tens of millions of instructions
5. Testing	Tested with system	Tested by simulation	Structured walk-throughs conducted	Modules tested but not as a system	Untested modules
6. Alternatives	Alternatives exist; alternative design not important	Alternatives exist; design somewhat important	Potential for alternatives in development	Potential alternatives being considered	Alternative does not exist but is required
7. Schedule and management	Relaxed schedule, serial activities, high review cycle frequency, early first review	Modest schedule, few concurrent activities, review cycle reasonable	Modest schedule, many concurrent activities, occasional reviews, late first review	Fast track on schedule, many concurrent activities	Fast track, missed milestones, review at demonstrations only, no periodic reviews

Source: U.S. Air Force.

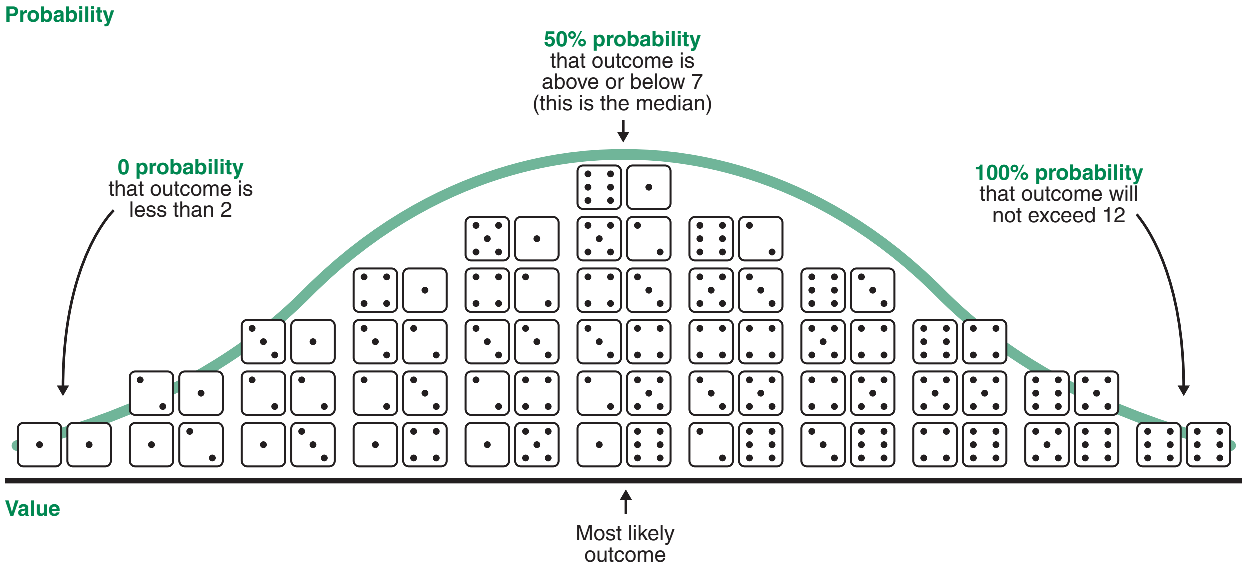
Technical engineers score program elements between 0 and 10 for each category and then rank the categories according to the program's effect. Next, each element's risk score is translated into a cost impact by (1) multiplying a factor by an element's estimated cost (for example, a score of 2 increases the cost of an element by 10 percent) or (2) multiplying a factor by predetermined costs (a score of 2 has a cost impact of $50,000) or (3) developing a weighted average risk assessment score that is mapped to a historical cost growth distribution.

After using one or several of these methods to determine the cost risk, the estimator's next step is to choose probability distributions to model the risk for each WBS cost element that has uncertainty.

Step 2: Develop Probability Distributions to Model Uncertainty

Uncertainty is best modeled with a probability distribution that accounts for all possible outcomes according to the probability that they will occur. Figure 18 gives an example of a known distribution that models all outcomes associated with rolling a pair of dice.

Figure 18: The Distribution of Sums from Rolling Two Dice



Source: GAO.

In figure 18, the horizontal axis shows the potential value of dice rolls, while the vertical axis shows the probability associated with each roll. The value at the midpoint of all rolls is the median. In the example, the median is also the most likely value (that is, average = a roll of 7), because the outcomes associated with rolling a pair of dice are symmetric.

Besides descriptive statistics, probability distributions provide other useful information, such as the boundaries of an outcome. For example, the lower bound in figure 18 is 2 and the upper bound is 12. By examining the distribution, it is easy to see that both the upper and lower bounds have the lowest probability of occurring, while the chances of rolling a 6, 7, or 8 are much greater.

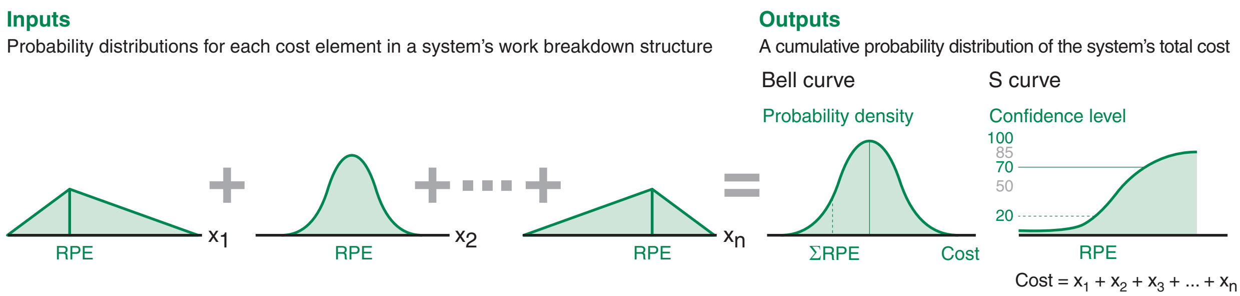
It is difficult to pick an appropriate probability distribution for the point cost estimate as a whole, because it is composed of several subsidiary estimates based on the WBS. These WBS elements are often estimated with a variety of techniques, each with its own uncertainty distributions that may be asymmetrical. Therefore, just simply adding the most likely WBS element costs does not result in the most likely cost estimate because the risk distributions associated with the subelements differ.

One way to resolve this issue is to create statistical probability distributions for each WBS element or risk by specifying the risk shape and bounds that reflect the relative spread and skewness of the distribution. The probability distribution represents the risk shape, and the tails of the distribution reflect the best and worst case outcomes. Even though the bounds are extremes and unlikely to occur, the distribution acknowledges the possibility and probability that they could happen. Probability distributions are typically determined using the 3-point estimates of optimistic, most likely, and pessimistic values to identify the amount of spread and skewness of the data. However, if risks are used directly, they will be assigned to specific cost elements or activities in a schedule and will perform appropriately in a simulation.[57]

[57] Risks can be entered directly or they can be assigned as multiplication factors to specific cost elements or schedule activities. If this "risk driver" approach is used, the data collected, including probability of occurrence and impact (typically a 3-point estimate) will be on the risks themselves. Hence, the focus is on the risks, not on their impact on activities or cost line items. This focus on the risks makes it easy to understand the results and to focus on mitigating risks directly.

Using a simulation tool such as Monte Carlo, a cost estimator can develop a statistical summation of all probable costs, allowing for a better understanding of how likely it is that the point estimate can be met. A Monte Carlo simulation also does a better job of capturing risk, because it takes into consideration that some risks will occur while others may not. Furthermore, the simulation can adjust the risks beyond the upper and lower bounds to account for the fact that experts do not typically think in extremes. Figure 19 shows why different WBS element distributions need to be statistically summed in order to develop the overall point estimate probability distribution.

Figure 19: A Point Estimate Probability Distribution Driven by WBS Distributions



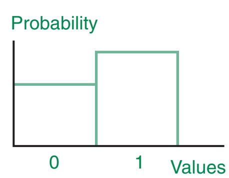
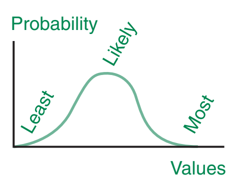
Source: NASA.

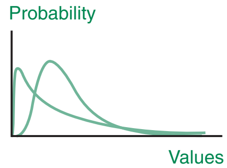
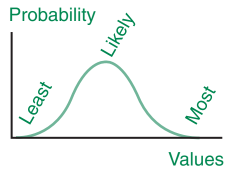
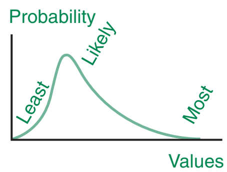
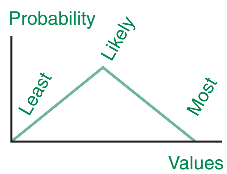
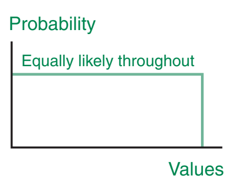
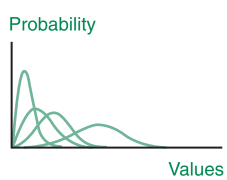
Note: RPE = reference point estimate.

In figure 19, the sum of the reference point estimates has a low level of probability on the S curve. In other words, there is only a 20 percent chance or less of meeting the point estimate cost. Therefore, in order to increase the confidence in the program cost estimate, it will be necessary to add more funding to reach a higher level of confidence.

Next to knowing the bounds or 3-point estimates for the uncertainty of the WBS element or risk, choosing the right probability distribution for each WBS element is important for capturing the uncertainty correctly. For any WBS element, selecting the probability distribution should be based on how effectively it models actual outcomes. Since different distributions model different types of risk, knowing the shape of the distribution helps in visualizing how the risk will affect the overall cost estimate uncertainty. A variety of probability distribution shapes are available for modeling cost risk. Table 24 lists eight of the most common probability distributions used in cost estimating uncertainty analysis.

Table 24: Eight Common Probability Distributions

Distribution	Description	Shape	Typical application
Bernoulli	Assigns probabilities of "p" for success and "1 – p" for failure; mean = "p"; variance = "1 – p"		With likelihood and consequence risk cube models; good for representing the probability of a risk occurring but not for the impact on the program
Beta	Similar to normal distribution but does not allow for negative cost or duration, this continuous distribution can be symmetric or skewed		To capture outcomes biased toward the tail ends of a range; often used with engineering data or analogy estimates; the shape parameters usually cannot be collected from interviewees

Distribution	Description	Shape	Typical application
Lognormal	A continuous distribution positively skewed with a limitless upper bound and known lower bound; skewed to the right to reflect the tendency toward higher cost		To characterize uncertainty in nonlinear cost estimating relationships; it is important to know how to scale the standard deviation, which is needed for this distribution
Normal	Used for outcomes likely to occur on either side of the average value; symmetric and continuous, allowing for negative costs and durations. In a normal distribution, about 68% of the values fall within one standard deviation of the mean		To assess uncertainty with cost estimating methods; standard deviation or standard error of the estimate is used to determine dispersion. Since data must be symmetrical, it is not as useful for defining risk, which is usually asymmetrical, but can be useful for scaling estimating error
Poisson	Peaks early and has a long tail compared to other distributions		To predict all kinds of outcomes, like the number of software defects or test failures
Triangular	Characterized by three points (most likely, pessimistic, and optimistic values) can be skewed or symmetric and is easy to understand because it is intuitive; one drawback is the absoluteness of the end points, although this is not a limitation in practice since it is used in a simulation		To express technical uncertainty, because it works for any system architecture or design; also used to determine schedule uncertainty
Uniform	Has no peaks because all values, including highest and lowest possible values, are equally likely		With engineering data or analogy estimates
Weibull	Versatile, can take on the characteristics of other distributions, based on the value of the shape parameter "b"—e.g., Rayleigh and exponential distributions can be derived from it[a]		In life data and reliability analysis because it can mimic other distributions and its objective relationship to reliability modeling

Source: DOD, NASA, SCEA, and Industry.

[a]The Rayleigh and exponential distributions are a class of continuous probability distribution.

The triangular, lognormal, beta, uniform and normal distributions in table 24 are the most common distributions that cost estimators may use to perform an uncertainty analysis. They are generally sufficient, given the quality of the information derived from interviews and the granularity of the results. However, many other types of distributions are discussed in myriad literature sources and are available through a variety of statistical tools.

The point to remember is that the shape of the distribution is determined by the characteristics of the risks they represent. If they are applied to WBS elements, they may combine the impact of several risks, so it may take some thought to determine the most appropriate distribution to use. For a CER, it is a best practice to use prediction interval statistical analysis to determine the bounds of the probability distribution because it is an objective method for determining variability. The prediction interval captures the error around a regression estimate and results in a wider variance for the CER.

When there is no objective way to pick the distribution bounds, a cost estimator will resort to interviewing several people—especially experienced personnel both within and outside the program—about what the distribution bounds should be. Promising anonymity to the interviewees may help secure their unbiased thoughts. Separating the risk analysis function organizationally from the program and program manager often provides the needed independence to withstand political and other pressures for biased results.

Since there is the potential for experts to be success oriented when choosing the upper and lower extremes of the distribution, one way to avoid this is to look for historical data that back up the distribution range. If historical data are not available, it may be necessary to adjust the tails to account for the fact that being overly optimistic usually results in programs costing more and taking longer than planned. Thus, it is necessary to skew the tails to account for this possibility in order to properly represent the overall risk. Organizations should, as a best practice, examine and publish default distribution bounds that cost estimators can use when the data cannot be obtained objectively.

Once all cost element risks have been identified in step 1 and distributions have been chosen to model them in step 2, correlation between the cost elements must be examined in order to fully capture risk, especially risk related to level-of-effort cost elements.

Step 3: Account for Correlation between Cost Elements

Because different WBS elements' costs may be affected by the same external factors, some degree of correlation exists between them. Correlation identifies the relationship between WBS elements such that when one WBS element's cost is high within its own probability distribution, the other WBS element will also show a high cost in its own probability distribution. Thus, correlated cost elements should rise and fall together. Without correlating the two elements, inconsistent scenarios where one is high and the other is low could occur during the simulation, causing erroneous results. Therefore, a change in one WBS element's cost will usually be found with a change in the same direction (if positive correlation) in another element's cost. If this is so for many elements, the cumulative effect tends to increase the range of possible costs. Consider the following examples:

- If a supplier delivers an item late, other scheduled deliveries could be missed, resulting in additional cost.
- If technical performance problems occur, unexpected design changes and unplanned testing may result, affecting the final schedule and cost.

- If concurrence is great between activities, a slip in one activity could have a cascading effect on others, resulting in a high degree of schedule and cost uncertainty.
- If the number of software lines of code depends heavily on the software language and the definition of what constitutes a line of code, a change in the counting definition or software language will change the number of lines of code affecting both schedule and cost.

As these examples show, many parts of a cost estimate may move together, and when they do, summing their costs results in reinforcement in both negative and positive directions. Therefore, mitigating a risk that affects two or more WBS cost elements can reduce uncertainty on several cost elements. A case in point is the standing army effect, which occurs when a schedule slip in one element results in delays in many other cost elements as staff wait to complete their work. As such, inter-element correlation must be addressed so that the total cost probability distribution properly reflects the risks.

To properly capture functional correlation, the cost model should be structured with all dependencies intact. For instance, if the cost of training is modeled as a factor of hardware cost, then any uncertainty in the hardware cost will be positively correlated to the risk in training cost. Thus, when the simulation is run, risks fluctuating within main cost element probability distributions will accurately flow down to dependent WBS elements.

One of the advantages of a cost estimating relationship based cost model is the manner in which the statistical analysis used to derive the CERs can also be drawn on to identify, and in some cases quantify, the correlations between various cost risk elements. It is also important to ensure that uncertain cost method inputs (weight, labor rates) are correlated appropriately.

In some cases, however, it may be necessary to inject correlation to "below the line" dependent elements to account for correlated risk. These elements are typically level-of-effort support activities, like systems engineering and program management. In addition, correlation may have to be injected into the cost model to account for effects that the model may not capture. For example, a program risk may be that the length of an aircraft wing increases. If that happens, a larger engine than was originally estimated would then be required. Because this risk effect is not correlated in the cost model, it must be injected into the risk scenario.

Estimators should examine the correlation coefficients from the simulation model to determine the amount of correlation that already exists in the cost model. As a rule of thumb, it is better to insert an overall nominal correlation of 0.25 than to show no correlation at all. This will prevent the simulation from drawing a low value for one element and a high value for another element, causing a cancellation of risk when both elements are positively correlated.

Regardless of which approach is taken, it is important to note that correlation should never be ignored. Doing so can significantly affect the cost risk analysis, resulting in a dramatically understated probability distribution that can create a false sense of confidence in the resulting estimate. Therefore, highly risky programs should show a wide range of possible costs. (More information on correlation and how to account for schedule risk affecting the cost estimate is in appendix X.)

Step 4: Perform Uncertainty Analysis with a Monte Carlo Simulation

The most common technique for combining the individual elements and their distributions is Monte Carlo simulation.[58] In one approach, the distributions for each cost element are treated as individual populations from which random samples are taken. In another approach, each risk is modeled and assigned to the WBS elements it affects; in this approach, a risk may affect more than one WBS element's cost, and a WBS element's cost may be affected by more than one risk. In either case, during the simulation a cost model is recalculated thousands of times by repeatedly drawing random values from each WBS distribution or distribution of risk factors, so that many, thousands, or nearly all possible outcomes are taken into account. The simulation's output illustrates (1) the likelihood of achieving the program's cost objectives, given the current plan and risks as they are known and quantified; (2) the likelihood of other possible outcomes, which can be a way to determine the cost value that has an acceptable probability of being exceeded; and (3) by sensitivity, the high-priority risks or WBS elements as a guide to effective risk mitigation.

Not a new concept, Monte Carlo simulation has been a respected method of analyzing risk in engineering and science for more than 60 years. Mathematicians working on the Manhattan project used it during World War II and this technique was used to determine the value of pi (π) to within 6 decimal points. Developed by a mathematician who pondered the probabilities associated with winning a card game of solitaire, Monte Carlo simulation is used to approximate the probability outcomes of multiple trials by generating random numbers. In determining the uncertainty associated with a program's point estimate, a Monte Carlo simulation randomly generates values for uncertain variables over and over to simulate a model.

Without the aid of simulation, the analyst generally produces a single outcome, for the total program cost, usually by adding up the individual WBS element cost estimates. This value is not necessarily the most likely or average scenario. In fact, without a risk analysis, it is not known how adequate this single-point estimate is likely to be for handling the program risks. But after hundreds or thousands of trials, one can view the frequency distribution of the results and determine the certainty of any outcome. Performing an uncertainty analysis using Monte Carlo simulation quantifies the amount of cost risk within a program. Only by quantifying the cost risk can management make informed decisions about risk mitigation strategies and provide a benchmark against which to measure progress.

To perform an uncertainty analysis, each WBS element's risk or risk factor is assigned a specific probability distribution of feasible values. In setting up the simulation, any identified causality may be modeled. Also, correlations are specified, including identified correlated elements and estimated strength of the correlation. These are automatically taken into account by the software during the simulation, where a random draw from each distribution is taken and the results are added up. This random drawing among distributions is repeated thousands of times with statistical software in order to determine the frequency distribution. Since the simulation's inputs are probability distributions, the outputs are also distributions. The result is a distribution of random total program costs based on the overall mean and standard deviation. Rather than being normal, the total cost distribution is usually lognormal. This happens because the overall cost distribution is derived from the lower-level WBS elements, each of which has

[58] Latin hypercube simulation can also be used. This method partitions the "simulation draw area" into equal area segments and results in convergence to the "correct" answer with fewer iterations.

unique distributions. Since many of these underlying distributions tend to be skewed to the right, the overall distribution is typically lognormal. This makes sense since most cost estimates tend to overrun rather than underrun. This distribution can also be converted to an S curve like the S curves shown in figures 16 and 19.

An advantage of using a Monte Carlo simulation is that both good and bad effects can be modeled, as well as any offsets that occur when both happen at the same time. In addition, Monte Carlo simulation not only recognizes the uncertainty inherent in the point estimate but also captures the uncertainty with all other possible estimates, allowing for a better analysis of alternatives. Using this technique, management can base decisions on cost estimate probabilities rather than relying on a single point estimate with no level of confidence attached.

Step 5: Identify the Probability Associated with the Point Estimate

After the simulation has been run and causality and correlation have been accounted for, the next step is to determine the probability associated with the point estimate. The cumulative probability distribution resulting from the Monte Carlo simulation provides the cost estimator and management with risk-adjusted estimates and corresponding probabilities. The output of the simulation is useful for determining the level of probability in achieving the point estimate, along with a range of possible outcomes bounded by minimum and maximum costs. This probability can then be weighed against available funding to understand the confidence one can place in the program's meeting its objectives.

Uncertainty analysis using a Monte Carlo simulation communicates to stakeholders how likely a program is to finish at the estimated cost and schedule, how much cost contingency reserve is needed to provide the desired degree of certainty that the estimate will be adequate, and the likely risks so that proactive responses can be developed.[59] It also determines how different two competing alternatives are in terms of cost. In addition, estimating future costs with probabilities is better than just relying on a point estimate, because informed decisions can be made regarding all possible outcomes.

Because we can never know all the risks until the program is finally complete, the risk analysis and cost risk simulation exercise should be conducted periodically through the life of the program. Organizations often require such an analysis before major milestone decision points.

Step 6: Recommend Sufficient Contingency Reserves

The main purpose of risk and uncertainty analysis is to ensure that a program's cost, schedule, and performance goals can be met. The analysis also communicates to decision makers the specific risks that contribute to a program's cost estimate uncertainty. Without this knowledge, a program's estimated cost could be understated and subject to underfunding and cost overruns, putting it at risk of being reduced in scope or requiring additional funding to meet its objectives. Moreover, probability data from an uncertainty analysis can result in more equitable distribution of budget in an EVM system, ensuring that the most risky cost elements receive adequate budget up front.

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[59] Cost and schedule Monte Carlo simulations tend to be performed separately by different specialists. Cost uncertainty models seldom address schedule risk issues. Performing a schedule risk analysis can more adequately address schedule risk issues. (More detail is in appendix X.)

Using information from the S curve, management can determine the contingency reserves needed to reach a specified level of confidence. The difference in cost between the point estimate and the desired confidence level determines the required contingency reserve. Because cost distributions tend to be right skewed (that is, the tendency is for costs to overrun rather than underrun), the mean of the distribution tends to fall somewhere between the 55 percent and 65 percent confidence levels. Therefore, if it is decided to fund a program at the 50 percent confidence level, there is still a chance that the program will need additional funding because the expected value is at a higher confidence level. Moreover, extremely risky programs will require funding at a level closer to the 65 percent confidence level or higher. Since each program is unique and so are its risks, there are no set rules as to what level of contingency is sufficient. Decision makers have to decide the level of confidence at which to set the budget. Having adequate funding is paramount for optimal program execution, since it can take many months to obtain necessary funding to address an emergent program issue. Without available risk funding, cost growth is likely.

We caution that the validity of the results depends on the knowledge, experience, and data regarding a program's risks. When the uncertainty analysis has been poorly executed, management may have a false sense of security that all risks have been accounted for and that the analysis was based on sound data. When this happens, program decisions will be based on bad information. Thus, it is imperative that the cost estimators properly correlate cost elements and consider a broad range of potential program risks rather than simply focusing on the risks that most concern the program office or contractor. Furthermore, to ensure that best practices have been followed and to prevent errors such as not properly accounting for correlation between cost elements, it is a best practice to vet the uncertainty analysis through a core group of experts to ensure that results are robust and valid.

In addition, to ensure that accurate information is available for performing uncertainty analysis, the estimate should be continually updated with actual costs and any variances recorded. This will enable organizations to identify areas where estimating was difficult or sources of risk were not considered. Doing so will guard against presenting misleading results to management and will result in continuous improvements in the uncertainty analysis process.

A program's early phases entail a lot of uncertainty, and the amount of contingency funding required may exceed acceptable levels. Management may gain insight from the uncertainty analysis by acting to reduce risk to keep the program affordable. It may also examine different levels of contingency reserve funds to understand what level of confidence the program can afford. Most importantly, management needs to understand that any uncertainty analysis or risk mitigation is only as good as the comprehensiveness of risks and uncertainties identified. Unknown risks could still cause problems, and these are difficult, if not impossible, to quantify.

Step 7: Allocate, Phase, and Convert a Risk-Adjusted Cost Estimate to Then-Year Dollars and Identify High-Risk Elements

Uncertainty is calculated on the total cost estimate results, not year by year. Therefore, since a budget is requested in then-year dollars, it is necessary to convert the cost estimate into then-year dollars by phasing the WBS element costs over time. Because WBS element results at a specific confidence level will not sum to the parent levels, it will be necessary to pick the level in the WBS from which risk dollars are to be managed. The difference between the point estimate and the risk result at the selected confidence level is the amount of contingency reserve to be set aside for mitigating risks in lower WBS level elements.

Once the amount of contingency reserve has been identified, reserves need to be identified and set aside for the WBS elements that harbor the most risks so that funding will be available to mitigate risks quickly. To identify which WBS elements may need contingency reserve, results from the uncertainty analysis are used to prioritize risks, based on probability and impact as they affected the cost estimate during the simulation. Knowing which risks are important will guide the allocation of contingency reserve.

Risk Management

Risk and uncertainty analysis is just the beginning of the overall risk management process. Risk management is a structured and efficient process for identifying risks, assessing their effect, and developing ways to reduce or eliminate risk. It is a continuous process that constantly monitors a program's health. In this process, program management develops risk handling plans and continually tracks them to assess the status of program risk mitigation activities and abatement plans. In addition, risk management anticipates what can go wrong before it becomes necessary to react to a problem that has already occurred. Identifying and measuring risk by evaluating the likelihood and consequences of an undesirable event are key steps in risk management. The risk management process should address five steps:

1. identify risks,
2. analyze risks (that is, assess their severity and prioritize them),
3. plan for risk mitigation,
4. implement a risk mitigation plan, and
5. track risks.

Steps 1 and 2 should have already been taken during the risk and uncertainty analysis. Steps 3–5 should begin before the actual work starts and continue throughout the life of the program. Over time, some risks will be realized, others will be retired, and some will be discovered: Risk management never ends. Establishing a baseline of risk expectations early provides a reference from which actual cost risk can be measured. The baseline helps program managers track and defend the need to apply risk reserves to resolve problems.

Integrating risk management with a program's systems engineering and program management process permits enhanced root cause analysis and consequence management, and it ensures that risks are handled at the appropriate management level. Furthermore, successful risk mitigation requires communication and coordination between government and the contractor to identify and address risks. A common database of risks available to both is a valuable tool for mitigating risk so that performance and cost are monitored continually.

Regular event-driven reviews are also helpful in defining a program that meets users' needs while minimizing risk. Similarly, relying on technology demonstrations, modeling and simulation, and prototyping can be effective in containing risk. When risks materialize, risk management should provide a structure for identifying and analyzing root causes.

Effective risk management depends on identifying and analyzing risk early, while there is still time to make corrections. By developing a watch list of risk issues that may cause future problems, management can monitor and detect potential risks once the program is under contract. Programs that have an EVM system can provide early warning of emerging risk items and worsening performance trends, allowing for implementing corrections quickly.

EVM systems also require the contractor to provide an estimate at completion and written corrective action plans for any variances that can be assessed for realism, using risk management data and techniques. Moreover, during an integrated baseline review (IBR), the joint government and contractor team evaluates program risks associated with work definition, schedule, and the adequacy of budgets. This review enhances mutual understanding of risks facing the program and lays the foundation for tracking them in the EVM system. It also establishes a realistic baseline from which to measure performance and identify risk early.

Risk management is continual because risks change significantly during a program's life. A risk event's likelihood and consequences may change as the program matures and more information becomes known. Program management needs always to reevaluate the risk watch list to keep it current and examine new root causes. Successful risk management requires timely reporting to alert management to risks that are surfacing, so that mitigation action can be approved quickly. Having an active risk management process in place is a best practice: When it is implemented correctly, it minimizes risks and maximizes a program's chances of being delivered on time, within budget, and with the promised functionality.

11. Best Practices Checklist: Cost Risk and Uncertainty

- ☐ A risk and uncertainty analysis quantified the imperfectly understood risks that are in the program and identified the effects of changing key cost driver assumptions and factors.
  - ✓ Management was given a range of possible costs and the level of certainty in achieving the point estimate.
  - ✓ A risk adjusted estimate that reflects the program's risks was determined.
  - ✓ A cumulative probability density function, an S curve, mapped various cost estimates to a certain probability level and defensible contingency reserves were developed.
  - ✓ Periodic risk and uncertainty analysis was conducted to improve estimate uncertainty.
- ☐ The following steps were taken in performing an uncertainty analysis:
  - ✓ Program cost drivers and associated risks were determined, including those related to changing requirements, cost estimating errors, business or economic uncertainty, and technology, schedule, program, and software uncertainty.
    - o All risks were documented for source, data quality and availability, and probability and consequence.
    - o Risks were collected from staff within and outside the program to counter optimism.
    - o Uncertainty was determined by cost growth factor, expert opinion (adjusted to consider a wider range of risks), statistics and Monte Carlo simulation, technology readiness levels, software engineering maturity models and risk evaluation methods, schedule risk analysis, risk cube (P-I matrix) method, or risk scoring.
  - ✓ A probability distribution modeled each cost element's uncertainty based on data availability, reliability, and variability.
    - o A range of values and their respective probabilities were determined either based on statistics or expressed as 3-point estimates (best case, most likely, and worst case), and rationale for choosing which method was discussed.
    - o Documentation of the rationale for choosing the probability distributions should be provided.

- o Probability distribution reflects the risk shape and the tails of the distribution reflect the best and worst case spread as well as any skewness. Distribution bounds were adjusted to account for stakeholder bias using organization default values when data specific to the program are not available.
- o If the risk driver approach is used, the data collected, including probability of occurrence and impact was applied to the risk themselves.
- o Prediction interval statistical analysis was used for CER distribution bounds.

✓ The correlation between cost elements was accounted for to capture risk.

- o The correlation ensures that related cost elements move together during the simulation, resulting in reinforcement of the risks.
- o Cost estimators examined the amount of correlation already existing in the model. If no correlation is present, an insertion of 0.25 correlation was added.

✓ A Monte Carlo simulation model was used to develop a distribution of total possible costs and an S curve showing alternative cost estimate probabilities.

- o High-priority risks were examined and identified for risk mitigation.
- o Strength of correlated cost elements were examined and additional correlation added if necessary to account for risk.

✓ The probability associated with the point estimate was identified.

✓ Contingency reserves were recommended for achieving the desired confidence level.

- o The mean of the distribution tends to fall around the 55%–65% confidence level because the total cost distribution follows a lognormal trend (i.e., tendency to overrun rather than underrun costs).
- o Budgeting to at least the mean of the distribution or higher is necessary to guard against potential risk.
- o The cost risk and uncertainty results were vetted through a core group of experts to ensure that the proper steps were followed.
- o The estimate is continually updated with actual costs and any variances recorded to identify areas where estimating was difficult or sources of risks not considered.

✓ The risk-adjusted cost estimate was allocated, phased, and converted to then-year dollars for budgeting, and high-risk elements were identified to mitigate risks.

- o Results from the uncertainty analysis were used to prioritize risks based on probability and impacts as they affected the cost estimate.

☐ A risk management plan was implemented jointly with the contractor to identify and analyze risk, plan for risk mitigation, and continually track risk.

✓ A risk database watch list was developed, and a contractor's EVM system was used for root cause analysis of cost and schedule variances, monitoring worsening trends, and providing early risk warning.

✓ Event-driven reviews, technology demonstrations, modeling and simulation, and risk-mitigation prototyping were implemented.

CHAPTER 15

Validating the Estimate

It is important that cost estimators and organizations independent of the program office validate that all cost elements are credible and can be justified by acceptable estimating methods, adequate data, and detailed documentation. This crucial step ensures that a high-quality cost estimate is developed, presented, and defended to management. This process verifies that the cost estimate adequately reflects the program baseline and provides a reasonable estimate of how much it will cost to accomplish all tasks. It also confirms that the program cost estimate is traceable and accurate and reflects realistic assumptions.

Validating the point estimate is considered a best practice. One reason for this is that independent cost estimators typically rely on historical data and therefore tend to estimate more realistic program schedules and costs for state-of-the-art technologies. Moreover, independent cost estimators are less likely to automatically accept unproven assumptions associated with anticipated savings. That is, they bring more objectivity to their analyses, resulting in estimates that are less optimistic and higher in cost. An independent view provides a reality check of the point estimate and helps reduce the odds that management will invest in an unrealistic program that is bound to fail.

The Cost Estimating Community's Best Practices for Validating Estimates

OMB's Circular No. A-94 and best practices established by professional cost analysis organizations, such as SCEA, identify four characteristics of a high-quality, reliable cost estimate. [60] It is well-documented, comprehensive, accurate, and credible.

By well documented is meant that an estimate is thoroughly documented, including source data and significance, clearly detailed calculations and results, and explanations of why particular methods and references were chosen. Data can be traced to their source documents.

An estimate is comprehensive if it has enough detail to ensure that cost elements are neither omitted nor double counted. All cost-influencing ground rules and assumptions are detailed in the estimate's documentation.

An estimate that is accurate is unbiased, not overly conservative or overly optimistic, and is based on an assessment of most likely costs. Few, if any, mathematical mistakes are present and those that are are minor.

As for credibility, any limitations of the analysis because of uncertainty or bias surrounding data or assumptions are discussed. Major assumptions are varied, and other outcomes are recomputed to determine how sensitive they are to changes in the assumptions. Risk and uncertainty analysis is

[60] For the OMB guidelines, see *Guidelines and Discount Rates for Benefit-Cost Analysis of Federal Programs*, Circular No. A-94 (Washington, D.C.: Oct. 29, 1992), and Director, OMB, "2009 Discount Rates for OMB Circular No. A-94," memorandum for the heads of departments and agencies, Executive Office of the President, OMB, Washington, D.C., Dec. 12, 2008.

performed to determine the level of risk associated with the estimate. The estimate's results are cross-checked, and an independent cost estimate (ICE) conducted by a group outside the acquiring organization is developed to determine whether other estimating methods produce similar results.

Table 25 shows how the 12 steps of a high-quality cost estimating process, described in table 2, can be mapped to these four characteristics of a high-quality, reliable cost estimate.

Table 25: The Twelve Steps of High-Quality Cost Estimating, Mapped to the Characteristics of a High-Quality Cost Estimate

Cost estimate characteristic	Cost-estimating step
Well documented	
The estimate is thoroughly documented, including source data and significance, clearly detailed calculations and results, and explanations for choosing a particular method or reference ▪ Data are traced back to the source documentation ▪ Includes a technical baseline description ▪ Documents all steps in developing the estimate so that a cost analyst unfamiliar with the program can recreate it quickly with the same result ▪ Documents all data sources for how the data were normalized ▪ Describes in detail the estimating methodology and rationale used to derive each WBS element's cost	1. Define the estimate's purpose 3. Define the program 5. Identify ground rules and assumptions 6. Obtain the data 10. Document the estimate 11. Present the estimate to management
Comprehensive	
The estimate's level of detail ensures that cost elements are neither omitted nor double counted ▪ Details all cost-influencing ground rules and assumptions ▪ Defines the WBS and describes each element in a WBS dictionary ▪ A major automated information system program may have only a cost element structure	2. Develop the estimating plan 4. Determine the estimating approach
Accurate	
The estimate is unbiased, not overly conservative or overly optimistic, and based on an assessment of most likely costs ▪ It has few, if any, mathematical mistakes; its mistakes are minor ▪ It has been validated for errors like double counting and omitted costs ▪ Cost drivers have been cross-checked to see if results are similar ▪ It is timely ▪ It is updated to reflect changes in technical or program assumptions and new phases or milestones ▪ Estimates are replaced with EVM EAC and the independent EAC from the integrated EVM system	7. Develop the point estimate and compare it to an independent cost estimate 12. Update the estimate to reflect actual costs and changes
Credible	
Discusses any limitations of the analysis from uncertainty or biases surrounding data or assumptions ▪ Major assumptions are varied and other outcomes recomputed to determine their sensitivity to changes in assumptions ▪ Risk and uncertainty analysis is performed to determine the level of risk associated with the estimate ▪ An independent cost estimate is developed to determine if other estimating methods produce similar results	7. Develop the point estimate and compare it to an independent cost estimate 8. Conduct sensitivity analysis 9. Conduct risk and uncertainty analysis

Source: GAO.

It is important that cost estimates be validated, because lessons learned have shown that cost estimates tend to be deficient in this area (see case study 41).

Case Study 41: Validating the Estimate, from ***Chemical Demilitarization*****, GAO-07-240R**

GAO reviewed and evaluated the cost analyses that the U.S. Army used to prepare its cost-benefit report on the DuPont plan of treatment and disposal options for the VX nerve agent stockpile at the Newport, Indiana depot. GAO also interviewed Army and contractor officials on the data and assumptions they had used to prepare their analyses. To determine the accuracy of the underlying data, GAO independently calculated values based on provided assumptions to compare with values in the supporting spreadsheets. GAO compared values from the supporting spreadsheets with summary data in the supporting posttreatment estimate report that the Shaw Environmental Group had prepared, Shaw being the contractor that helped perform the analysis for the U.S. Army Chemical Materials Agency report.

GAO found, based on OMB criteria and criteria approved by the cost estimating community, that the underlying cost estimates in the Army's report were not reliable and that the effect of this on the Army's finding that the DuPont plan had "significant cost savings over the three considered alternatives" was uncertain. GAO's finding of unreliable cost estimates included (1) the quantity and magnitude of errors, (2) quality control weaknesses, (3) questionable or inadequate supporting source data and documentation, and (4) the undetermined sensitivity of key assumptions. Neither the Army nor the contractor had a system for cross-checking costs, underlying assumptions, or technical parameters that went into the estimates.

Moreover, GAO determined that the results from the Army's program risk analysis were unreliable because they had been generated from previously discussed, unreliable cost estimates and because the Army attributed no risk to potential permit, legal, or other challenges to the DuPont plan. It was unclear whether the program risks of other alternatives were understated or overstated.

Overall, GAO could not determine the cumulative effect of these problems on the outcome or results of the Army's analysis, largely because GAO had no confidence in much of the supporting data, given these problems. Without reliable underlying cost estimates, the Army, the Congress, and the public could not have confidence that the most cost-effective solution had been selected.

GAO's recommendations were that the Army conduct its cost-benefit analysis again, using best practices, so that its data and conclusions would be comprehensive, traceable, accurate, and credible; that it correct any technical and mathematical errors in the cost estimate; that it establish quality control and independent review processes to check data sources, calculations, and assumptions; and that it perform a sensitivity analysis of key assumptions.

GAO, *Chemical Demilitarization: Actions Needed to Improve the Reliability of the Army's Cost Comparison Analysis for Treatment and Disposal Options for Newport's VX Hydrolysate*, GAO-07-240R (Washington, D.C.: Jan. 6, 2007).

Too often, we have reported that program cost estimates are unrealistic and that, as a result, they cost more than originally promised. One way to avoid this predicament is to ensure that program cost estimates are both internally and externally validated—that is, that they are comprehensive, well-documented, accurate, and credible. This increases the confidence that an estimate is reasonable and as accurate as possible. A detail review of these characteristics follows.

1. Determine That the Estimate Is Well Documented

Cost estimates are considered valid if they are well documented to the point at which they can be easily repeated or updated and can be traced to original sources through auditing. Rigorous documentation also increases an estimate's credibility and helps support an organization's decision making. The documentation should explicitly identify the primary methods, calculations, results, rationales or assumptions, and sources of the data used to generate each cost element.

Cost estimate documentation should be detailed enough to provide an accurate assessment of the cost estimate's quality. For example, it should identify the data sources, justify all assumptions, and describe each estimating method (including any cost estimating relationships) for every WBS cost element. Further, schedule milestones and deliverables should be traceable and consistent with the cost estimate documentation. Finally, estimating methods used to develop each WBS cost element should be thoroughly documented so that their derivation can be traced to all sources, allowing for the estimate to be easily replicated and updated.

2. Determine That the Estimate Is Comprehensive

Analysts should make sure that the cost estimate is complete and accounts for all possible costs. They should confirm its completeness, its consistency, and the realism of its information to ensure that all pertinent costs are included. Comprehensive cost estimates completely define the program, reflect the current schedule, and are technically reasonable. In addition, cost estimates should be structured in sufficient detail to ensure that cost elements are neither omitted nor double-counted. For example, if it is assumed that software will be reused, the estimate should account for all associated costs, such as interface design, modification, integration, testing, and documentation.

To determine whether an estimate is comprehensive, an objective review must be performed to certify that the estimate's criteria and requirements have been met, since they create the estimate's framework. This step also infuses quality assurance practices into the cost estimate. In this effort, the reviewer checks that the estimate captures the complete technical scope of the work to be performed, using a logical WBS that accounts for all performance criteria and requirements. In addition, the reviewer must determine that all assumptions and exclusions the estimate is based on are clearly identified, explained, and reasonable.

3. Determine That the Estimate Is Accurate

Estimates are accurate when they are not overly conservative or too optimistic, based on an assessment of most likely costs, adjusted properly for inflation, and contain few, if any, minor mistakes. In addition, when schedules or other assumptions change, cost estimates should be revised to reflect their current status.

Validating that a cost estimate is accurate requires thoroughly understanding and investigating how the cost model was constructed. For example, all WBS cost estimates should be checked to verify that calculations are accurate and account for all costs, including indirect costs. Moreover, proper escalation factors should be used to inflate costs so that they are expressed consistently and accurately. Finally, rechecking spreadsheet formulas and data input is imperative to validate cost model accuracy.

Besides these basic checks for accuracy, the estimating technique used for each cost element should be reviewed. Depending on the analytical method chosen, several questions should be answered to ensure accuracy. Table 26 outlines typical questions associated with various estimating techniques.

Table 26: Questions for Checking the Accuracy of Estimating Techniques

Technique	Question
Analogy	▪ What heritage programs and scaling factors were used to create the analogy? ▪ Are the analogous data from reliable sources? ▪ Did technical experts validate the scaling factor? ▪ Can any unusual requirements invalidate the analogy? ▪ Are the parameters used to develop an analogous factor similar to the program being estimated? ▪ How were adjustments made to account for differences between existing and new systems? Were they logical, credible, and acceptable?
Data collection	▪ How old are the data? Are they still relevant to the new program? ▪ Is there enough knowledge about the data source to determine if it can be used to estimate accurate costs for the new program? ▪ Has a data scatter plot been developed to determine whether any outliers, relationships, and trends exist? ▪ Were descriptive statistics generated to describe the data, including the historical average, mean, standard deviation, and coefficient of variation? ▪ If data outliers were removed, did the data fall outside three standard deviations? ▪ Were comparisons made to historical data to show they were an anomaly? ▪ Were the data properly normalized so that comparisons and projections are valid? ▪ Were the cost data adjusted for inflation so that they could be described in like terms?
Engineering build-up	▪ Was each WBS cost element defined in enough detail to use this method correctly? ▪ Are data adequate to accurately estimate the cost of each WBS element? ▪ Did experienced experts help determine a reasonable cost estimate? ▪ Was the estimate based on specific quantities that would be ordered at one time, allowing for quantity discounts? ▪ Did the estimate account for contractor material handling overhead? ▪ Is there a definitive understanding of each WBS cost element's composition? ▪ Were labor rates based on auditable sources? Did they include all applicable overhead, general and administrative costs, and fees? Were they consistent with industry standards? ▪ Is a detailed and accurate materials and parts list available?
Expert opinion	▪ Do quantitative historical data back up the expert opinion? ▪ How did the estimate account for the possibility that bias influenced the results?
Extrapolate from actuals (averages, learning curves, estimates at completion)	▪ Were cost reports used for extrapolation validated as accurate? ▪ Was the cost element at least 25% complete before using its data as an extrapolation? ▪ Were functional experts consulted to validate the reported percentage as complete? ▪ Were contractors interviewed to ensure the cost data's validity? ▪ Were recurring and nonrecurring costs separated to avoid double counting? ▪ How were first unit costs of the learning curve determined? What historical data were used to determine the learning curve slope? ▪ Were recurring and nonrecurring costs separated when the learning curve was developed? ▪ How were partial units treated in the learning curve equation? ▪ Were production rate effects considered? How were production break effects determined?

Technique	Question
Parametric	▪ Was a valid statistical relationship, or CER, between historical costs and program, physical, and performance characteristics established? ▪ How logical is the relationship between key cost drivers and cost? ▪ Was the CER used to develop the estimate validated and accepted? ▪ How old are the data in the CER database? Are they still relevant for the program being estimated? ▪ Do the independent variables for the program fall within the CER data range? ▪ What is the level of variation in the CER? How well does the CER explain the variation (R^2) and how much of the variation does the model not explain? ▪ Do any outliers affect the overall fit? ▪ How significant is the relationship between cost and its independent variables? ▪ How well does the CER predict costs?
Software estimating	▪ Was the software estimate broken into unique categories: new development, reuse, commercial off-the-shelf, modified code, glue code, integration? ▪ What input parameters—programmer skills, applications experience, development language, environment, process—were used for commercial software cost models, and how were they justified? ▪ How was the software effort sized? Was the sizing method reasonable? ▪ How were productivity factors determined? ▪ How were labor hours converted to cost? How many productive hours were assumed in each day? ▪ How were savings from autogenerated code and commercial off-the-shelf software estimated? Are the savings reasonable? ▪ What were the assumptions behind the amount of code reuse? Were they supported? ▪ How was the integration between the software, commercial software, system, and hardware estimated, and what historical data supported the results? ▪ Were software license costs based on actual or historical data? ▪ Were software maintenance costs adequately identified and reasonable?

Source: DOD, SCEA, and industry.

CERs and cost models also need to be validated to demonstrate that they can predict costs within an acceptable range of accuracy. To do this, data from historical programs similar to the new program should be collected to determine whether the CER selected is a reliable predictor of costs. In this review, technical parameters for the historical programs should be examined to determine whether they are similar to the program being estimated. For the CER to be accurate, the new and historical programs should have similar functions, objectives, and program factors, like acquisition strategy, or results could be misleading. Equally important, CERs should be developed with established and enforced policies and procedures that require staff to have proper experience and training to ensure the model's continued integrity.

Before a parametric model is used to develop an estimate, the model should be calibrated and validated to ensure that it is based on current, accurate, and complete data and is therefore a good predictor of cost. Like a CER, a parametric model is validated by determining that its users have enough experience and training and that formal estimating system policies and procedures have been established. The procedures focus on the model's background and history, identifying key cost drivers and recommending steps for calibrating and developing the estimate. To stay current, parametric models should be continually updated and calibrated.

Validation with calibration gives confidence that the model is a reliable estimating technique. To evaluate a model's ability to predict costs, a variety of assessment tests can be performed. One is to compare calibrated values with independent data that were not included in the model's calibration. Comparing the model's results to the independent test data's "known value" provides a useful benchmark for how accurately the model can predict costs. An alternative is to use the model to prepare an estimate and then compare its result with an independent estimate based on another estimating technique.

The accuracy of both CERs and parametric models can be verified with regression statistics, which measure the accuracy and goodness of fit, such as the coefficient of determination (R^2). CERs with an R^2 equal to 1.0 would indicate that the CER predicts the sample data perfectly. While this is hardly ever the case, an R^2 close to 1.0 is more accurate than an R^2 that is less than 0.70, meaning 30 percent of the variation is unexplained.

4. Determine That the Estimate Is Credible

Credible cost estimates clearly identify limitations because of uncertainty or bias surrounding the data or assumptions. Major assumptions should be varied and other outcomes recomputed to determine how sensitive outcomes are to changes in the assumptions. In addition, a risk and uncertainty analysis should be performed to determine the level of risk associated with the estimate. Finally, the results of the estimate should be cross-checked and an ICE performed to determine whether alternative estimate views produce similar results.

To determine an estimate's credibility, key cost elements should be tested for sensitivity, and other cost estimating techniques should be used to cross-check the reasonableness of GR&As. It is also important to determine how sensitive the final results are to changes in key assumptions and parameters. A sensitivity analysis identifies key elements that drive cost and permits what-if analysis, often used to develop cost ranges and risk reserves. This enables management to know the potential for cost growth and the reasons behind it.

Along with a sensitivity analysis, a risk and uncertainty analysis adds to the credibility of the cost estimate, because it identifies the level of confidence associated with achieving the cost estimate. Risk and uncertainty analysis produces more realistic results, because it assesses the variability in the cost estimate from such effects as schedules slipping, missions changing, and proposed solutions not meeting users' needs. An uncertainty analysis gives decision makers perspective on the potential variability of the estimate should facts, circumstances, and assumptions change. By examining the effects of varying the estimate's elements, a degree of uncertainty about the estimate can be expressed with a range of potential costs that is qualified by a factor of confidence.

Another way to reinforce the credibility of the cost estimate is to see whether applying a different method produces similar results. In addition, industry rules of thumb can constitute a sanity check. The main purpose of cross-checking is to determine whether alternative methods produce similar results. If so, then confidence in the estimate increases, leading to greater credibility. If not, then the cost estimator should examine and explain the reason for the difference and determine whether it is acceptable.

An ICE is considered one of the best and most reliable validation methods. ICEs are typically performed by organizations higher in the decision-making process than the office performing the baseline estimate. They provide an independent view of expected program costs that tests the program office's estimate for reasonableness. Therefore, ICEs can provide decision makers with additional insight into a program's potential costs—in part, because they frequently use different methods and are less burdened with organizational bias. Moreover, ICEs tend to incorporate adequate risk and, therefore, tend to be more conservative by forecasting higher costs than the program office.

The ICE is usually developed from the same technical baseline description the program office used so that the estimates are comparable. An ICE's major benefit is that it provides an objective and unbiased assessment of whether the program estimate can be achieved, reducing the risk that the program will proceed underfunded. It also can be used as a benchmark to assess the reasonableness of a contractor's proposed costs, improving management's ability to make sound investment decisions, and accurately assess the contractor's performance.

In most cases, the ICE team does not have insight into daily program events, so it is usually forced to estimate at a higher level or use analogous estimating techniques. It is, in fact, expected that the ICE team will use different estimating techniques and, where possible, data sources from those used to develop the baseline estimate. It is important for the ICE team and the program's cost estimate team to reconcile the two estimates.

Two issues with ICEs are the degree of independence and the depth of the analysis. Degree of independence depends on how far removed the estimator is from the program office. The greater the independence, the more detached and disinterested the cost estimator is in the program's success. The basic test for independence, therefore, is whether the cost estimator can be influenced by the program office.

Thus, independence is determined by the position of the cost estimator in relation to the program office and whether there is a common superior between the two. For example, if an independent cost estimator is hired by the program office, the estimator may be susceptible to success-oriented bias. When this happens, the ICE can end up too optimistic.

While an ICE reveals for decision makers any optimistic assumptions or items that may have been overlooked, in some cases management may choose to ignore it because the estimate is too high, as in case study 42.

History has shown a clear pattern of higher cost estimates the further away from the program office that the ICE is created. This is because the ICE team is more objective and less prone to accept optimistic assumptions. To be of value, however, an ICE must not only be performed by entities far removed from the acquiring program office but must also be accepted by management as a valuable risk reduction resource that can be used to minimize unrealistic expectations. The second issue with an ICE is the depth of the review.

Case Study 42: Independent Cost Estimates, from *Space Acquisitions*, GAO-07-96

In a review of the Advanced Extremely High Frequency (AEHF) satellite program, the National Polar-orbiting Operational Environmental Satellite System (NPOESS), and the Space Based Infrared System (SBIRS) High program, GAO found examples of program decision makers' not relying on independent cost estimates (ICE). Independent estimates had forecast considerably higher costs and lengthier schedules than program office or service cost estimates. To establish budgets for their programs, however, the milestone decision authorities had used program office estimates, or even lower estimates, rather than the independent estimates.

DOD's space acquisition policy required that ICEs be prepared outside the acquisition chain of command and that program and DOD decision makers consider them at key acquisition decision points. The policy did not require, however, that the independent estimates be relied on for setting budgets.

In 2004, AEHF program decision makers relied on the program office cost estimate rather than the independent estimate the CAIG had developed to support the production decision. The program office had estimated that AEHF would cost about $6 billion; the CAIG had estimated $8.7 billion, some $2.7 billion more.

The program office estimate was based on the assumption that AEHF would have ten times more capacity than Milstar, the predecessor satellite, at half the cost and weight. The CAIG believed that this assumption was overly optimistic, given that since AEHF began in 1999, its weight had more than doubled to obtain the desired increase in data rate.

NPOESS was another example of large differences between program office and independent cost estimates. In 2003, government decision makers relied on the program office's $7.2 billion cost estimate rather than the $8.8 billion independent cost estimate that the Air Force Cost Analysis Agency (AFCAA) had presented to support the development contract award. Program officials and decision makers had preferred the more optimistic assumptions and costs of the program office estimate, having viewed the independent estimate as too high.

The SBIRS High program office and AFCAA predicted program cost growth as early as 1996, when the program began. While the two estimates, in 2006 dollars, were close—$5.7 billion by the program office and $5.6 billion by AFCAA—both were much more than the contractor's estimate. Nevertheless, the program office budgeted SBIRS High at $3.6 billion, almost $2 billion less than either the program office or AFCAA had estimated.

GAO, *Space Acquisitions: DOD Needs to Take More Action to Address Unrealistic Initial Cost Estimates of Space Systems*, GAO-07-96 (Washington, D.C.: Nov. 17, 2006).

Table 27 lists eight types of ICE reviews and describes what they entail.

Table 27: Eight Types of Independent Cost Estimate Reviews

Review	Description
Document review	An inventory of existing documentation to determine whether information is missing and an assessment of the available documentation supports the estimate
Independent cost assessment	An outside evaluation of a program's cost estimate that examines its quality and accuracy, with emphasis on specific cost and technical risks; involves the same procedures as those of the program estimate but using different methods and techniques
Independent cost estimate	Conducted by an organization outside the acquisition chain, using the same detailed technical information as the program estimate, is a comparison with the program estimate to determine whether it is accurate and realistic
Independent government cost estimate	Analyzing contractors' prices or cost proposals, it estimates the cost of activities outlined in the statement of work; does not include all costs associated with a program and can only reflect costs from a contractor's viewpoint. Assumes that all technical challenges can be met as outlined in the proposal, meaning that it cannot account for potential risks associated with design problems
Nonadvocate review	Performed by experienced but independent internal nonadvocate staff, it ascertains the adequacy and accuracy of a program's estimated budget; assesses the validity of program scope, requirements, capabilities, acquisition strategy, and estimated life-cycle costs
Parametric estimating technique	Usually performed at the summary WBS level, includes all activities associated with a reasonableness review and incorporates cross-checks using parametric techniques and factors based on historical data to analyze the estimate's validity
Reasonableness, or sufficiency, review	A review of all documentation by an independent cost team, meeting with staff responsible for developing the program estimate, to analyze whether the estimate is sufficient with regard to the validity of cost and schedule assumptions and cost estimate methodology rationale and whether it is complete
Sampling technique	An independent estimate of key cost drivers of major WBS elements whose sensitivity affects the overall estimate; detailed independent government cost estimates developed for these key drivers include vendor quotes and material, labor, and subcontractor costs. Other program costs are estimated using the program estimate, as long as a reasonableness review has been conducted to ensure their validity

Source: DOD, DOE, and NASA.

As the table shows, the most rigorous independent review is an ICE. Other independent cost reviews address only a program's high-value, high-risk, and high-interest elements and simply pass through program estimate values for the other costs. While they are useful to management, not all provide the objectivity necessary to ensure that the estimate going forward for a decision is valid.

After an ICE or independent review is completed, it is reconciled to the baseline estimate to ensure that both estimates are based on the same GR&As. A synopsis of the estimates and their differences is then presented to management. Using this information, decision makers use the ICE or independent review to validate whether the program estimate is reasonable.

Since the ICE team is outside the acquisition chain, is not associated with the program, and has nothing at stake with regard to program outcome or funding decisions, its estimate is usually considered more accurate. Some ICEs are mandated by law, such as those for DOD's major acquisition programs. Nevertheless, the history of myriad DOD programs clearly shows that ICEs are usually higher, and more accurate, than baseline estimates. Thus, if a program cost estimate is close to ICE results, one can be more confident that it is accurate and more likely to result in funding at a reasonable level.

12. Best Practices Checklist: Validating the Estimate

The cost estimate was validated against four characteristics:

- ☐ It is comprehensive, includes all possible costs, ensures that no costs were omitted or double-counted, and explains and documents key assumptions.
  - ✓ It completely defines the program, reflects the current schedule, and contains technically reasonable assumptions.
  - ✓ It captures the complete technical scope of the work to be performed, using a logical WBS that accounts for all performance criteria and requirements.
- ☐ It was documented so well that it can easily be repeated or updated and traced to original sources by auditing.
  - ✓ Supporting documentation identifies data sources, justifies all assumptions, and describes all estimating methods (including relationships) for all WBS elements.
  - ✓ Schedule milestones and deliverables can be traced and are consistent with the documentation.
- ☐ It is accurate, not too conservative or too optimistic; is based on an assessment of most likely costs, adjusted properly for inflation; and contains few minor mistakes.
  - ✓ WBS estimates were checked to verify that calculations were accurate and accounted for all costs and that proper escalation factors were used to inflate costs so they were expressed consistently and accurately.
  - ✓ Questions associated with estimating techniques were answered to determine the estimate's accuracy.
  - ✓ CERs and parametric cost models were validated to ensure that they were good predictors of costs, their data were current and applied to the program, the relationships between technical parameters were logical and statistically significant, and results were tested with independent data.
- ☐ Data limitations from uncertainty or bias were identified; results were cross-checked; an ICE was developed to see if results were similar.
  - ✓ Major assumptions were varied and other outcomes recomputed to determine their sensitivity to changes in the assumptions.
  - ✓ Risk and uncertainty analysis was conducted.

CHAPTER 16

Documenting the Estimate

Well-documented cost estimates are considered a best practice for high-quality cost estimates, for several reasons.

- First, thorough documentation is essential for validating and defending a cost estimate. That is, a well documented estimate can present a convincing argument of an estimate's validity and can help answer decision makers' and oversight groups' probing questions.
- Second, documenting the estimate in detail, step by step, provides enough information so that someone unfamiliar with the program could easily recreate or update it.
- Third, good documentation helps with analyzing changes in program costs and contributes to the collection of cost and technical data that can be used to support future cost estimates.
- Finally, a well-documented cost estimate is essential if an effective independent review is to ensure that it is valid and credible. It also supports reconciling differences with an independent cost estimate, improving understanding of the cost elements and their differences so that decision makers can be better informed.

Documentation provides total recall of the estimate's detail so that it can be replicated by someone other than those who prepared it. It also serves as a reference to support future estimates. Documenting the cost estimate makes available a written justification showing how it was developed and aiding in updating it as key assumptions change and more information becomes available.

Estimates should be documented to show all parameters, assumptions, descriptions, methods, and calculations used to develop a cost estimate. A best practice is to use both a narrative and cost tables to describe the basis for the estimate, with a focus on the methods and calculations used to derive the estimate. With this standard approach, the documentation provides a clear understanding of how the cost estimate was constructed. Moreover, cost estimate documentation should explain why particular methods and data sets were chosen and why these choices are reasonable. It should also reveal the pros and cons of each method selected. Finally, there should be enough detail so that the documentation serves as an audit trail of backup data, methods, and results, allowing for clear tracking of a program's costs as it moves through its various life-cycle phases.

Estimates that lack documentation are not useful for updates or information sharing and can hinder understanding and proper use. Experience shows that poorly documented estimates can cause a program's credibility to suffer because the documentation cannot explain the rationale of the underlying cost elements. Case study 43 takes a closer look at the effect a poorly documented cost estimate can have on decision making.

Case Study 43: Documenting the Estimate, from *Telecommunications*, GAO-07-268

The General Services Administration (GSA) provided GAO with documentation of its method, the calculations it used to derive each cost element, its results, and many of the previous transition costs for Networx—its program of governmentwide telecommunications contracts enabling agencies to make a transition to new, innovative services and operations. It had not, however, documented significant assumptions. Specifically, GSA had not documented the rationale behind its 76 percent transition traffic factor or why it had chosen 30 months for the transition—two key assumptions of its analysis.

GSA also did not provide documentation of certain data sources. Specifically, program officials could not provide supporting data for the estimate of an agency transition cost valued at $4.7 million. Likewise, GSA could not document the data sources used to estimate costs for contractor support in planning and implementing the transition. While many costs in its estimate were based on charges incurred during the previous transition, GSA officials stated that it was not appropriate to use previous costs as a basis for the contractor cost element.

They explained that unlike the previous transition, GSA would not provide agencies with on-site contractor support. They had made this decision because, in part, the 2-1/2 years of transition planning that had taken place was expected to result in the agencies' better preparation and ability to facilitate making their transition without direct assistance from GSA or its contractors.

Instead of basing projection of contractor costs on prior charges, program officials told GAO that GSA management had decided that contractor support costs should not exceed $35 million. Program officials could not provide any data or analysis to support this decision.

GSA had not used sound analysis when estimating the funds needed to meet its transition-related commitments. These weaknesses could be attributed, in part, to the lack of a cost estimation policy that reflected best practices. While GSA's intentionally conservative approach minimized the risk that it would have inadequate funds to pay for committed transition costs, it increased the risk that GSA would retain excess funds that could be used for other purposes.

GAO, *Telecommunications: GSA Has Accumulated Adequate Funding for Transition to New Contracts but Needs Cost Estimation Policy*, GAO-07-268 (Washington, D.C.: Feb. 23, 2007).

In addition to these requirements, good documentation is necessary to

- satisfy policy requirements for properly recording the basis of the estimate,
- convince management and oversight staff that the estimate is credible,
- provide supporting data that can be used to create a historical database,
- help answer questions about the approach or data used to create the estimate,
- record lessons learned and provide a history for tracking why costs changed,
- define the scope of the analysis,

- allow for replication so that an analyst unfamiliar with the program can understand the logic behind the estimate, and
- help conduct future cost estimates and train junior analysts.

Elements of Cost Estimate Documentation

Two important criteria should be kept in mind when generating high-quality cost estimate documentation. First, it should describe the cost estimating process, data sources, and methods and should be clearly detailed to allow anyone to easily reconstruct the estimate. Second, the results of the estimating process should be presented in a format that makes it easy to prepare reports and briefings to upper management.

Cost estimators should document all the steps used to develop the estimate. As a best practice, the cost estimate documentation should address how the estimate satisfies the 12-step process and corresponding best practices identified in this guide for creating high-quality cost estimates. Table 28 describes the various sections of proper documentation and what they should include.

Table 28: What Cost Estimate Documentation Includes

Document section and cost-estimating step	Description
Cover page and table of contents	
2–3	▪ Names the cost estimators, the organization they belong to, etc. ▪ Gives the program's name, date, and milestones ▪ Lists the document's contents, including supporting appendixes
Executive summary	
6–9	▪ Summarizes clearly and concisely the cost estimate results, with enough information about cost drivers and high-risk areas for management to make informed decisions ▪ Presents a time-phased display of the LCCE in constant and current year dollars, broken out by major WBS cost elements; if an update, tracks the results and discusses lessons learned ▪ Identifies critical ground rules and assumptions ▪ Identifies data sources and methods used to develop major WBS cost elements and reasons for each approach ▪ Discusses ICE results and differences and explains whether the point estimate can be considered reasonable ▪ Discusses the results of a sensitivity analysis, the level of uncertainty associated with the point estimate, and any contingency reserve recommendations and compares them to the funding profile
Introduction	
1–5	▪ Gives a program overview: who estimated it, how cost was estimated, the date associated with the estimate ▪ Addresses the estimate's purpose, need, and whether it is an initial estimate or update ▪ Names the requester, citing tasks assigned and related correspondence (in an appendix, if necessary) ▪ Gives the estimate's scope, describing major program phases and their estimated time periods, and what the estimate includes and excludes, with reasons ▪ Describes GR&As and technical and program assumptions, such as inflation rates

Document section and cost-estimating step	Description
System description	
5	▪ Describes the program background and system, with detailed technical and program data, major system components, performance parameters, and support requirements ▪ Describes contract type, acquisition strategy, and other information in the technical baseline description
Program inputs	
1–3	▪ Gives the team composition—names, organizational affiliations, who was responsible for developing the estimate ▪ Details the program schedule, including master schedule and deliverables ▪ Describes the acquisition strategy
Estimating method and data by WBS cost element	
6, 7, 10	▪ The bulk of the documentation, describing in a logical flow how each WBS cost element in the executive summary was estimated; details each cost element enough that someone independent of the program recreating the estimate could arrive at the same results. Supporting information too detailed for this section is placed in an appendix ▪ Defines the cost element and describes how it was derived ▪ Summarizes costs spread by fiscal year in constant year dollars, matching the current program schedule ▪ Details the method, sources, models, and calculations for developing the estimate; fully documents CERs, including the rationale for the relationship between cost and the independent variables, the applicable range for independent variables, and the process for validating the CER, including descriptive statistics associated with the relationship ▪ If cost models were used, documents input and output data and any calibrations to the model; the cost model, data input, and results are in an appendix ▪ Documents the data in detail with a display of all database information used for parametric or analogy-based estimates; describes judgments about parametric variables, analogy scaling, or complexity factors and adjustments of the data; identifies data limitations and qualifies the data, based on sources (historical data, budget estimates), time periods they represent, and adjustments to normalize them or account for significant events like production breaks
6, 7, 10	▪ Identifies direct and indirect labor rates, labor hours, material and subcontractor costs, overhead rates, learning curves, inflation indexes, and factors, including their basis ▪ Shows the calculation of the cost estimate, with a logical link to input data ▪ Identifies and discusses significant cost drivers; identifies specialists whose judgments were used and their qualifications ▪ Discusses the cross-check approach for validating the estimate ▪ Discusses the ICE's results and differences and whether it corroborates the point estimate as reasonable
Sensitivity analysis	
8	▪ Describes the effect of changing key cost drivers and assumptions independently ▪ Identifies the major cost drivers that should be closely monitored

Document section and cost-estimating step	Description
Risk and uncertainty analysis	
9	▪ Discusses sources of risk and uncertainty, including critical assumptions, associated with the estimate ▪ The effect of uncertainty associated with the point estimate is quantified with probability distributions, and the resulting S curve is fully documented; the method for quantifying uncertainty is discussed and backed up by supporting data ▪ The basis for contingency reserves and how they were calculated is fully documented
Management approval	
11	▪ Includes briefings presenting the LCCE to management for approval, explaining the technical and program baseline, estimating approach, sensitivity analysis, risk and uncertainty analysis, ICE results and reasons for differences, and an affordability analysis to identify any funding shortfalls ▪ Presents the estimate's limitations and strengths ▪ Includes management approval memorandums, recommendations for change, and feedback
Updates reflecting actual costs and changes	
12	▪ Reflects changes in technical or program assumptions or new program phases or milestones ▪ Replaces estimates with actual costs from the EVM system and reports progress on meeting cost and schedule estimates ▪ Includes results of post mortems and lessons learned, with precise reasons for why actual costs or schedules differ from the estimate

Source: DOD, DHS, DOE, NASA, SCEA, and industry.

While documentation of the cost estimate is typically in the form of a written document, the documentation can be completed in other acceptable ways. For example, some organizations rely on cost models that automatically develop documentation, while others use detailed MS Excel spreadsheets with cell notes and hyperlinks to other documents. The important thing to consider is whether the documentation allows someone to trace the data, calculations, modeling assumptions, and rationale back to a source document for verification and validation. In addition, it should also address the reconciliation with the independent cost estimate so that others can understand areas of risk.

Other Considerations

Documenting the cost estimate should not be a last-minute effort. If documentation is left untouched until the end of the estimating process, it will be much harder to recapture the rationale and judgments that formed the cost estimate and will increase the chance of overlooking important information that can cause credibility issues. Documentation should be done in parallel with the estimate's development, so that the quality of the data, methods, and rationale are fully justified. More information is preferred over too little, since the purpose of documenting the estimate is to allow for recreating it or updating it by someone else who knows nothing about the program or estimate. Consequently, documentation should be written step by step and should include everything necessary for another analyst to easily and quickly replicate the estimate and arrive at the same results. In addition, access to an electronic copy of the cost model supporting the estimate should be available with the documentation so that updates can be performed efficiently. Finally, the cost estimate and documentation need to be stored so that authorized personnel can easily find it and use it for future estimates.

13. Best Practices Checklist: Documenting the Estimate

- ☐ The documentation describes the cost estimating process, data sources, and methods step by step so that a cost analyst unfamiliar with the program could understand what was done and replicate it.
  - ✓ Supporting data are adequate for easily updating the estimate to reflect actual costs or program changes and using them for future estimates.
  - ✓ The documentation describes the estimate with narrative and cost tables.
  - ✓ It contains an executive summary, introduction, and descriptions of methods, with data broken out by WBS cost elements, sensitivity analysis, risk and uncertainty analysis, management approval, and updates that reflect actual costs and changes.
  - ✓ Detail addresses best practices and the 12 steps of high-quality estimates.
  - ✓ The documentation is mathematically sensible and logical.
  - ✓ It discusses contingency reserves and how they were derived from risk and uncertainty analysis and the LCCE funding profile.
- ☐ It includes access to an electronic copy, and both are stored so that authorized personnel can easily find and use them for other cost estimates.

CHAPTER 17

Presenting the Estimate to Management

A cost estimate is not considered valid until management has approved it. Since many cost estimates are developed to support a budget request or make a decision between competing alternatives, it is vital that management is briefed on how the estimate was developed, including risks associated with the underlying data and methods. Therefore, the cost estimator should prepare a briefing for management with enough detail to easily defend the estimate by showing how it is accurate, complete, and high in quality. The briefing should present the documented LCCE with an explanation of the program's technical and program baseline.

The briefing should be clear and complete, making it easy for those unfamiliar with the estimate to comprehend its level of competence. The briefing should focus on illustrating to management, in a logical manner, what the largest cost drivers are. Slides with visuals should be available to answer more probing questions. A best practice is to present the briefing in a consistent format to facilitate management's understanding the completeness of the cost estimate, as well as its quality. Moreover, decision makers who are familiar with a standard briefing format will be better able to concentrate on the briefing's contents, and on the cost estimate, rather than focusing on the format itself.

The cost estimate briefing should succinctly illustrate key points that center on the main cost drivers and the final cost estimate's outcome. Communicating results simply and clearly engenders management confidence in the ground rules, methods, and results and in the process that was followed to develop the estimate. The presentation must include program and technical information specific to the program, along with displays of budget implications, contractor staffing levels, and industrial base considerations, to name a few. These items should be included in the briefing:

- The title page, briefing date, and the name of the person being briefed.
- A top-level outline.
- The estimate's purpose: why it was developed and what approval is needed.
- A brief program overview: its physical and performance characteristics and acquisition strategy, sufficient to understand its technical foundation and objectives.
- Estimating ground rules and assumptions.
- Life-cycle cost estimate: time-phased in constant-year dollars and tracked to any previous estimate.
- For each WBS cost element, show the estimating method for cost drivers and high-value items; show a breakout of cost elements and their percentage of the total cost estimate to identify key cost drivers.
- Sensitivity analysis, interpreting results carefully if there is a high degree of sensitivity.
- Discussion of risk and uncertainty analysis: (1) cost drivers, the magnitude of outside influences, contingencies, and the confidence interval surrounding the point estimate and the corresponding

S curve showing the range within which the actual estimate should fall; (2) other historic data for reality checks; and (3) how uncertainty, bounds, and distributions were defined.

- Comparison to an independent cost estimate, explaining differences and discussing results.
- Comparison of the LCCE, expressed in current-year dollars, to the funding profile, including contingency reserve based on the risk analysis and any budget shortfall and its effect.
- Concerns or challenges the audience should be aware of.
- Conclusions, recommendations, and associated level of confidence in the estimate.

When briefing management on LCCEs, the presenter should include separate sections for each program phase—research and development, procurement, operations and support, disposal—and should provide the same type of information as the cost estimate documentation contains. In addition, the briefing should present the summary information, main conclusions, and recommendations first, followed by detailed explanations of the estimating process.

This approach allows management to gain confidence in the estimating process and, thus, the estimate itself. At the conclusion of the briefing, the cost estimator should ask management whether it accepts the cost estimate. Acceptance, along with any feedback from management, should be acted on and documented in the cost estimate documentation package.

14. Best Practices Checklist: Presenting the Estimate to Management

- ☐ The briefing to management
  - ✓ was simple, clear, and concise enough to convey its level of competence.
  - ✓ illustrated the largest cost drivers, presenting them logically, with backup charts for responding to more probing questions.
  - ✓ was consistent, allowing management to focus on the estimate's content.
- ☐ The briefing contained
  - ✓ A title page, outline, and brief statement of purpose of the estimate.
  - ✓ An overview of the program's technical foundation and objectives.
  - ✓ LCCE results in time-phased constant-year dollars, tracked to previous estimates.
  - ✓ A discussion of GR&As.
  - ✓ The method and process for each WBS cost element, with estimating techniques and data sources.
  - ✓ The results of sensitivity analysis and cost drivers that were identified.
  - ✓ The results of risk and uncertainty analysis with confidence interval, S curve analysis, and bounds and distributions.
  - ✓ The comparison of the point estimate to an ICE with discussion of differences and whether the point estimate was reasonable.
  - ✓ An affordability analysis based on funding and contingency reserves.
  - ✓ Discussion of any other concerns or challenges
  - ✓ Conclusions and recommendations.
- ☐ Feedback from the briefing, including management's acceptance of the estimate, was acted on and recorded in the cost estimate documentation.

CHAPTER 18

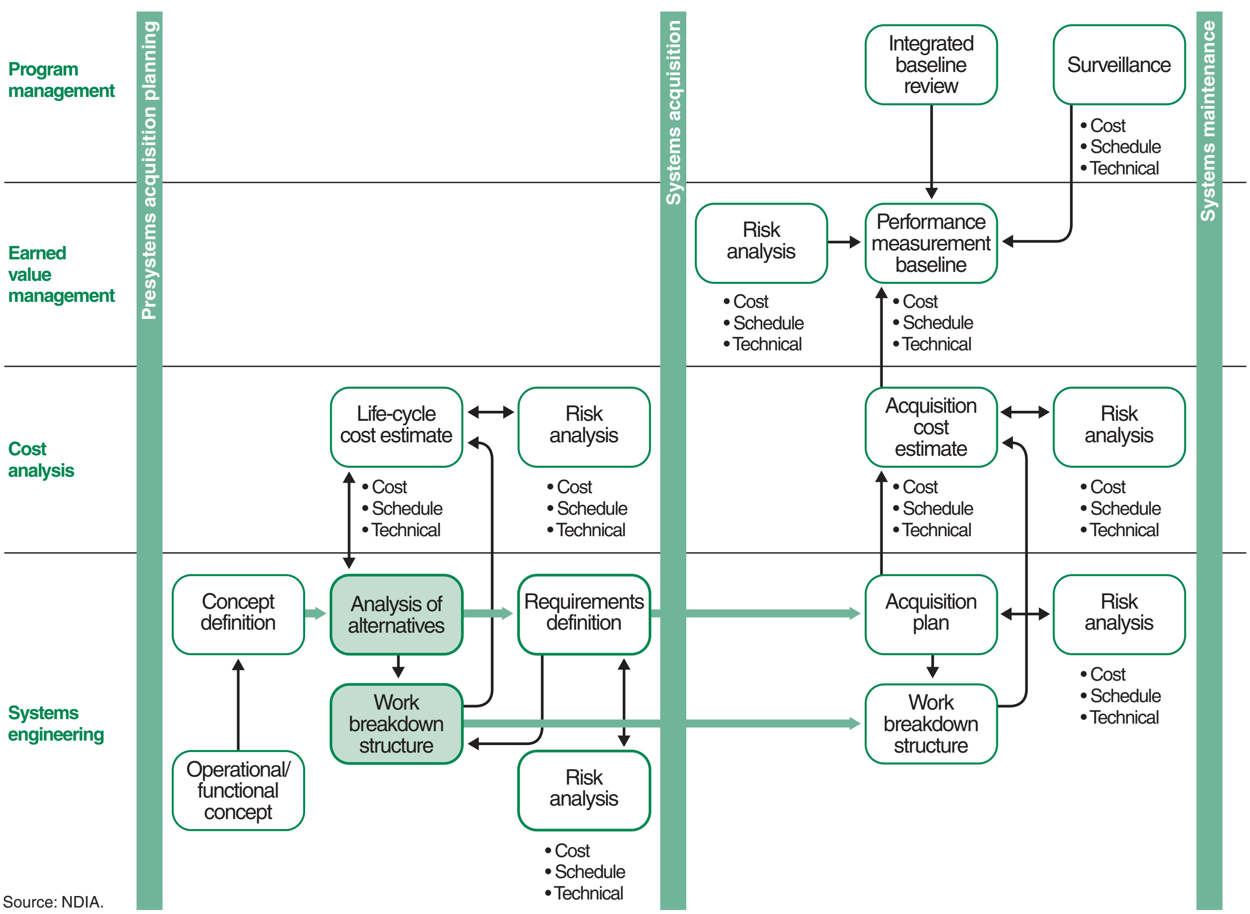
Managing Program Costs: Planning

In this chapter, we review the importance of obtaining the best perspective on a program and its inherent risks by linking cost estimating and EVM. We describe a best practice for cost estimators and EVM analysts: sharing data to update program costs and examining differences between estimated and actual costs to present scope changes, risks, and other opportunities to management with sufficient lead time to plan for and mitigate their impact. Then we summarize the history and nature of EVM—its concepts, tools, and benefits. Finally, we describe EVM as managing program costs through proper planning.

Linking Cost Estimation as the Foundation for EVM Analysis

A credible cost estimate lies at the heart of EVM analysis. Figure 20 depicts how cost estimating supports the EVM process. It also lays out the specific flow of activity between key functions such as cost estimation, system development oversight, and risk management.

Figure 20: Integrating Cost Estimation, Systems Development Oversight, and Risk Management



Source: NDIA.

As the lower left of figure 20 shows, a program's life cycle begins with planning, where systems engineering defines the program's concept, requirements, and WBS. When these activities are complete, the information is passed on to the cost analysis team so that they can develop the program's LCCE. Before a system is acquired, however, a risk analysis examining cost, schedule, and technical impacts is performed. The results of the LCCE and risk analysis are presented to executive management for an informed decision on whether the program should proceed to systems acquisition.

If management approves the program for acquisition, then systems engineering and cost analyses continue, in conjunction with the development of the program's EVM performance measurement baseline. [61] This baseline is necessary for defining the time-phased budget plan from which actual program performance is measured. After the performance measurement baseline has been established, the program manager and supplier participate in an IBR to ensure mutual understanding of all the risks. This review also validates that the program baseline is adequate and realistically portrays all authorized work according to the schedule. When appropriate, an IBR may begin before contract award to mitigate risk. The Federal Acquisition Regulation (FAR) provides for a pre-award IBR as an option, in accordance with agency procedures.[62]

Preparing for and managing program risk occurs during both planning and system acquisition. In planning, a detailed WBS is developed that completely defines the program and encompasses all risks from program initiation through assigning adequate resources to perform the work. During acquisition, risks are linked to specific WBS elements so that they can be prioritized and tracked through risk management, using data from systems engineering, cost estimating, risk analysis, and program management. These efforts should result in an executable program baseline that is based on realistic cost, schedule, and technical goals and that provides a mechanism for addressing risks.

Cost Estimation and EVM in System Development Oversight

Government cost estimating and EVM are often conducted by different groups that barely interact during system development. As a result, program managers do not benefit from an integration of their efforts. Once the cost estimate has been developed and approved, cost estimators tend to move on to the next program, often not updating the cost estimate with actual costs after a contract has been awarded. In some cases, cost estimators do not update a cost estimate unless significant cost overruns or schedule delays have occurred or major requirements have changed.

Also, EVM analysts are usually not that familiar with a program's technical baseline document, GR&As, and cost estimate data or methodology. They tend to start monitoring programs without adequate knowledge of where and why risks are associated with the underlying cost estimate. Limited integration can mean that

- cost estimators may update the program estimate without fully understanding what the earned value data represent,

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[61] The system acquisition phase includes both contract and in-house organization efforts. If in-house staffing is selected, the effort should be managed in the same way as contract work. This means that in-house efforts are expected to meet the same cost, schedule, and technical performance goals that would be required for contract work to ensure the greatest probability of program success.

[62] Federal Acquisition Regulation (FAR), 48 C.F.R. § 34.202 (added by Federal Acquisition Circular 2005-11, July 5, 2006).

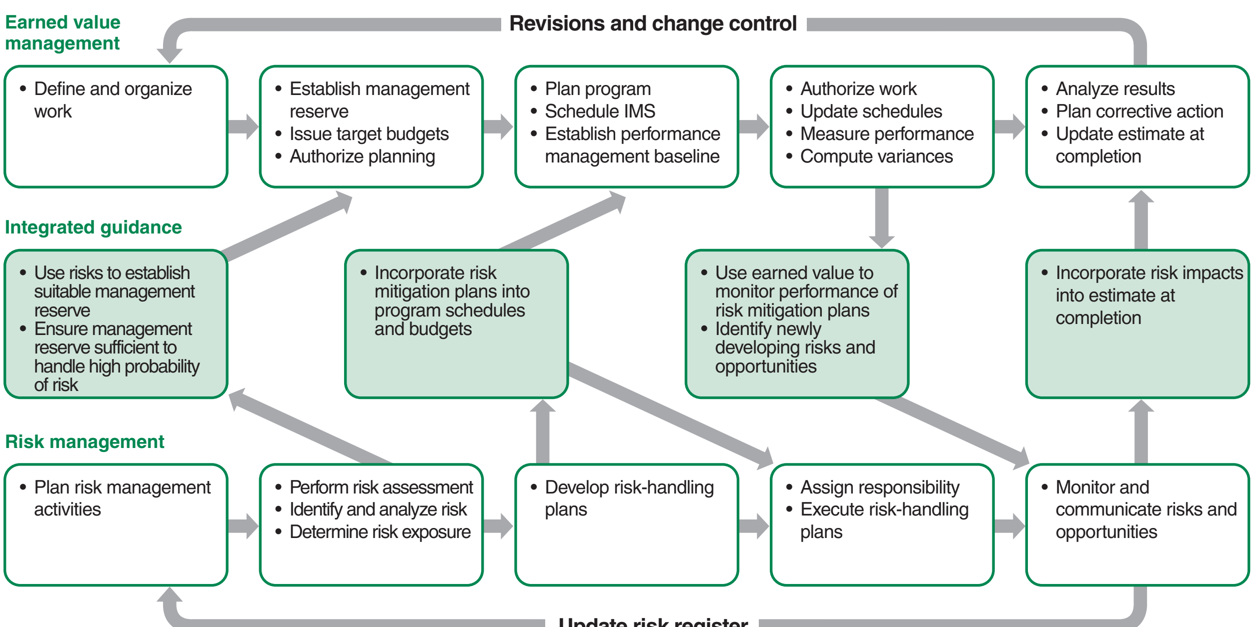
- EVM analysts do not benefit from cost estimators' insight into the possible cost and schedule risks associated with the program, and
- neither fully understands how risks identified with the cost estimate S curve (or cumulative probability distribution) translate into the program's performance measurement baseline.

Therefore, it is considered a best practice to link cost estimating and EVM analysis. Joining forces, cost estimators and EVM analysts can use each other's data to update program costs and examine differences between estimated and actual costs. Scope changes, risks, and opportunities can be presented to management in time to plan for or mitigate them. Program status can be compared to historical data to understand variances. Finally, cost estimators can help EVM analysts calculate a cumulative probability distribution to determine the confidence level in the baseline.

EVM and Acquisition: A Baseline for Risk Management

Using generally accepted risk management techniques, a program manager can decide how much management reserve budget to set aside to cover risks that were unknown at the program's start. As the program develops according to the baseline plan, metrics from the EVM system can be analyzed to identify risks that have been realized, as well as emerging risks and opportunities. By integrating EVM data and risk management, program managers can develop EACs for all management levels, including OMB reporting requirements. In figure 21, EVM is integrated with risk management for a better program view.

Figure 21: Integrating EVM and Risk Management



Source: NDIA.

Often, organizational barriers can keep the EVM and risk management processes independent of one another rather than tightly integrated. Senior management should encourage cross-organizational communication and training between these two disciplines to ensure that they are working together to better manage the risks facing a program. Doing so will promote a thorough understanding of program risks and help improve risk mitigation. Additionally, addressing risk in the formulation of the program EVM baseline will result in higher credibility and the greater likelihood of success. Risk identification and mitigation plans should be provided to the IBR team before the IBR and assessed as part of the IBR process. Next, we turn to what EVM is, what some of its concepts are, and how to use its tools and gain from its benefits.

The Nature and History of EVM

What EVM Is

Earned value management goes beyond simply comparing budgeted costs to actual costs. It measures the value of work accomplished in a given period and compares it with the planned value of work scheduled for that period and with the actual cost of work accomplished. By using the metrics derived from these values to understand performance status and to estimate cost and time to complete, EVM can alert program managers to potential problems sooner than expenditures alone can.

Assume, for example, that a contract calls for 4 miles of railroad track to be laid in 4 weeks at a cost of $4 million. After 3 weeks of work, only $2 million has been spent. An analysis of planned versus actual expenditures suggests that the project is underrunning its estimated costs. However, an earned value analysis reveals that the project is in trouble because even though only $2 million has been spent, only 1 mile of track has been laid and, therefore, the contract is only 25 percent complete. Given the value of work done, the project will cost the contractor $8 million ($2 million to complete each mile of track), and the 4 miles of track will take a total of 12 weeks to complete (3 weeks for each mile of track) instead of the originally estimated 4 weeks.

Thus, EVM is a means of cost and schedule performance analysis. By knowing what the planned cost is at any time and comparing that value to the planned cost of completed work and to the actual cost incurred, analysts can measure the program's cost and schedule status. Without knowing the planned cost of completed work and work in progress (that is, earned value), true program status cannot be determined. Earned value provides the missing information necessary for understanding the health of a program; it provides an objective view of program status. Moreover, because EVM provides data in consistent units (usually labor hours or dollars), the progress of vastly different work efforts can be combined. For example, earned value can be used to combine feet of cabling, square feet of sheet metal, or tons of rebar with effort for systems design and development. That is, earned value can be employed as long as a program is broken down into well-defined tasks.

EVM's History

EVM is not a new concept. It has been around in one form or another since the early 1900s, when industrial engineers used it to assess factory performance. They compared physical work output—earned value, or something gained through some effort—to the planned physical work and subsequent actual costs. In the 1920s, General Motors used a form of EVM called flexible budgets; by the early 1960s, EVM had graduated to the Program Evaluation and Review Technique, which relied on resource loaded networked schedules and budgets to plan and manage work.

In 1967, DOD adopted EVM as Cost/Schedule and Control System Criteria (C/SCSC). These criteria, based on the best management practices used in American industry since the early 1900s, defined for defense contractors the minimum acceptable standards for providing the government with objective program performance reporting. C/SCSC also required contractors to integrate effort, schedule, and cost into a single plan. This was a broad divergence from DOD's typical analysis of "spend plans"—comparing planned costs to actual costs—which gave no insight into what was actually accomplished for the money spent.

Earned value technique now required contractors to report progress on cost, schedule, and technical achievement, giving managers access for the first time to timely and accurate status updates. The data gave managers the ability to confidently predict how much money it would cost and how long it would take to complete a contract. Rather than enforcing a particular system for contractors to implement, however, C/SCSC required them to develop their own management control systems that could satisfy the standards to use earned value effectively.

Along with the many benefits to implementing C/SCSC came many problems. For instance, some programs found C/SCSC criteria overwhelming, causing them to maintain two sets of data—one for managing the program and one for reporting C/SCSC data. In other instances, EVM was viewed only as a financial management tool to be administered with audit-like rigor. A 1997 GAO report found that while EVM was intended to serve many different groups, program managers often ignored the data even though they could have benefited from responding to impending cost and schedule overruns on major contracts.

To try to resolve these problems, the Office of the Secretary of Defense encouraged industry to define new EVM criteria that were more flexible and useful to industry and government. In 1996, DOD accepted industry's revamped criteria, stating that they brought EVM back to its intended purposes of integrating cost, schedule, and technical effort for management and providing reliable data to decision makers.

EVM Guidelines in Practice Today

The new EVM approach encompasses 32 guidelines, organized into 5 categories of effort: (1) organizing, (2) planning and budgeting, (3) accounting, (4) analysis, and (5) making revisions. The guidelines define the major principles for managing programs, including, among other things,

- defining and detailed planning of the scope of work using a WBS,
- identifying organizational responsibility for doing the work,
- scheduling authorized work,
- applying realistic resources and budget to complete the work,
- measuring the progress of work by objective indicators,
- developing a project measurement baseline,
- collecting the cost of labor and materials associated with the work performed,
- analyzing variances from planned cost and schedules,
- forecasting costs at completion,
- taking management actions to control risk, and
- controlling changes.

The EVM guidelines today are often viewed as common sense program management practices that would be necessary to successfully manage any development program, regardless of size, cost, or complexity. Moreover, they have become the standard for EVM and have been adopted by industry, major U.S. government agencies, and government agencies in Australia, Canada, Japan, Sweden, and the United Kingdom. Furthermore, when reviewing agencies' annual budget requests, OMB uses agency-reported EVM data to decide which acquisition programs to continue funding. Accordingly, government and industry consider EVM a worldwide best practice management tool for improving program performance.

As a key management concept, EVM has evolved from an industrial engineering tool to a government and industry best practice, providing improved oversight of acquisition programs. Using EVM is like forming an intelligent plan that first identifies what needs to be done and then uses objective measures of progress to predict future effort. Commercial firms told us that they use the earned value concept to manage their programs because they believe that good up-front technical planning and scheduling not only make sense but are essential for delivering successful programs.

Implementing EVM

For EVM to be effective, strong leadership from the top is necessary to create a shared vision of success that brings together areas often stove-piped by organizational boundaries. To accomplish this shared vision, senior management should set an expectation that reliable and credible data are key aspects to managing a successful program and show an active interest in program status to send a message to their staff that they are accountable and that results matter. Accordingly, stakeholders need to take an interest in and empower those doing the work and make sure that corporate practices are in place that allow them to know the truth about how a program is doing. Leadership must require information sharing in an open, honest, and timely fashion so it can provide resources and expertise immediately when problems begin to arise.

To ingrain this expectation, agencies should set forth policies that clearly define and require disciplined program management practices for planning and execution. As part of that policy, the focus should be on integrating cost, schedule, and technical performance data so that objective program progress can be measured and deviations from the baseline acted upon quickly. Moreover, the policy should also address the importance of continuous training in cost estimating, EVM, scheduling, and risk and uncertainty analysis that will provide the organization with high-performing and accountable people who are experienced in these essential disciplines. Training should be provided and enforced for all program personnel needing such training, not just those with program management responsibilities. While program managers and staff need to be able to interpret and validate EVM data to effectively manage deliverables, costs, and schedules, oversight personnel and decision-makers also need to understand EVM terms and analysis products in order to ask the right questions, obtain performance views into the program, and make sound investment decisions.

The Purpose of Implementing an EVM System

Using the value of completed work for estimating the cost and time needed to complete a program should alert program managers to potential problems early in the program and reduce the chance and magnitude of cost overruns and schedule delays. EVM also provides program managers with early warning of developing trends—both problems and opportunities—allowing them to focus on the most critical issues.

The two main purposes for implementing an EVM system are to (1) encourage the use of effective internal cost and schedule management control systems and (2) allow the customer to rely on timely and accurate data for determining product-oriented contract status. To be effective, an EVM system should constitute management processes that serve as a comprehensive tool for integrating program planning and execution across cost, schedule, and technical disciplines. In essence, an EVM system should provide the means for planning, reporting, and analyzing program performance.

EVM as a Planning Tool

EVM imposes the discipline of planning all work in sufficient detail so that the cost, technical effort, and schedule dependencies are known at the outset. When EVM is used as a planning tool, all work is planned from the beginning—current work in detail, future work outlined at higher levels. As the work is planned to a manageable level of detail, it is broken into descriptive work packages that are allocated a portion of the program budget. These units are then spread across the program schedule to form the performance measurement baseline, which is used to detect deviations from the plan and give insight into problems and potential impacts.

EVM as a Management Reporting Tool

EVM objectively measures program status with objective methods such as discrete units and weighted milestones to determine work accomplished. These measures are based on specific criteria that are defined before the work starts. As work is accomplished, its value is measured against a time-phased schedule. While the guidelines require no specific scheduling technique, more complex programs typically use a networked schedule that highlights the program's critical path.[63] The earned value is measured in terms of the planned cost of work actually completed. This difference of including earned value allows for objective measurements of program status that other reporting systems cannot provide.

EVM as an Analysis and Decision Support Tool

EVM indicates how past performance may affect future performance. For example, EVM data isolate cost and schedule variances by WBS element, allowing an understanding of technical problems that may be causing the variances. Problems can be seen and mitigated early. In addition, opportunity can be taken in areas that are performing well to reallocate available budgets for work that has not yet started.[64]

Key Benefits of Implementing EVM

Table 29 describes some of the key benefits that can be derived from successfully implementing an EVM system, and figure 22 shows the expected inputs and outputs associated with tracking earned value.

[63] DOD interprets the guidelines to require a network schedule.

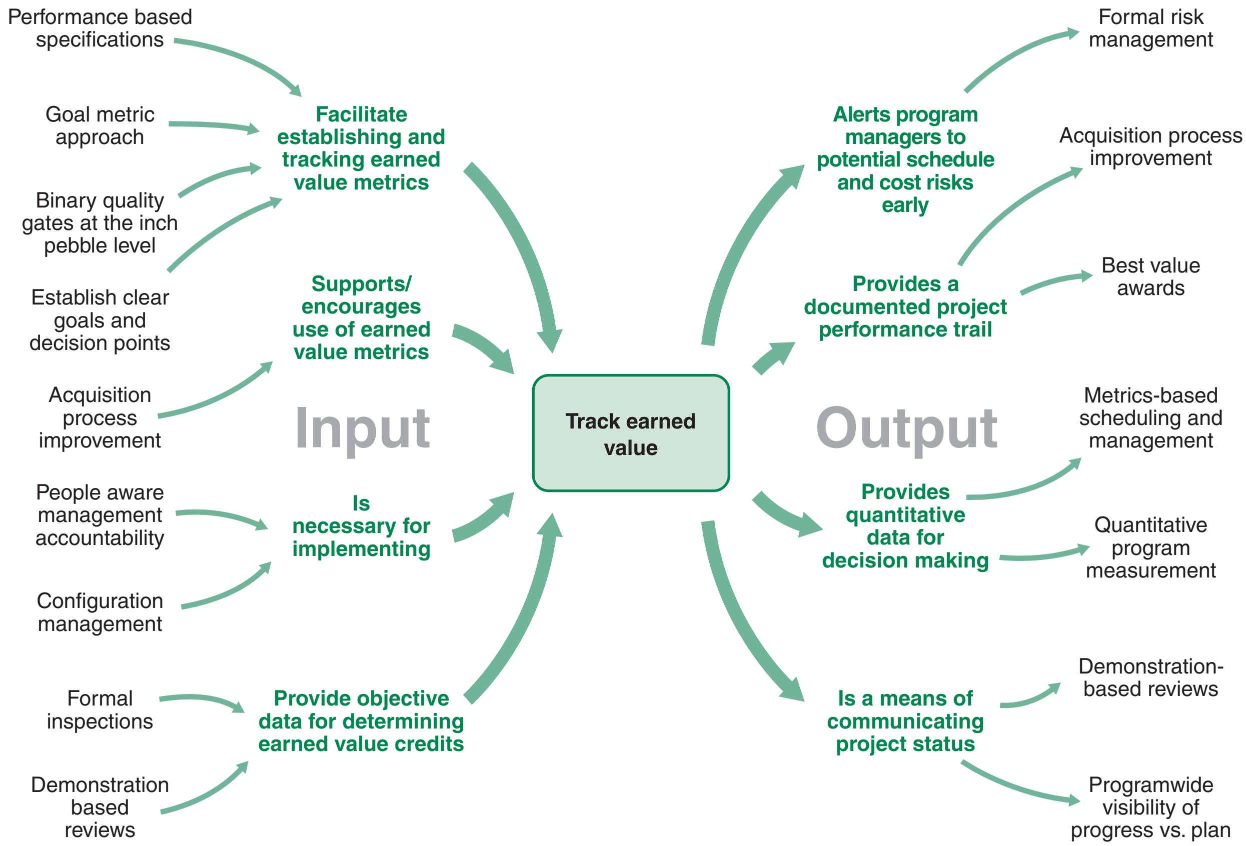
[64] We consulted the expert community on the issue of reallocation of budget for completed activities that underrun. The experts explained that while the term budget in EVM represents the plan, it is not the same thing as funding. Therefore, in EVM, a control account's budget is fully earned once the effort is 100 percent complete, even if the actual cost of the effort was more or less than the budget. As a result, budget for past work, earned value, and actual costs need to stay together in an EVM system in order to maintain reporting integrity. However, if a WBS control account's or work package's actual cost (WBS) is under running the planned budget, this may suggest that the budget for future work packages may be over budgeted as well. If that is the case, then budget for future work could be recalled into management reserve to be available for critical path activities. According to the EVM guidelines, a contractor's EVM system should allow for that.

Table 29: Key Benefits of Implementing EVM

Key benefit	Description
Provides a single management control system	■ The criteria for developing an EVM system promote the integration of cost, schedule, and technical processes with risk management, improving the efficiency and effectiveness of program management; they require measuring progress, accumulating actual costs, analyzing variances, forecasting costs at completion, and incorporating changes in a timely manner ■ Implemented correctly, EVM provides a single management control system that prevents organizations from managing with one system and reporting from another. The concept that all work should be scheduled and traceable from the master plan to the details demonstrates that no specific scheduling software is required
Improves insight into program performance	■ Enhanced insight into program performance results from the upfront planning, scheduling, and control EVM requires; this is important since the window of opportunity for correcting project problems occurs very early in a program ■ Studies based on the performance of over 700 contracts show that performance trends indicate final outcome once they are about 15% to 20% complete; thus, programs operating within an EVM system can quickly uncover, address, and resolve problems before they become out of control
Reduces cycle time to deliver a product	■ EVM imposes discipline and objective measurement and analysis on cost, schedule, and technical processes; planning and analysis often address and prevent problems from surfacing later ■ If costly and untimely rework can be circumvented, the time to deliver the end product may also be reduced
Promotes management by exception	■ EVM directs management attention to only the most critical problems, reducing information overload. Since EVM allows quick communication of cost and schedule variances relative to the baseline plan, management can focus on the most pressing problems first
Fosters accountability	■ EVM requires breaking a program down into sufficiently detailed tasks to clearly define what is expected and when; this allows those responsible for implementing specific tasks to better understand how their work fits into the overall program plan, establishes accountability, gives personnel a sense of ownership, and can result in more realistic estimates at completion of future tasks ■ When technical staff are held accountable for their performance, they tend to better understand the implications of how it affects overall program success; managers held accountable for their planning are more likely to implement a disciplined process for estimating work and tracking it through completion
Allows comparative analysis against completed projects	■ Consistent reporting of projects with EVM processes (following established guidelines) has for many decades resulted in a database useful for comparative analysis, giving managers insight into how their programs perform compared to historical program data ■ They can also use the data for planning programs, improving the cost estimating process, and determining which suppliers provided the best value in the past
Provides objective information for managing the program	■ Measuring program performance gives objective information for identifying and managing risk; it allows early detection and resolution of problems by anticipating what could go wrong, based on past trends ■ Objective data obtained from an EVM system enable management to defend and justify decisions and determine the best course of action when problems arise

Source: GAO, DOD, NASA, SCEA, and industry.

Figure 22: Inputs and Outputs for Tracking Earned Value



Source: DOD and GAO.

Obstacles to EVM

Obstacles, real or imagined, stop many programs and organizations from implementing EVM. Table 30 describes ten common concerns about EVM implementation and discusses the basis of each one.

Table 30: Ten Common Concerns about EVM

Concern	Basis for concern
1. EVM is too expensive to implement	▪ It is expensive to implement EVM when no formal EVM system is in place. Some companies spend $1 million to $2 million to put a good system in place from scratch ▪ Many have some elements in place and can get certified with less effort; even so, most of the time this is a significant investment, translating into several hundred thousand dollars. A simple spreadsheet workbook with worksheets for the plan and each time stamped snap shot of status to date can serve an effective EVM function for smaller projects ▪ Companies that do establish a good EVM system realize better project management decision making, fewer cost and schedule overruns, and potentially greater repeat business. It is hard to measure those gains, but some experts have noted that the return on investment is reasonable. The smaller the company, the more difficult it is to implement because upfront costs are prohibitive ▪ While an EVM system is expensive to implement, not having one may cost a company future work because of the inability to compete with others that have a system. The cost of not getting potential business is also expensive. Balancing must be done to implement what is required in a manner that is sensitive to the corporate bottom line

Concern	Basis for concern
2. EVM is not useful for short-term, small-dollar projects	■ A certain amount of judgment must be applied to determine the viability and utility of a full-blown EVM system for short-term or small-dollar projects. Because typical EVM reporting is monthly, a project of 6 months or less cannot use trends (at least three data points) effectively: it would be half way completed before any trending could be adequately used, and then corrective action would take another data point or two to realize. Weekly reporting would impose significantly higher resource demands and costs that might not be acceptable for small-dollar contracts ■ Even on shorter, less costly projects, a well-structured, planned, and executed project is desirable. Most projects do not trip a threshold of $20 million or $50 million, for example. In some cases, for every large and high visibility project there are between 10-20 small projects. Failure to execute on time or within costs on these small projects is just as unacceptable as on large projects, even though the relative impact is smaller. Several small projects can add up to a substantial loss of money and unhappy customers and can result in the loss of larger projects or future awards if a pattern of overrunning is evident ■ EVM can be tailored and ingrained into the culture to ensure that project cost and schedule goals are met for smaller or shorter projects; smaller projects will benefit from having the work scope defined by a WBS and having a detailed plan and schedule for accomplishing the work. Small-dollar projects still need to have a baseline in place to manage changes and variances and require risk management plans to address issues ■ On the corporate side, losing money is not an acceptable option, even if the project's visibility is lower. Poor performance on a smaller project can damage a company's reputation just as much as poor performance on a large, highly visible project. So even though a full EVM system is not required for small, short-term projects, the need to apply the fundamentals of EVM may still pertain. EVM is good, practical project management
3. EVM practices go above and beyond basic project management practices	■ Our experts noted project managers who claim that they have been successfully not using EVM to manage their projects for years; when pressed to say how they ensure that cost and schedule goals are met, and how they manage their baselines along with changes, however, they inevitably resort to EVM by other means ■ The biggest difference for successful project managers is the formality and rigor of EVM. Our experts noted that project managers who do not use a formal EVM system generally do so because they are not required to. Those who are forced to use formal EVM practices often do so grudgingly but warm up to it over time. Those who have been using formal EVM for years often do not know how they got by without it in the past ■ A second difference between formal EVM practices and basic project management practices is the uniformity of data and formatting of information that makes it possible to draw comparisons against other like projects. Successful project managers who do not use a formal EVM system invariably have their "own system" that works for them and does much of the same things as a formal system. Unfortunately, it is very difficult to compare their systems to other projects, to do analysis, or to validate the data for good decision making. How much management visibility these systems have for timely decision making is debatable. Many companies, hindered by problem identification and corrective actions, have limited management insight into their projects ■ The rigor and discipline of a formal EVM system ensure a certain continuity and consistency that are useful, notwithstanding the availability and turnover of knowledgeable personnel. When staff leave the job for an extended time, the structure of the system makes it possible for another person to take over for those who left. The new staff may not have the personal knowledge of the specific project, schedule, or EVM data but may understand enough about EVM to know how to interpret the data and evaluate the processes because of this disciplined structure ■ Thus, EVM practices go beyond the basics, have greater rigor and formality; the benefit is that this ensures uniform practices that are auditable and consistent with other entities for relative comparison and benchmarking. Without this formality, it would be much more difficult to draw industry standard benchmarks and comparisons for improvement

Concern	Basis for concern
4. EVM is merely a government reporting requirement	▪ It is, viewed only as a reporting requirement. But the benefit of a formal EVM system in government reporting is that the end-product occurs after organizing, planning, authorizing, executing, change management, analysis, and controlling are completed. The reports give management as well as government a view into the health of a project to make sure taxpayer money is being used judiciously ▪ While it makes for project visibility to the government, it is primarily intended as a systematic approach to help in managing a project or program. Reports are only as good as the data and the processes that support them, EVM serves more as a set of mandated government project management tools with reporting as a by-product
5. Reports are a key product of EVM	▪ Yes they are, but it would be short sighted to focus on reporting without recognizing the need for other subsets of an EVM system to provide reliable and auditable data. What comes out is a by product of what goes in and how well it is maintained ▪ EVM reporting is intended to provide reliable information for timely decision making to maximize the probability of successfully executing a project; it is a project management "process tool set" that helps make certain that proven management techniques are used to run projects ▪ Where EVM is institutionalized, management uses reports to identify significant variances and drill down into areas of exception (management by exception) for corrective actions and decision making. When EVM is ingrained, reports are greatly anticipated and thoroughly discussed by senior management
6. EVM is a financial management tool	▪ Yes, to some degree, but in reality, it is an enhancement to traditional financial management; EVM requirements came about largely to reduce the high percentage of cost and schedule overruns that still ended up delivering a product that was technically inferior to the government. Trying to do forensic analysis of a failed project is tough enough without a reliable and rigorous system in place. If one can prevent having a failed project in the first place, forensics may not be necessary ▪ EVM enhances the traditional financial management tool by adding visibility of actual performance for budgeted tasks; this dimension of information, coupled with the traditional planned budget vs. actual costs allows for better forecasting of final costs, as well as early warning of performance variances for timely decision making and corrective actions ▪ Because EVM is a more accurate mechanism for predicting costs than the traditional financial models, it is more reliable for determining funding requirements and use
7. EVM data are backward looking and too old to be useful	▪ This is only partially true. Some metrics data an EVM system produce are backward looking and show performance to date, both cumulative and by period; they can help identify past trends that can reliably be used to predict costs and schedule performance, along with the final cost of a project ▪ Presenting standard graphics is a best practice for reporting EVM trends and status to senior management ▪ Using EVM, management has the ability to make timely decisions and adjustments as needed to affect the final outcome of a project and maximize profitability
8. Variances EVM reveals are bad and should always be avoided	▪ Variances are expected because programs are rarely performed to plan: neither good nor bad, they simply measure how much actual performance has varied from the plan ▪ Variance thresholds try to quantify an acceptable range of deviation; those that do not exceed a threshold are not usually a concern while those that do are worthy of further inspection to determine the best course of action to minimize any negative impacts to cost and schedule objectives ▪ Variances can indicate one or more of the following: how well the project was planned (statement of work definition, estimating and estimating assumptions, execution strategy, procurement strategy, risk management); how well changes to the baseline plan are being implemented; how much planned and unplanned change has occurred since inception; how well the project is being executed

Concern	Basis for concern
9. No one cares about EVM data	▪ False. That is like saying that the pilot of a jet aircraft does not care about what the navigation instrumentation says. EVM data are the navigation instrumentation that tells the project manager how well the flight plan is working ▪ If line managers and the project manager ignore the EVM data, they may not arrive at cost and schedule goals; the data help them make the necessary midcourse adjustments so they can arrive at the planned destination on time
10. EVM does not help with managing a program	▪ False: Refer to previous 9 items, especially 3, 7, 8, and 9, which apply to both projects and programs ▪ When managing a program, it is very important to identify and manage resources to ensure that over- or underallocations do not exist; EVM helps identify these conditions ▪ It helps identify and manage program and project risks and program and project funding requirements to ensure that funding shortfalls do not surprise the program manager

Source: GAO.

Implementing EVM at the Program Level

Implementing EVM at the program rather than just the contract level is considered a best practice. Furthermore, it directly supports federal law requiring executive agency heads to approve or define the cost, performance, and schedule goals for major agency acquisition programs. Specifically, the Federal Acquisition Streamlining Act of 1994 established the congressional policy that the head of each executive agency should achieve, on average, 90 percent of the agency's cost, performance, and schedule goals established for major acquisition programs.[65] When it is necessary to implement this policy, agency heads are to determine whether there is a continuing need for programs that are significantly behind schedule, over budget, or not in compliance with the performance or capability requirements and identify suitable actions to be taken, including termination. Additionally, OMB Circular A-11, part 7, section 300, addresses the use of EVM as an important part of a program's management and decision making.[66] That policy requires the use of an integrated EVM system across the entire program to measure how well the government and its contractors are meeting a program's approved cost, schedule, and performance goals. Integrating government and contractor cost, schedule, and performance status should result in better program execution through more effective management. In addition, integrated EVM data can be used to justify budget requests.

Requiring EVM at the program level also makes government functional area personnel accountable for their contributions to the program. Further, it requires government agencies to plan for a risk-adjusted program budget so that time and funds are available when needed to meet the program's approved baseline objectives. Continuous planning through program-level EVM also helps government program

[65] 41 U.S.C. § 263. A similar requirement in 10 U.S.C. § 2220 applied to the Department of Defense but was later amended to remove the 90 percent measure. DOD has its own major program performance oversight requirements in chapters 144 (Major Defense Acquisition Programs) and 144A (Major Automated Information System Programs) of title 10 of the U.S. Code, including the Nunn-McCurdy cost reporting process at 10 U.S.C. § 2433. Regarding information technology programs, 40 U.S.C. § 11317 (formerly 40 U.S.C. § 1427) requires agencies to identify in their strategic information resources management plans any major information technology acquisition program, or phase or increment of that program, that has significantly deviated from cost, performance, or schedule goals established for the program.

[66] OMB, *Preparation, Submission, and Execution of the Budget*, Circular A-11 (Washington, D.C.: Executive Office of the President, June 2006), part 7, *Planning, Budgeting, Acquisition, and Management of Capital Assets*, sec. 300. www.whitehouse.gov/omb/circulars/index.html.

managers adequately plan for the receipt of material, like government-furnished equipment, to ensure that the contractor can execute the program as planned. Finally, program-level EVM helps identify key decision points up front that should be integrated into both the contractor's schedule and the overall program master schedule, so that significant events and delivery milestones are clearly established and known by all. IBRs should include all government and contractor organizations involved in performing the program, as well as those responsible for establishing requirements, performing tests, and monitoring performance.

Federal and Industry Guidelines for Implementing EVM

The benefits of using EVM are singularly dependent on the data from the EVM system. Organizations must be able to evaluate the quality of an EVM system in order to determine the extent to which the cost, schedule, and technical performance data can be relied on for program management purposes. In recognition of this, the American National Standards Institute (ANSI) and the Electronic Industries Alliance (EIA) have jointly established a national standard for EVM systems—ANSI/EIA-748-B. The National Defense Industrial Association (NDIA) is the subject matter expert for the standard.[67]

Soon after the standard was established, leading companies, including commercial businesses, began using it to manage their programs, even though they did not mandate EVM. They saw ANSI and EIA standards as best practices that provided a scaleable approach to using EVM for any contract type, contract size, and duration.

DOD adopted the ANSI guidelines for managing government programs with the expectation that program managers would be responsible for ensuring that industry-developed standards were being met by ongoing process surveillance. Other agencies soon followed DOD's example. Recently, OMB imposed the use of EVM for all major capital acquisitions in accordance with OMB Circular A-11, Part 7—OMB stated in its 2006 Capital Programming Guide that all major acquisitions with development effort are to require that contractors use an EVM system that meets the ANSI guidelines.[68]

The ANSI guidelines were originally written for companies, but the EIA-748-B version began introducing more generic terminology for government and other organizations. They consist of 32 guidelines in five basic categories: (1) organization; (2) planning, scheduling, and budgeting; (3) accounting considerations; (4) analysis and management reports; and (5) revisions and data maintenance (see table 31). In general, they define acceptable methods for organizations to define the contract or program scope of work using a WBS; identify the organizations responsible for performing the work; integrate internal management subsystems; schedule and budget authorized work; measure the progress of work based on objective indicators; collect the cost of labor and materials associated with the work performed; analyze variances from planned cost and schedules; forecast costs at contract completion; and control changes.

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[67] See, for example, ANSI/EIA 748 32 Industry Guidelines (American National Standards Institute (ANSI)/Electronic Industries Alliance (EIA) Standard, Earned Value Management Systems, ANSI/EIA-748-B-2007, approved July 9, 2007, at www.acq.osd.mil/pm/historical/Timeline/EV%20Timeline.htm, and NDIA, National Defense Industrial Association (NDIA) Program Management Systems Committee (PMSC) ANSI/EIA-748-A Standard for Earned Value Management Systems Intent Guide (Arlington, Va.: January 2005).

[68] See OMB, Capital Programming Guide, II.2.4, "Establishing an Earned Value Management System." The OMB requirements are also reflected in the FAR at 48 C.F.R. subpart 34.2.

Table 31: ANSI Guidelines for EVM Systems

Guideline	Category and statement
Organization	
1	Define the authorized work elements for the program. A WBS, tailored for effective internal management control, is commonly used in this process
2	Identify the program organizational structure, including the major subcontractors responsible for accomplishing the authorized work, and define the organizational elements in which work will be planned and controlled
3	Provide for the integration of the planning, scheduling, budgeting, work authorization, and cost accumulation processes with one another and, as appropriate, the program WBS and program organizational structure
4	Identify the organization or function responsible for controlling overhead (indirect costs)
5	Provide for integration of the program WBS and the program organizational structure in a manner that permits cost and schedule performance measurement by elements of either or both structures as needed
Planning, scheduling, and budgeting	
6	Schedule the authorized work in a way that describes the sequence of work and identifies significant task interdependencies required to meet the program's requirements
7	Identify physical products, milestones, technical performance goals, or other indicators that will be used to measure progress
8	Establish and maintain a time-phased budget baseline, at the control account level, against which program performance can be measured. Initial budgets established for performance measurement will be based on either internal management goals or the external customer-negotiated target cost, including estimates for authorized but undefinitized work.[a] Budget for far-term efforts may be held in higher-level accounts until an appropriate time for allocation at the control account level. If an overtarget baseline is used for performance measurement reporting purposes, prior notification must be provided to the customer
9	Establish budgets for authorized work with identification of significant cost elements (labor, material) as needed for internal management and control of subcontractors
10	To the extent it is practical to identify the authorized work in discrete work packages, establish budgets for this work in terms of dollars, hours, or other measurable units. Where the entire control account is not subdivided into work packages, identify the far-term effort in larger planning packages for budget and scheduling purposes
11	Provide that the sum of all work package budgets and planning package budgets within a control account equals the control account budget
12	Identify and control level-of-effort activity by time-phased budgets established for this purpose. Only effort not measurable or for which measurement is impractical may be classified as level of effort
13	Establish overhead budgets for each significant organizational component for expenses that will become indirect costs. Reflect in the program budgets, at the appropriate level, the amounts in overhead pools that are planned to be allocated to the program as indirect costs
14	Identify management reserves and undistributed budget
15	Provide that the program target cost goal is reconciled with the sum of all internal program budgets and management reserves
Accounting considerations	
16	Record direct costs in a manner consistent with the budgets in a formal system controlled by the general books of account
17	When a WBS is used, summarize direct costs from control accounts into the WBS without allocating a single control account to two or more WBS elements

Guideline	Category and statement
18	Summarize direct costs from the control accounts into the organizational elements without allocating a single control account to two or more organizational elements
19	Record all indirect costs that will be allocated to the program consistent with the overhead budgets
20	Identify unit costs, equivalent unit costs, or lot costs when needed
21	For EVM system, the material accounting system will provide for (1) accurate cost accumulation and assignment of costs to control accounts in a manner consistent with the budgets using recognized, acceptable, costing techniques; (2) cost recorded for accomplishing work performed in the same period that earned value is measured and at the point in time most suitable for the category of material involved but no earlier than the time of actual receipt of material; (3) full accountability of all material purchased for the program, including the residual inventory
Analysis and management reports	
22	At least monthly, generate the following information at the control account and other levels as necessary for management control, using actual cost data from, or reconcilable with, the accounting system: (1) comparison of the amount of planned budget and the amount of budget earned for work accomplished (this comparison provides the schedule variance); (2) comparison of the amount of the budget earned and the actual (applied where appropriate) direct costs for the same work (this comparison provides the cost variance)
23	Identify, at least monthly, the significant differences between both planned and actual schedule performance and planned and actual cost performance and provide the reasons for the variances in the detail needed by program management
24	Identify budgeted and applied (or actual) indirect costs at the level and frequency needed by management for effective control, along with the reasons for any significant variances
25	Summarize the data elements and associated variances through the program organization or WBS to support management needs and any customer reporting specified in the contract
26	Implement managerial actions taken as the result of earned value information
27	Develop revised estimates of cost at completion based on performance to date, commitment values for material, and estimates of future conditions. Compare this information with the performance measurement baseline to identify variances at completion important to management and any applicable customer reporting requirements, including statements of funding requirements
Revisions and data maintenance	
28	Incorporate authorized changes in a timely manner, recording their effects in budgets and schedules. In the directed effort before negotiating a change, base such revisions on the amount estimated and budgeted to the program organizations
29	Reconcile current budgets to prior budgets in terms of changes to authorized work and internal replanning in the detail needed by management for effective control
30	Control retroactive changes to records pertaining to work performed that would change previously reported amounts for actual costs, earned value, or budgets. Adjustments should be made only for correction of errors, routine accounting adjustments, effects of customer or management directed changes, or to improve the baseline integrity and accuracy of performance measurement data
31	Prevent revisions to the program budget except for authorized changes
32	Document changes to the performance measurement baseline

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[a]An undefinitized contract is one in which the contracting parties have not fully agreed on the terms and conditions.

As noted earlier, OMB requires the use of EVM on all major acquisition programs for development. Further, it must be compliant with agencies' implementation of the ANSI guidelines. Several other guides are available to help agencies implement EVM systems. We outlined these guides in table 3 and list them again here in table 32).

Table 32: EVM Implementation Guides

Guide	Applicable agency	Description
DOD, The Program Manager's Guide to the Integrated Baseline Review Process (Washington, D.C.: OSD (AT&L), April 2003)	DOD	Defines the IBR's purpose, goals, and objectives; discusses how it leads to mutual understanding of risks inherent in contractors' performance plans and management control systems; and explains the importance of formulating a plan to handle and mitigate these risks
NDIA, National Defense Industrial Association (NDIA) Program Management Systems Committee (PMSC) Surveillance Guide (Arlington, Va.: October 2004).	All	Defines a standard industry approach for monitoring whether an EVM system satisfies the processes and procedures outlined in the ANSI guidelines
NDIA, National Defense Industrial Association (NDIA) Program Management Systems Committee (PMSC) Earned Value Management Systems Intent Guide (Arlington, Va.: January 2005).	All	Defines in detail the management value and intent for all 32 ANSI guidelines. Contractors use it to assess initial compliance and perform implementation surveillance
Defense Contract Management Agency, Department of Defense Earned Value Management Implementation Guide (Alexandria, Va.: October 2006)	DOD, FAA, NASA	Provides guidance on the framework to follow during implementation and surveillance of an EVM system.
National Defense Industrial Association, Program Management Systems Committee, "NDIA PMSC ANSI/EIA 748 Earned Value Management System Acceptance Guide," draft, working release for user comment (Arlington, Va.: November 2006)	All	Defines an EVM system acceptance process that would apply to industry and government. NDIA has expanded this proposal to a draft EVM process implementation guide that will connect its guides with more specific information on how they relate to one another
National Defense Industrial Association, Program Management Systems Committee, "NDIA PMSC Earned Value Management Systems Application Guide," draft, working release for use and comment (Arlington, Va.: March 2007)	All	Defines a standard approach for all organizations implementing an EVM system through all phases of acquisition

Source: GAO.

The remainder of the Cost Guide assumes that readers understand basic EVM principles. Readers unfamiliar with EVM can also obtain such information from, for example, the Defense Acquisition University and the Project Management Institute (PMI).[69]

[69] See, for example, DAU's fundamental courses at www.dau.mil/schedules/schedule.asp and PMI's literature at www.pmibookstore.org/PMIBookStore/productDetails.aspx?itemID=372&varID=1.

The Thirteen Steps in the EVM Process

The EVM process has thirteen fundamental steps, outlined and described in this section:

1. define the scope of effort using a WBS;
2. identify who in the organization will perform the work;
3. schedule the work;
4. estimate the labor and material required to perform the work and authorize the budgets, including management reserve;
5. determine objective measure of earned value;
6. develop the performance measurement baseline;
7. execute the work plan and record all costs;
8. analyze EVM performance data and record variances from the PMB plan;
9. forecast EACs using EVM;
10. conduct an integrated cost-schedule risk analysis;
11. compare EACs from EVM (step 9) with EAC from risk analysis (step 10);[70]
12. take management action to mitigate risks; and
13. update the performance measurement baseline as changes occur.

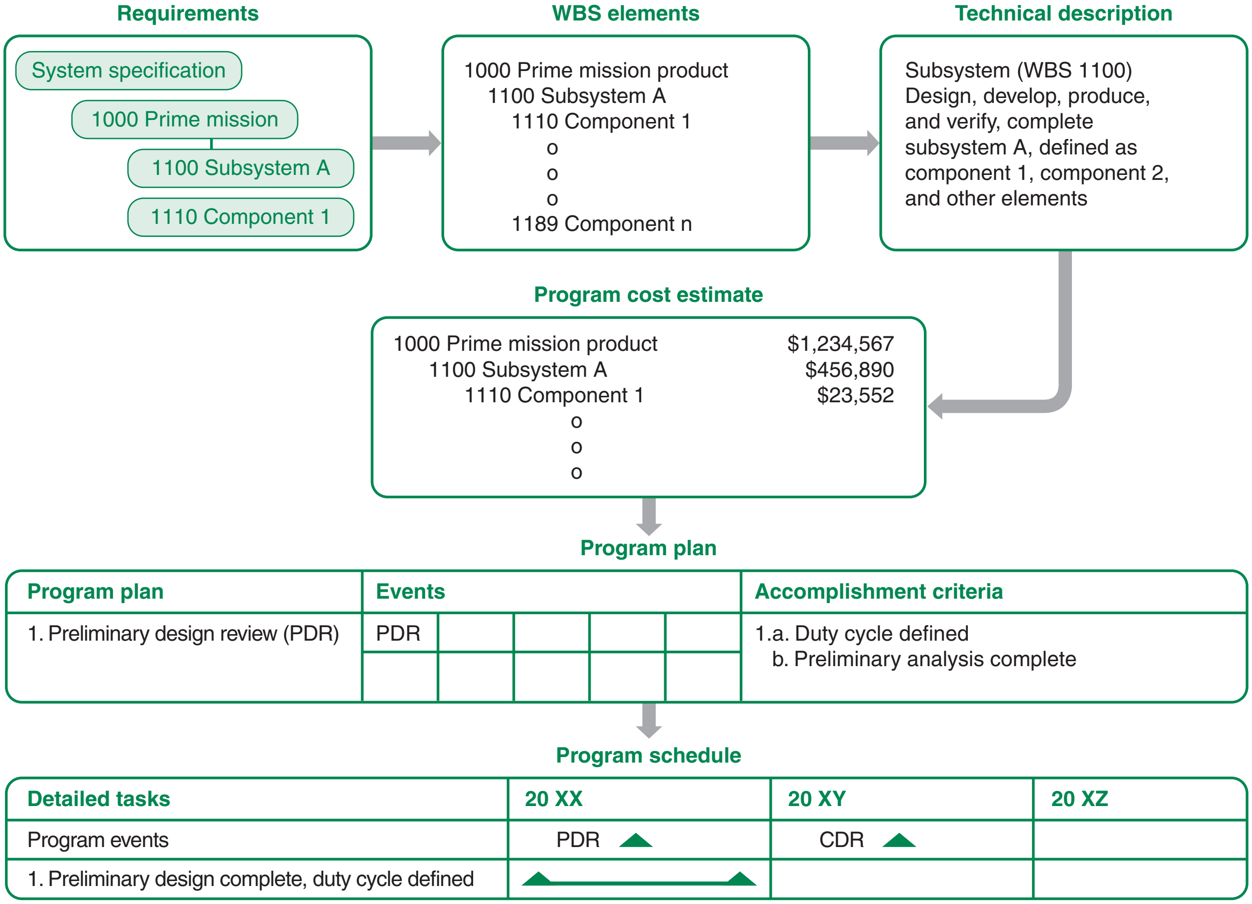
Define the Scope with a WBS

The WBS, a critical component of EVM that defines the work to be performed, should be the basis of the cost estimate and the project schedule. In the schedule, the WBS elements are linked to one another with logical relationships and lead to the end product or final delivery. The WBS progressively deconstructs the deliverables of the entire effort through lower-level WBS elements and control accounts.

Figure 23 shows how the overall program plan breaks down. The hierarchical WBS ensures that the entire statement of work accounts for the detailed technical tasks and, when completed, facilitates communication between the customer and supplier on cost, schedule, technical information, and the progress of the work. It is important that the WBS is comprehensive enough to represent the entire program to a level of detail sufficient to manage the size, complexity, and risk associated with the program. In addition, the WBS should be the basis of the program schedule. Furthermore, there should be only one WBS for each program, and it should match the WBS used for the cost estimate and schedule so that actual costs can be fed back into the estimate and there is a correlation between the cost estimate and schedule. Moreover, while costs are usually tracked at lower levels, what is reported in an EVM system is usually summarized at a higher level, perhaps matching the summary level of the schedule that is often used for a schedule risk analysis, facilitating the preparation of an integrated cost-schedule risk analysis. However, through the fluidity of the parent-child relationship, the WBS can be expanded to varying degrees of detail so that problems can be quickly identified and tracked.

[70] This step demonstrates the integration of EVM and risk management processes.

Figure 23: WBS Integration of Cost, Schedule, and Technical Information



Source: NDIA.

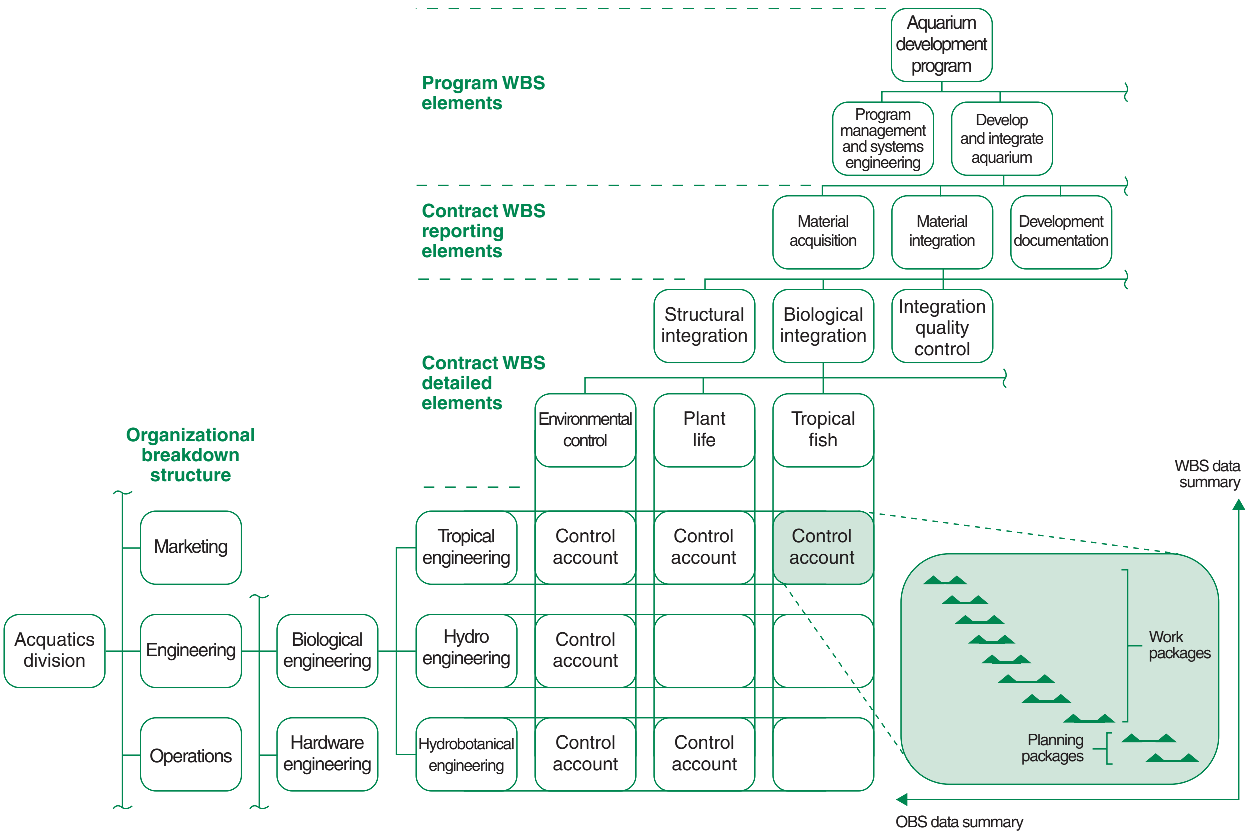
Note: CDR = critical design review.

Identify Who Will Do the Work

Once the WBS has been established, the next step is to assign someone to do the work. Typically, someone from the organization is assigned to perform a specific task identified in the WBS. To ensure that someone is accountable for every WBS element, it is useful to determine levels of accountability, or control accounts, at the points of intersection between the organizational breakdown structure and the WBS. The control account becomes the management focus of an EVM system and the focal point for performance measurement.

It is at the control account level that actual costs are collected and variances from the baseline plan are reported in the EVM system. Figure 24 shows how control accounts are determined. The WBS is shown at the top, including program elements and contract reporting elements and detailed elements. To the left is the organizational breakdown structure. The control accounts lie in the center of the figure, where the WBS and organizational breakdown structure intersect. As the box at the far right of the figure indicates, each control account is further broken down into work packages and planning packages. Each of these has staff who are assigned responsibility for managing and completing the work.

Figure 24: Identifying Responsibility for Managing Work at the Control Account



Source: © 2003 SCEA, "Earned Value Management Systems."

Control accounts represent the level by which actual costs are accumulated and compared to planned costs. A control account manager is responsible for managing, tracking, and reporting all earned value data defined within each control account. Thus, control accounts are the natural control point for EVM planning and management.

Work packages—detailed tasks typically 4 to 6 weeks long—require specific effort to meet control account objectives and are defined by who authorizes the effort and how the work will be measured and tracked. They reflect near-term effort. Planning packages are far-term work and usually planned at higher levels. Budgets for direct labor, overhead, and material are assigned to both work and planning packages so that total costs to complete the program are identified at the outset. As time passes, planning packages are broken down into detailed work packages. This conversion of work from a planning to a work package, commonly known as "rolling wave" planning, occurs for the entire life of the program until all work has been planned in detail. A best practice is to plan the rolling wave to a design review, test, or other major milestone rather than to an arbitrary period such as 6 months.

In planning the baseline, programs ought to consider the allocation of risk into the baseline up front—especially when addressing the issue of rework and retesting. Experts have noted that to set up a realistic baseline, anticipated rework could be a separate work package so as to account for a reasonable amount of rework but still have a way to track variances. Using this approach, programs are not to exclude rework from the budget baseline, because they acknowledge efforts that are bound to involve a lot of revision like design.

Schedule the Work to a Timeline

Developing a schedule provides a time sequence for the duration of the program's activities and helps everyone understand both the dates for major milestones and the activities, often called "critical and near-critical activities," that drive the schedule. A program schedule also provides the vehicle for developing a time-phased budget baseline. The typical method of schedule analysis is the critical path method, implemented in standard scheduling software packages.

Because some costs such as labor, supervision, rented equipment and facilities, and escalation cost more if the program takes longer, a schedule can contribute to an understanding of the cost impact if the program does not finish on time. The program's success also depends on the quality of its schedule. If it is well integrated, the schedule clearly shows the logical relationships between program activities, activity resource requirements and durations, and any constraints that affect their start or completion. The schedule shows when major events are expected as well as the completion dates for all activities leading up to them, which can help determine if the schedule is realistic and achievable. When fully laid out, a detailed schedule can be used to identify where problems are or could potentially be. Moreover, as changes occur within a program, a well-statused schedule will aid in analyzing how they affect the program.

For these reasons, an integrated schedule is key in managing program performance and is necessary for determining what work remains and the expected cost to complete it. As program complexity increases, so must the schedule's sophistication. To develop and maintain an integrated network schedule,

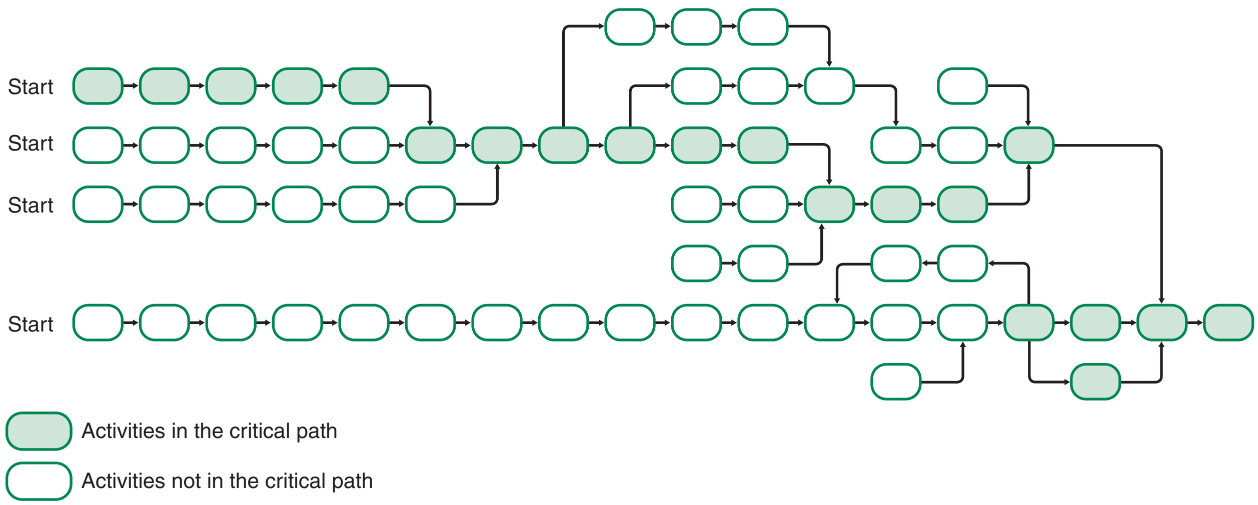
- all activities must be defined (using the WBS) at some level of detail;
- all activities must be sequenced and related using network logic. The schedule should be horizontally and vertically integrated;
- the activities must be resource-loaded with labor, material, and overhead;
- the duration of each activity must be estimated, usually with reference to the resources to be applied and their productivity, along with any external factors affecting duration;
- the program master schedule and critical path must be identified;
- float—the amount of time a task can slip before affecting the critical path—for activities must be calculated;
- a schedule risk analysis must be run for larger, more complex, important, or risky programs;
- the schedule should be continuously updated using logic and durations to determine dates; and
- the schedule should be analyzed continuously for variances and changes to the critical path and completion date.

We discuss each of these items next.

The schedule should reflect all activities (steps, events, outcomes), including activities the government and its contractors are to perform, and should be derived from the program's work breakdown structure. The schedule's activities should also be traceable to the program statement of work to ensure all effort is included. Steps 1 and 2 of the EVM process define the activities and provide input for loading the activities with labor costs.

The schedule should line up all activities in the order that they are to be carried out. In particular, activities that must finish before the start of other activities (that is, predecessor activities) as well as activities that cannot begin until other activities are completed (successor activities) should be identified. By doing so, dependencies among activities that lead to the accomplishment of events or milestones can be established and used as a basis for guiding work and measuring progress. When activities are sequenced, using dependencies between them that reflect the program's execution plan, the result is a network of activity chains like those shown in figure 25.

Figure 25: An Activity Network



Source: © 2005 MCR LLC, "Schedule Risk Analysis."

A network diagram not only outlines the order of the activities and their dependencies; it also documents how the program measures progress toward certain milestones. By linking activities with finish-to-start logic, one can know which activities must finish before others (known as predecessor activities) begin and which activities may not begin until others (successor activities) have been completed. Other relationships such as start-to-start and finish-to-finish are used as well. Using this approach, a valid Critical Path Method (CPM) network of logically linked tasks and events begins to emerge enabling the schedule network to calculate dates and to predict changes in future task performance. A valid CPM network should be the basis for any schedule so that it best represents the plan and can respond to changes. This information fosters communication between team members and better understanding of the program as a whole, identifies disconnects as well as hidden opportunities, and promotes efficiency and accuracy. Moreover, this also provides a method for controlling the program by comparing actual to planned progress.

Schedules should be integrated horizontally and vertically. Integrated horizontally, the schedule links the products and outcomes associated with already sequenced activities. These links are commonly referred to as hand offs and serve to verify that activities are arranged in the order that will achieve aggregated products or outcomes. Horizontal integration also demonstrates that the overall schedule is rational, planned in a logical sequence, accounts for interdependencies between work and planning packages, and provides a way to evaluate current status. Being traceable horizontally, however, is not a simple matter of making sure that each activity has a successor. Activities need to have certain predecessor-successor relationships so the schedule gives the correct results when they are updated or when durations change. Two logic requirements have to be provided:

1. a finish-to-start or start-to-start predecessors, so that if the activity is longer than scheduled it does not just start earlier automatically, and
2. finish-to-start or finish-to-finish successors that will be "pushed" if they take longer or finish later.

These logical requirements are needed to prevent "dangling logic" which happens when activities or tasks are created without predecessors and/or successors. Fundamentally, although a start-to-start successor is proper and sometimes useful, it is not sufficient to avoid danglers. With dangling logic, risk in activities will not cascade down to their successors automatically when schedules are updated. This is not only good critical path method scheduling but is also crucial during Monte Carlo simulation when activity durations are changed on purpose thousands of times. Without this logic, the simulation will not be able to identify the correct dates and critical paths when the durations change.

The schedule should also be integrated vertically, meaning that traceability exists among varying levels of activities and supporting tasks and subtasks. Such mapping or alignment within the layers of the schedule among levels—master, intermediate, detailed—enables different groups to work to the same master schedule. When schedules are vertically integrated, lower-level schedules are clearly traced to upper-tiered milestones, allowing for total schedule integrity and enabling different teams to work to the same schedule expectations.

More risky or more complex programs should have resource-loaded schedules—that is, schedules with resources of staff, facilities and materials needed to complete the activities that use them. Resource loading can assist in two ways:

1. scarce resources can be defined and their limits noted, so that when they are added to the activities and "resource-leveled," the resources in scarce supply will not be over-scheduled in any time period; and
2. all resources can be defined and have costs placed on them so that the program cost estimate can be developed within the scheduling package.

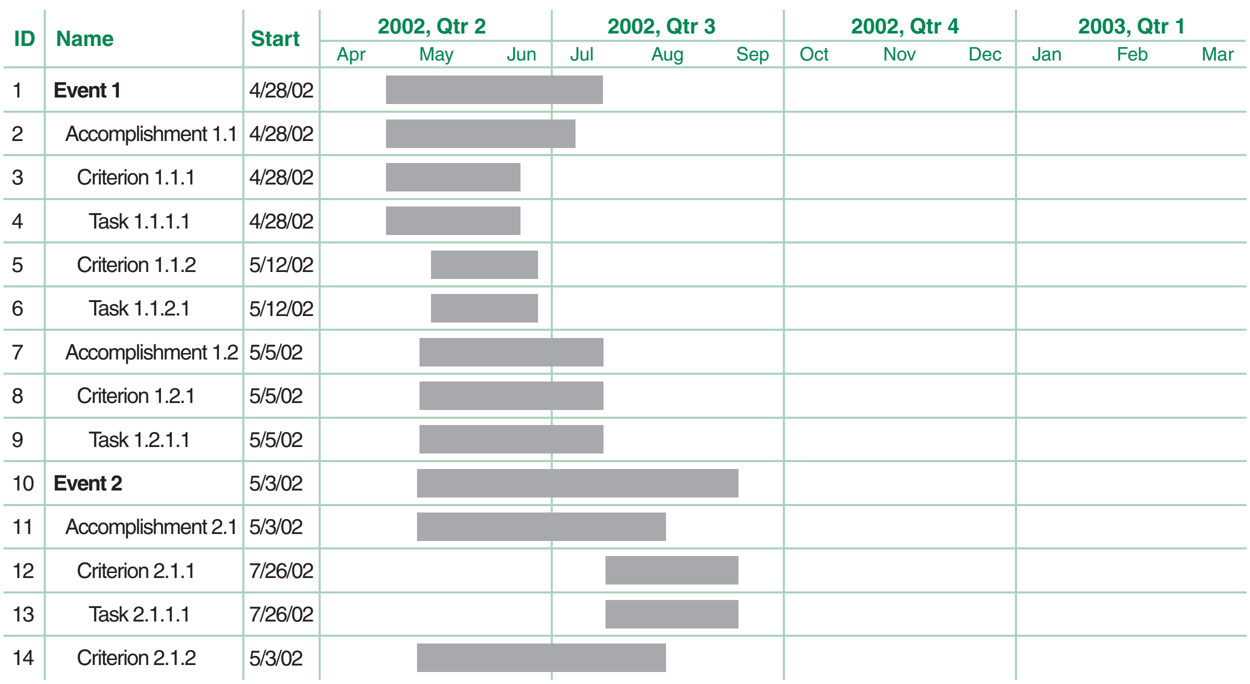
The next step is estimating how long each activity will take—who will do the work, whether the resources are available and their productivity, and whether any external factors might affect the duration (funding or time constraints). It is crucial at this point in schedule development to make realistic assumptions and specify realistic durations for the activities. In determining the duration of each activity, the same rationale, data, and assumptions used for cost estimating should be used for schedule estimating. Further, these durations should be as short as possible and they should have specific start and end dates. Excessively long periods needed to execute an activity should prompt further decomposition of the activity so that shorter execution durations will result.

Often the customer, management, or other stakeholder will ask to shorten the program schedule. Strategies may help. Some activities can be shortened by adding more people to do the work, although others will take a fixed amount of time no matter what resources are available. Other strategies often require “fast track” or “concurrent” scheduling which schedules successor activities or phases to finish before their logical predecessors have completed. In this case, activities or phases that would without the pressure for a shorter schedule, be scheduled in sequence are overlapped instead. This approach must be used with caution since shortening activity durations or overlapping activities may not be prudent or even possible.

Further, schedules need to consider program calendars and special calendars that may be more appropriate for shared resources—test facilities may work 24/7; calendars recognize holidays and other vacations. If training is required, it should be provided in the schedule. Also, since it is sometimes unwise to assume 100 percent productivity, many organizations routinely provide sick leave in their estimates. Procurement time for ordering and receiving material and equipment must be added so it is available when needed—some material and equipment take time to obtain or produce and are often called long lead time items. Schedules need to recognize these items as critical, so they can be ordered before design is complete.

It is useful to rely on historical data for scheduling information as much as possible when developing activity durations so they are as realistic as possible. Often parts of the program have no analogous estimates, so program participants will use expert judgment to estimate durations. Further , it is a best practice for schedule duration rationale to tie directly to the cost estimate documentation. Figure 26 shows the typical output of the activity duration estimate.

Figure 26: Activity Durations as a Gantt Chart



Source: DOD.

Historically, state-of-the-art technology development programs have taken longer than planned for the same reasons that costs often exceed the estimate: no point estimate for schedule duration is correct and risk is generally high in development programs. Instead, each estimate of activity duration has a range of possible outcomes, driven by various uncertainties such as lack of available technical capability, slow software development, integration problems, and test failures. Even if staff work overtime, schedule overruns may still occur, since overworked staff are less efficient. Understanding how program risks may affect durations is often accomplished by using 3-point estimate durations (optimistic, most likely and pessimistic) to check the reasonableness of the durations used. A standard way to use these values to improve the accuracy of the schedule durations is to average them. The resulting single-point or "deterministic" durations are usually more accurate than simply the most likely durations without considering other possible scenarios.

After the activity durations have been estimated, scheduling software can be used to determine the program's overall schedule and critical path, which represents the chain of dependent activities with the longest total duration.[71] Along the critical path—the shaded boxes in figure 25—if any activity slips, the entire program will be delayed. Therefore, management must focus not only on problems in activities along the critical path (activities with zero total float) but also on near-critical activities (activities with low total float), because these activities typically have the least time to slip before they delay the total program. Management should also identify whether the problems are associated with items being tracked on the program's risk management list. This helps management develop workarounds, shift resources from noncritical path activities to cover critical path problems, and implement risk management actions to address problem areas. In addition, the critical path in the overall schedule is invaluable in helping determine where management reserve and unfunded contingencies may exist.

The schedule should identify how long a predecessor activity can slip before the delay affects successor activities, known as float. As a general rule, activities along the critical path have the least amount of float. Therefore, critical path tasks have the least schedule flexibility.

Also called slack or total float or total slack, float is the time an activity can slip before it impacts the end date of the program. The time a predecessor activity can slip before the delay affects the successor activities is called free-float, or free-slack. It is a subset of the total float and is calculated, for a finish-to-start relationship, as the early start of the successor minus the early finish of the predecessor. For other relationships, this calculation is similar, going with the "flow" of their relationship. This concept of free-float is important, because some resources of the affected activities may be available only during certain time periods, which could be detrimental to the completion of the subsequent activities and even the entire program.

As the schedule is statused, float will change and can be positive or negative. Positive float indicates the amount of time the schedule can fluctuate before affecting the end date. Negative float indicates critical path effort and may require management action such as overtime, second or third shifts, or resequencing of work. As a result, float should be continuously assessed.

A schedule risk analysis should be performed using a good CPM schedule and data about project schedule risks, as well as Monte Carlo simulation techniques to predict the level of confidence in meeting a program's completion date, the amount of time contingency needed for a level of confidence and the identification of high-priority risks. This analysis focuses not only on critical path activities but also on

[71] Since the activity durations are estimates and may differ from those in the schedule, the actual critical path may differ from that computed by the scheduling software. This is one reason that a schedule risk analysis provides information on the schedule "criticality," the probability that schedule activities will be on the final critical path.

other schedule paths that may become critical, since they can potentially affect program status. A schedule / cost risk assessment recognizes the inter-relationship between schedule and cost and captures the risk that schedule durations and cost estimates may vary due to, among other things: limited data, optimistic estimating, technical challenges, lack of qualified personnel, unrealistic durations, poor or inadequate logic, overuse of constraints, several parallel paths, multiple merge points, material lead times, and external factors (weather, funding) and identifies activities that most affect the finish date. This helps management focus on important risk mitigation efforts. As a result, the baseline schedule should include a reserve of extra time for contingencies based on the results of a schedule risk analysis. This reserve should be held by the project manager and applied as needed to activities that take longer than scheduled because of the identified risks.

To determine the full effect of risks on the schedule, a schedule risk analysis should be conducted to determine the level of uncertainty. A schedule risk analysis can help answer three questions that are difficult for deterministic critical path method scheduling to address:

1. How likely is it that the program will finish on or before the scheduled completion or baseline date?
2. How much schedule reserve time is needed to provide a date that satisfies the stakeholders' desires for certainty?
3. Which activities or risks are the main drivers of schedule risk and the need for schedule reserve?

This last type of information helps management mitigate schedule risk to improve the chances of finishing on time. In addition, an 11-point assessment should be conducted (more detail is in appendix X).

Risk inherent in a schedule makes it prudent to add in schedule reserve for contingencies—a buffer for the schedule baseline. Typically, schedule reserve is calculated by conducting a schedule risk analysis, choosing a percentile that represents the organization's tolerance for overrun risk, and selecting the date that provides that degree of certainty. As a general rule, the reserve should be held by the project manager and applied as needed to activities that take longer than scheduled because of the identified risks. Reserves of time should not be apportioned in advance to any specific activity, since the risks that will actually occur and the magnitude of their impact are not known in advance.

Schedule reserve is a management tool for dealing with risk and should be identified separately in the schedule baseline. It is usually defined as an activity at the end of the schedule that has no specific scope assigned, since it is not known which risks may materialize. Best practices call for schedule reserve to be allocated, based on the results of the schedule risk analysis so that high-risk activities have first priority for schedule reserve.

Once this analysis is done, the schedule should use logic and durations in order to reflect realistic start and completion dates for program activities. Maintaining the integrity of the schedule logic is not only necessary to reflect true status, but is also required before conducting follow-on schedule risk analyses. The schedule should avoid logic overrides and artificial constraint dates that are chosen to create a certain result on paper.

To ensure that the schedule is properly updated, individuals trained in critical path method scheduling should be responsible for statusing the schedule. The schedule should be continually monitored to determine when forecasted completion dates differ from planned dates, which can be used to determine whether schedule variances will affect downstream work. In this analysis, the schedule should be monitored and progress reported regularly so that the current status of the activities, total float, and the resulting critical path can be determined. Variances between the baseline and current schedule should be examined and assessed for impact and significance. Changes to the program scope should also be incorporated with the appropriate logic.

From the analysis, management can make decisions about how best to handle poor schedule performance. For example, management could decide to move resources to critical path activities to improve status or allocate schedule reserve to immediately address a risk that is turning into an issue. Thus, schedule analysis is necessary for monitoring the adequacy of schedule reserve and determining whether the program can finish on time. It is also important for identifying problems early, when there is still time to act.

Estimate Resources and Authorize Budgets

Budgets should be authorized as part of the EVM process, and they must authorize the resources needed to do the work. They should not be limited to labor and material costs. All required resources should be accounted for, such as the costs for special laboratories, facilities, equipment, and tools. It is imperative that staff with the right skills have access to the necessary equipment, facilities, and laboratories. In step 3, we discussed how the schedule is resource loaded. This feeds directly into the EVM process and should tie back to the cost estimate methodology so it can be considered reasonable.

Management reserve should be included in the budget to cover uncertainties such as unanticipated effort resulting from accidents, errors, technical redirections, or contractor-initiated studies. When a portion of the management reserve budget is allocated to one of these issues, it becomes part of the performance measurement baseline that is used to measure and control program cost and schedule performance. Management reserve provides management with flexibility to quickly allocate budget to mitigate problems and control programs. However, it cannot be used to offset or minimize existing cost variances; it can be applied only to in-scope work.

Programs with greater risk, such as development programs, usually require higher amounts of management reserve than programs with less risk, such as programs in production. The two issues associated are how much management reserve should be provided to the program and how will it be controlled? Regarding the first issue, research has found that programs typically set their contract value so they can set aside 5 to 10 percent as management reserve. This amount may not be sufficient for some programs and may be more than others need. The best way to calibrate the amount of management reserve needed is to conduct a risk analysis for schedule (to determine the schedule reserve needed) and for cost (to determine the management reserve for cost).

The second issue is very important because if budgets are not spread according to the amount of anticipated risk, then control accounts that are overbudgeted will tend to consume all the budget rather than return it to management reserve—"budget allocated equals budget spent." If reserve is not set aside for risks further downstream, it tends to get consumed by early development activities, leaving inadequacies for later complex activities like integration and testing.

Experts agree that some form of integration of the program risk management system with the EVM system should exist. As a best practice, therefore, management reserve should be linked to a program's risk analysis so that WBS cost elements with the most risk are identified for risk mitigation (figure 21). Prioritizing and quantifying total management reserve this way helps ensure that adequate budget is available to mitigate the biggest risks that typically occur later in a program. Typically held at a high level, the management reserve budget may be controlled directly by the program manager or distributed among functional directors or team leaders. In any case, it must be identified and accounted for at all times.

In addition, the risks from the cost estimate uncertainty analysis should be compared against the management reserve allocation. This practice further ties the cost estimating risk analysis with EVM (as noted in figure 21). It can also help avoid using management reserve whenever a part of the program encounters a problem, ensuring that as more complicated tasks occur later in the program there will still be management reserve left if problems arise. When uncertainty analysis is used to specify the probability that cost of work will be performed within its budget, then the likelihood of meeting the budget can be increased by establishing a sufficient management reserve budget. Using this approach, the probability of achieving the budget as a whole can be understood up front. Moreover, using decision analysis tools, managers can use the overall probability of success as the basis for allocating budgets for each WBS element, increasing their ability to manage the entire program to successful completion. This method also allows allocating budget in a way that matches each control account's expected cost distribution, which is imperative for minimizing cost overruns.

Determine an Objective Measure for Earned Value

Performance measurement is key to earned value because performance represents the value of work accomplished. Before any work is started, the control account managers or teams should determine which performance measures will be used to objectively determine when work is completed. These measures are used to report progress in achieving milestones and should be integrated with technical performance measures. Examples of objective measures are requirements traced, reviews successfully completed, software units coded satisfactorily, and number of units fully integrated. Table 33 describes several acceptable, frequently used methods for determining earned value performance.

Table 33: Typical Methods for Measuring Earned Value Performance

Method	Description	Types of tasks using this method	Advantages and disadvantages
0/100	No performance is taken until a task is finished	Take less than 1 month to complete	Objective; commonly used for quick turnaround as in procuring material or brief meetings or trips; no partial credit is given
50/50, 25/75, etc.	Half the earned value is taken when the task starts, the other half when it is finished; other percentage combinations can be used	Usually completed within 2 months	Objective; provides for some credit when the task starts

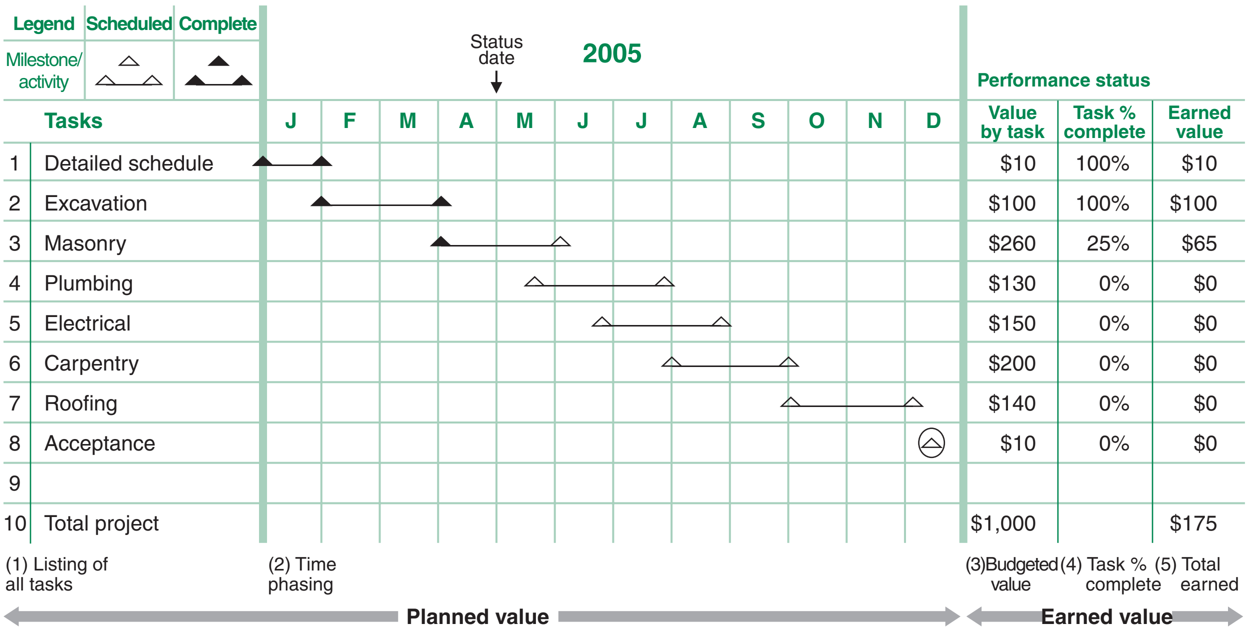
Method	Description	Types of tasks using this method	Advantages and disadvantages
Apportioned effort	Effort that by itself is not readily divisible into short-span work packages but is related in direct proportion to measured effort	Historically depend on another task that can be measured discretely	Provides more objective status information than the level-of-effort method
Level of effort	Performance always equals planned cost	Related to the passage of time with no physical products or defined deliverables, such as program management	Because performance always equals the scheduled amount, no schedule variances occur; cost variances may occur if actual costs are higher than planned
Milestone	Objective monthly milestones are established and the assigned budget is divided by the value assigned each milestone; earned value is taken as milestones are completed	Work packages exceed 2 months	Best for accurately and objectively measuring performance but not always practical or possible
Percent complete	Performance is equal to the percent a task is complete. Percent complete should be based on underlying, quantificable measures as much as possible (e.g., number of drawings completed) and can be measured by the statusing of the resource-loaded schedule	Do not have obvious interim milestones	If truly based on underlying quantifiable measures, this method is actually the most objective. If that is not possible, it can be too subjective and a more objective method should be utilized.
Weighted milestone	Performance is taken as defined milestones are accomplished; objective milestones (weighted by importance) are established monthly and the budget is divided by milestone weights; as milestones are completed, value is earned	Tasks that can be planned using interim milestones—and the like	Best method for work packages that exceed 2 months; the most accurate and objective way to measure earned value.

Source: DOD, © 2003 SCEA "Earned Value Management Systems Tracking Cost and Schedule Performance on Projects."

No one method for measuring earned value status is perfect for every program. Several WBS elements may use different methods. What is important is that the method be the most objective approach for measuring true progress. Therefore, level of effort should be used sparingly: programs that report using a high level of effort for measuring earned value are not providing objective data and the EVM system will not perform as expected. As a general rule, if more than 15 percent of a program's budget is classified as level of effort, then the amount should be scrutinized. When level of effort is used excessively for measuring status, the program is not really implementing EVM as intended and will fall short of the benefits EVM can offer. While the 15 percent benchmark is widely accepted as a trigger point for analysis, no given percentage should be interpreted as a hard threshold, because the nature of work on some programs and contracts does not always lend itself to more objective measurement.

The other methods provide a more solid means for objectively reporting work status. As work is performed, it is earned using the same units as it was planned with, whether dollars, labor hours, or other quantifiable units. Therefore, the budget value of the completed work is credited as earned value, which is then compared to the actual cost and planned value to determine cost and schedule variances. Figure 27 shows how this works.

Figure 27: Earned Value, Using the Percent Complete Method, Compared to Planned Costs



Source: GAO and Quentin W. Fleming at http://www.quentinf.com.

Figure 27 displays how planned effort is compared with work accomplished. It also shows how earned value represents the budgeted value of the work completed and directly relates to the percentage complete of each activity.

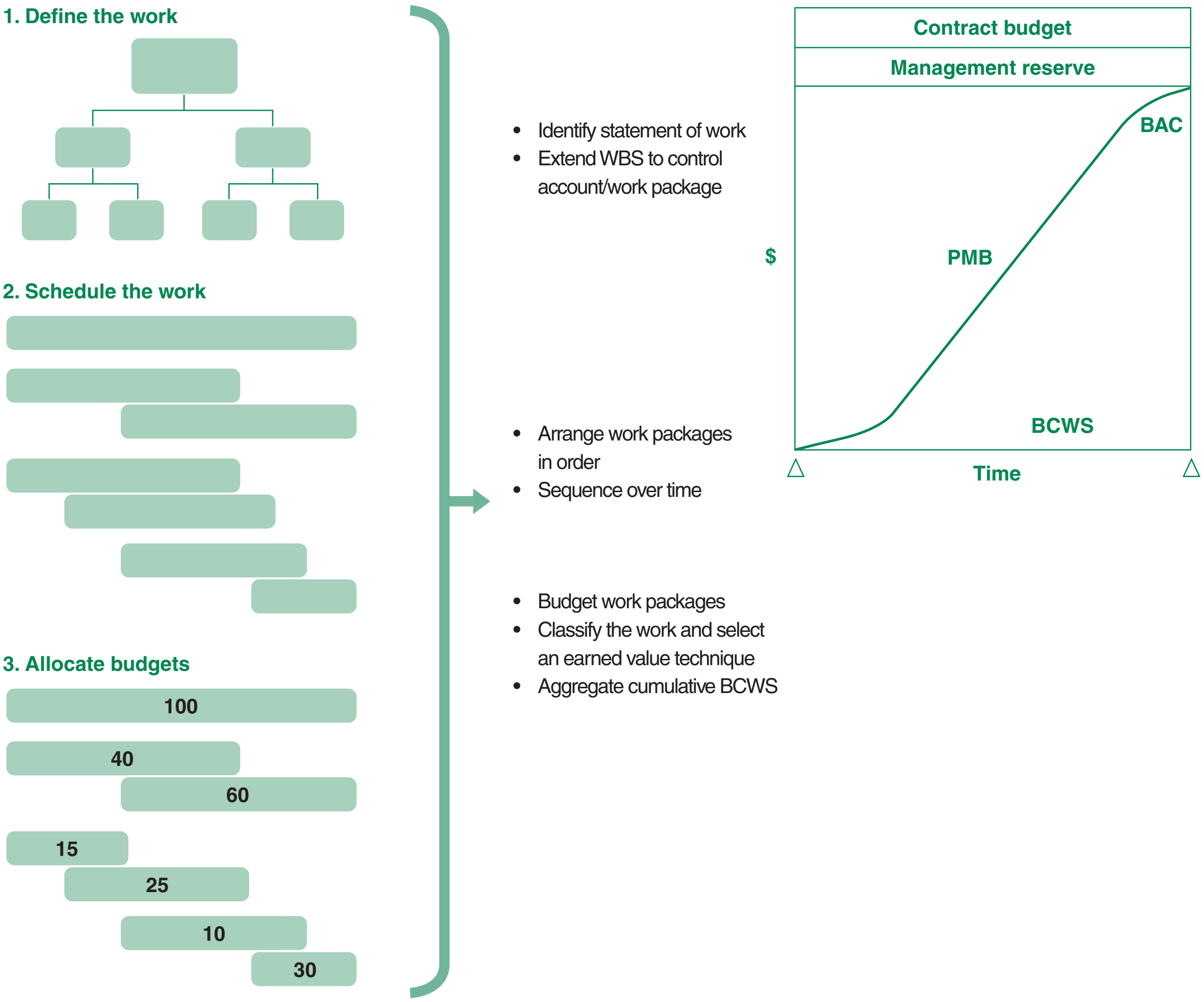
When earned value is compared to the planned value for the same work and to its actual cost, management has access to program status. This big picture provides management with a better view of program risks and better information for understanding what resources are needed to complete the program.

Develop the Performance Measurement Baseline

The performance measurement baseline represents the cumulative value of the planned work over time. It takes into account that program activities occur in a sequenced order, based on finite resources, with budgets representing those resources spread over time. The performance measurement baseline is essentially the resource consumption plan for the program and forms the time-phased baseline against which performance is measured. Deviations from the baseline identify areas where management should focus attention.

Figure 28 shows how it integrates cost, schedule, and technical effort into a single baseline.

Figure 28: The Genesis of the Performance Measurement Baseline



Source: © 2005 MCR, LLC, "Using Earned Value Data."

The performance measurement baseline includes all budgets for resources associated with completing the program, including direct and indirect labor costs, material costs, and other direct costs associated with the authorized work. It represents the formal baseline plan for accomplishing all work in a certain time and at a specific cost. It includes any undistributed budget, used as a short-term holding account for new work until it has been planned in detail and distributed to a particular control account. To help ensure timely performance measurement, it is important that undistributed budget be distributed to specific control accounts as soon as practicable. Some sources we reviewed stated that undistributed budget should be distributed within 60 to 90 days of acquiring the new funds or authorization.

The performance measurement baseline does not equal the program contract value, because it does not include management reserve or any fee. The budget for management reserve is accounted for outside the performance measurement baseline, since it cannot be associated with any particular effort until it is distributed to a particular control account when a risk occurs and leads to a recovery action. Together, the performance measurement baseline and the management reserve represent the contract budget base for the program, which in turn represents the total cost of the work. However, fee must be added to the contract budget base to reflect the total contract price.

Figure 29 depicts a typical time-phased cumulative performance measurement baseline that typically follows the shape of an S curve, portraying a gradual build-up of effort in the beginning, followed by stabilization in the middle, and finally a gradual reduction of effort near program completion. The management reserve and performance measurement baseline values together make up the contract budget base.

Figure 29: The Time-Phased Cumulative Performance Measurement Baseline

Source: © 2003 SCEA, "Earned Value Management Systems."

Note: BCWS = budgeted cost for work scheduled; CBB = contract budget base; PMB = performance measurement baseline.

Common problems in developing and managing the performance measurement baseline are, first, that it may be front-loaded—that is, a disproportionate share of budget has been allocated to early tasks. In this case, budget is typically insufficient to cover far-term work. Front-loading tends to hide problems until it is too late to correct them. The program can severely overrun in later phases, causing everyone involved to lose credibility and putting the program at risk of being canceled.

Second, the performance measurement baseline can have a rubber baseline—that is, a continual shift of the baseline budget to match actual expenditures in order to mask cost variances. Both problems result in deceptive baselines by covering up variances early in the program, delaying insight until they are difficult if not impossible to mitigate. Third, the performance measurement baseline can become outdated if changes are not incorporated quickly. As a result, variances do not reflect reality, and this hampers management in realizing the benefits of EVM.

Execute the Work Plan and Record All Costs

For this step, program personnel execute their tasks according to the performance measurement baseline and the underlying detailed work plans. Actual costs are recorded by the accounting system and are reconciled with the value of the work performed so that effective performance measurement can occur. A program cost-charging structure must be set up before the work begins, to ensure that actual costs can be compared with the associated budgets for each active control account. In particular, accounting for material costs should be consistent with how the budget was established, to keep variances due to accounting accrual issues to a minimum.

Analyze EVM Performance Data and Record Variances from the Performance Measurement Baseline Plan

Because programs all carry some degree of risk and uncertainty, cost and schedule variances are normal. Variances provide management with essential information on which to assess program performance and estimate cost and schedule outcomes. EVM guidelines provide for examining cost and schedule variances at the control account level at least monthly and for focusing management attention on variances with the most risk to the program. This means that for EVM data to be of any use, they must be regularly reviewed. In addition, management must identify solutions for problems early if there is any hope of averting degradation of program performance.

Forecast Estimates at Completion Using EVM

As in step 8, managers should rely on EVM data to generate EACs at least monthly. EACs are derived from the cost of work completed along with an estimate of what it will cost to complete all unaccomplished work. A best practice is to continually reassess the EAC, obviating the need for periodic bottoms-up estimating. It should be noted, however, that DOD requires an annual comprehensive EAC.

Conduct an Integrated Cost-Schedule Risk Analysis

An integrated schedule can be used, in combination with risk analysis data (often including traditional 3-point estimates of duration) and Monte Carlo simulation software, to estimate schedule risk and the EAC. Using the results of the schedule risk analysis, the cost elements that relate to time uncertainty (labor, management, rented facilities, escalation) can be linked directly to the uncertainty in the schedule.

In this approach, the schedule risk analysis provides—in addition to an estimate of when the program may finish and the key risk drivers—uncertainty in the schedule activities or summary tasks that relate to time-dependent cost elements. These results, which are probability distributions produced by the Monte Carlo simulation of the schedule, can be imported to a spreadsheet where cost models and estimates are often developed and stored.

The cost risk analysis uses these schedule risks to link the uncertainty in cost to the uncertainty in schedule. This approach models the way labor cost will be determined and converts time to a cost estimate by using headcount and labor and overhead rates with any material costs added to the final result. (Appendix X has more details on performing a schedule risk analysis.)

Compare EACs from EVM with EAC from Risk Analysis

The integrated cost-schedule risk analysis produces a cumulative probability distribution for the program's cost. This estimate can be compared to the estimate using EVM extrapolation techniques. The reasons to compare the two are that they use quite different approaches.

EVM uses baseline and actual data from the program. The variances are used to estimate future performance. Risk analysis uses data that represent the probability that risks will occur and, usually, 3-point estimates of the risks' impact on the schedule and cost. These data are projections. Although historical data can be used, much of the risk analysis data is derived from interviews and workshops and represents expert judgment.

If two methods so different in their approach, models, software, and input data make forecasts of the EAC given the current plan, it makes sense to compare their results. If their results are in general agreement, their conclusions are probably sound. If not, one or the other method (or both) should be reviewed for changes and revisions.

Take Management Action to Mitigate Risk

Management should integrate the results of information from steps 8 through 11 with the program's risk management plan to address and mitigate emerging and existing risks. Management should focus on corrective actions and identify ways to manage cost, schedule, and technical scope to meet program objectives. It should also keep track of all risks and analyze EVM data trends to identify future problems. (Chapter 19 discusses this step further.)

Update the PMB as Changes Occur

Because changes are normal, the ANSI guidelines allow for incorporating changes—unless it is a retroactive change to the performance data (with the exception of error correction). However, it is imperative that changes be incorporated into the EVM system as soon as possible to maintain the validity of the performance measurement baseline. When they occur, both budgets and schedules are reviewed and updated so that the EVM data stay current. Furthermore, the EVM system should outline procedures for maintaining a log of all changes and for incorporating them into the performance measurement baseline, and the log should be maintained so that changes can be tracked.

Integrated Baseline Reviews

Just as EVM supports risk management by identifying problems when there is still time to act, so an IBR helps program managers fully understand the detailed plan to accomplish program objectives and identifies risks so they can be included in the risk register and closely monitored. The purposes of the IBR are to verify as early as possible whether the performance measurement baseline is realistic and to ensure that the contractor and government (or implementing agency) mutually understand program scope, schedule, and risks. To do this, the IBR assesses the following risks:

- Is the technical scope of the work fully included and consistent with authorizing documents?
- Are key schedule milestones identified and does the schedule reflect a logical flow?

- Are resources involving cost—budgets, facilities, skilled staff—adequate and available for performing assigned tasks?
- Are tasks well planned and can they be measured objectively relative to technical progress?
- Are management processes in place and in use?

OMB requires the government to conduct an IBR for all programs in which EVM is required. While agency procedures dictate when the IBR should be conducted, the FAR allows contracting officers the option of conducting an IBR before a contract is awarded—this is known as a preaward IBR. Preaward IBRs help ensure that cost, schedule, and performance goals have been thoroughly reviewed before the contractor is selected.[72]

Although not mandatory, preaward IBRs verify that a realistic and fully inclusive technical and cost baseline has been established. This helps facilitate proposal analysis and negotiation. The benefits from doing an IBR (and when appropriate, a pre-award IBR) are that it

- ensures that both the government and offeror understand the statement of work as stated in the contract or request for proposals;
- allows the government to determine if the offeror's EVM system complies with agency implementation of the ANSI guidelines;
- ensures that the offeror's schedule process adequately maintains, tracks, and reports significant schedule conditions to the government;
- assesses the offeror's risk management plans for the program;
- assesses the offeror's business system's adequacy to maintain program control and report program performance objectively; and
- evaluates the adequacy of available and planned resources to support the program.

Preaward IBRs support confidence in proposal estimates. However, caution must be taken to safeguard competition-sensitive or source selection information if multiple offerors are engaged in the competition. To lessen the risk of inadvertent disclosure of sensitive information, additional steps such as firewalls may be necessary.

Although the pre- and postaward IBRs share the same overall goal, they are noticeably different in execution. On the contractor side, a preaward IBR requirement can involve the contract-pricers, marketers, and EVM specialists working together to develop the proposal. On the government side, EVM specialists and cost analysts become members of the technical evaluation team. However, unlike a traditional IBR, the government's EVM evaluation is limited to the proposal evaluation. Consequently, the government EVM or cost analysts cannot conduct control account manager interviews; instead, they submit technical

[72] According to OMB, if a preaward IBR is required, it must be included in the proposed evaluation process during the best value trade-off analysis. If a preaward IBR was not contemplated at the time of the solicitation, but the source selection team determines that the proposals received do not clearly demonstrate that the cost, schedule, and performance goals have a high probability of being met, an IBR may be conducted before the award is made.

evaluation questions to the contractors' equivalent personnel about any issues found in a preaward IBR proposal.

In the preaward IBR, the government reviews the adequacy of the proposed performance measurement baseline and how it relates to the integrated master schedule and Integrated Master Plan (IMP) milestones and deliverables. In addition, the government reviews the amount of management reserve in relation to the risk identified in the proposal. A preaward IBR can also be used to determine potential critical path issues by comparing proposed staff levels and costs to these events and associated risks.

The benefits of conducting a preaward IBR are numerous. First, it provides a new tool to the acquisition community that can give insight into contractor performance and management disciplines before contract award. Second, it requires the government and contractor to work together to determine the reasonableness of a contractor's proposed baseline. Third, it can allow a contractor to showcase how it plans to use EVM to manage the proposed solution. Finally, a preaward IBR forces competing contractors to establish high-level baselines that the government can assess for risks before contract award. This analysis can help in choosing viable contractors and reducing baseline setup time after contract award.

While there is a cost to both the government and contractor to perform a preaward IBR, the view on risks and proposed performance management is worth the extra effort. Subsequently, if a preaward IBR is performed, a less-detailed IBR will likely occur after award, resulting in a quicker postaward review. (The details of conducting IBRs are discussed in chapter 19.)

Award Fees

Contracts with provisions for award fees allow the government to adjust the fee based on how the contractor is performing. The purpose of award fee contracting is to provide motivation to the contractor for excellence in such areas as quality, timeliness, technical ingenuity, and cost effective management. Before issuing the solicitation, the government establishes the award fee criteria. It is important that the criteria be selected to properly motivate the contractor to perform well and encourage improved management processes during the award fee period.

It is bad management practice to use EVM measures, such as variances or indexes, as award fee criteria, because they put emphasis on the contractor's meeting a predetermined number instead of achieving program outcomes. Award fees tied to reported EVM measures may encourage the contractor to behave in undesirable ways, such as overstating performance or changing the baseline budget to "make the number" and secure potential profit. These actions undermine the benefits to be gained from the EVM system and can result in a loss of program control. For example, contractors may front-load the performance measurement baseline or categorize discrete work as level of effort, with the result that variances are hidden until the last possible moment. Moreover, tying award fee criteria to specific dates for completing contract management milestones, such as the IBR, is also bad practice, because it may encourage the contractor to conduct the review before it is ready.

Best practices indicate that award fee criteria should motivate the contractor to effectively manage its contract using EVM to deliver the best product possible. For example, criteria that reward the contractor for integrating EVM with program management, establishing realistic budgets and schedules and estimates of costs at completion, providing meaningful variance analysis, performing adequate cost control, and providing accurate and timely data represent best practices. In addition, experts agree that award fee periods should be tied to specific contract events like preliminary design review rather than monthly cycles. (More detail on award fee best practices criteria for EVM is in appendix XIII.)

Progress and Performance-Based Payments Under Fixed-Price Contracts

The principles of EVM are best management practices that are applicable in the administration of certain fixed-price type contracts that typically involve non-commercial items. These contracts use performance-based payments or progress payments based on a percentage or stage of completion. Applying relevant EVM principles is particularly useful in setting up the progress or performance-based payment structure at contract inception and in administering progress payments during contract performance. The informal use of EVM principles here does not involve applying the comprehensive "ANSI-compliant EVM" that is often used in large cost-reimbursement type contracts where the government faces more risks.

The Federal Acquisition Regulation authorizes progress payments and performance-based payments in certain circumstances for fixed-price type contracts for non-commercial items.[73] Progress payments are based on (1) costs incurred by the contractor as work progresses under the contract or (2) a percentage or stage of completion. Progress payments based on a percentage or stage of completion may be used as a payment method for work accomplished that meets the quality standards established under the contract. Performance-based payments are contract financing payments made on the basis of performance measured by objective and quantifiable methods, accomplishment of defined events, or other quantifiable measures or results.

The FAR addresses in detail the use of progress payments based on costs incurred. However, it is the category of progress payments based on percentage or stage of completion that provides the opportunity to apply EVM principles. Specifically, a schedule of values is established between the contractor and the government that divides the contract value into quantifiable scope elements. In some cases the contract requires that this schedule of values be generated as an output of the resource-loaded, critical path method (CPM) schedule, thereby reinforcing the EVM concept of cost and schedule integration. The percent complete method, based on either quantifiable units of measure or statused schedule activities can be utilized to assess partial progress prior to each scope element's completion. For this reason, progress payments are usually preferred by contractors over milestone-based payments (discussed next), since progress they allow for a more favorable cash flow position throughout the project's execution.

The performance-based payments arrangement also provides opportunities to apply EVM principles. Performance-based payments differ from the more traditional progress payments in that they are based on the 0/100 or milestone methods as shown in figure 30. Establishing the performance-based payments structure requires the government customer and contractor to agree on a set of milestones that will become the basis for the performance-based payments. Choosing the milestones usually results in selecting critical path activities that lead up to successfully achieving a significant event. This effort requires detailed planning to fully identify the work that needs to be accomplished and the relative dollar value of the milestones. After the parties have agreed on the performance plan, actual performance is monitored and

[73] Federal Acquisition Regulation section 32.102 and subparts 32.5 and 32.10.

payments are made according to the actual achievement of the established milestones. When properly planned and implemented, the performance-based payments approach can result in less oversight costs for the government compared to a progress payment arrangement, and enhanced technical and schedule focus for the contractor. However, as mentioned above, such an arrangement may not be preferred by the contractor because of the impact on cash flow. (See figure 30.)

Figure 30: A Performance-Based Payments Structured Contract

Legend	Scheduled	Complete
Milestones	△	▲
Tasks	△——△	▲——▲

Status date: April (2005)

	Tasks	J	F	M	A	M	J	J	A	S	O	N	D	Value by M/S	M/S % complete	Total payment
1	Detailed schedule	▲												$10	100%	$10
2	Excavation				▲									$100	100%	$100
3	Masonry						△							$260	0%	$0
4	Plumbing							△						$130	0%	$0
5	Electrical								△					$150	0%	$0
6	Carpentry									△				$200	0%	$0
7	Roofing												△	$140	0%	$0
8	Acceptance												△	$10	0%	$0
9																
10	Total project													$1,000		$110

(1) Listing of milestones; (2) Time phasing; (3) Contract values; (4) Status complete; (5) Total earned

Performance assessment of $110,000 less a 10% withhold = Payment due of $99,000

Source: GAO and Quentin W. Fleming at http://www.quentinf.com.

Note: M/S = Milestone.

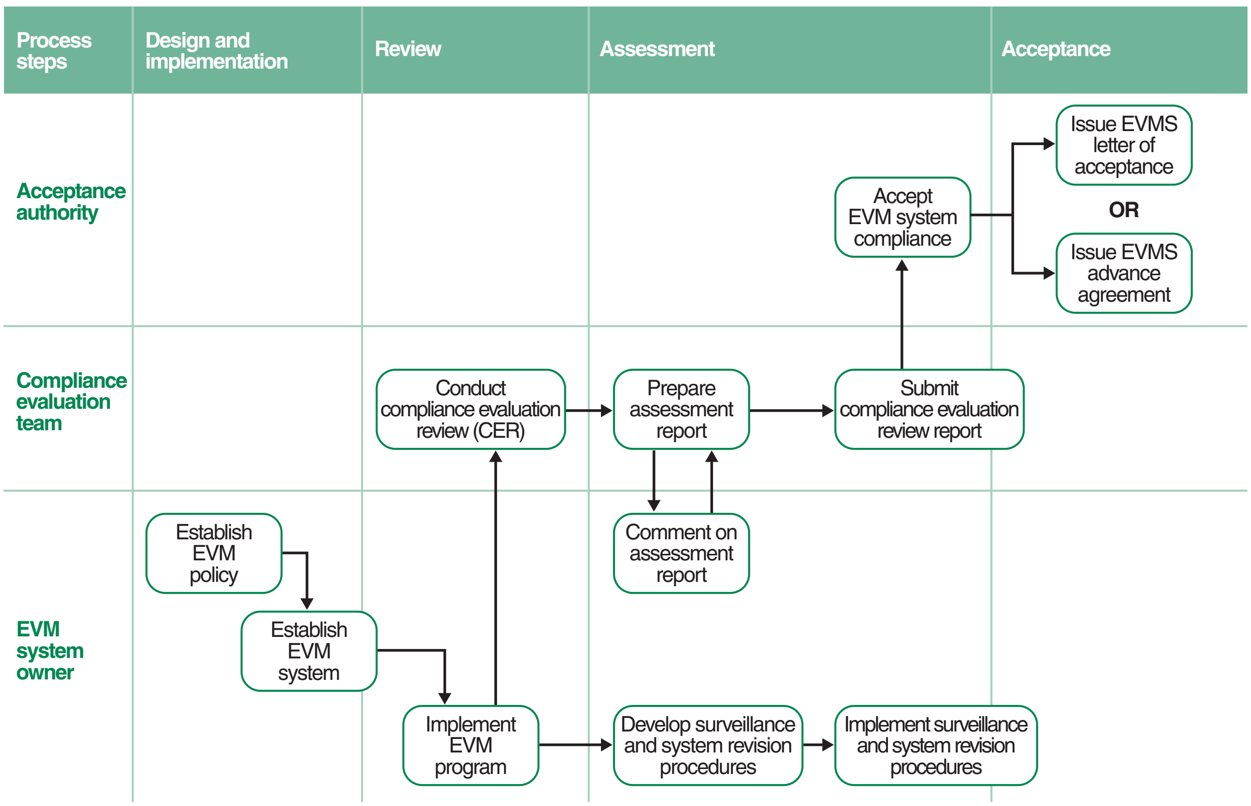
In the example in figure 30, eight milestones will be used to determine payments. At this point in time, two milestones have been met at a cost of $110,000. However, under the performance-based payments arrangement, the government would pay the contractor only $99,000, since it will hold back the final 10 percent until the work is complete (this method of withholding "retainage" is also common practice in progress-based payment systems).

Both progress payment and performance-based payment methods require detailed planning to fully identify the work that needs to be accomplished and the relative dollar value of the scope elements or milestones. While both are a simplified form of EVM in that physical progress is the basis for payments, the government does not have visibility into actual costs borne by the contractor because of the fixed price nature of the contract. Therefore, care must be taken to ensure that in either method the contractor has not "front-loaded" the schedule of values or the performance baseline to increase early payments. In addition, progress and milestone events should represent measurable performance in terms of quality and technical performance as well as cost and schedule. This is why government review and approval is required in both cases at contract inception—the government can thereby guard against paying too much for work as it is actually accomplished (which is important should the initial contractor need to be replaced and the remaining work re-solicited), while maintaining the protection against paying for any final cost overruns that a fixed-price type contract normally provides. By focusing on these issues, government projects performed under fixed-price type contracts have reported improved ability to meet requirements, better focus on outcomes, and improved completion timeframes.

Validating the EVM System

If EVM is to be used to manage a program, the contractor's (and subcontractors') EVM system should be validated to ensure that it complies with the agency's implementation of the ANSI guidelines, provides reliable data for managing the program and reporting its status to the government, and is actively used to manage the program. This validation process is commonly referred to as system acceptance. The steps involved in the system acceptance process are shown in figure 31. Sometimes these steps may overlap rather than go in sequence because of resource or capability constraints between the EVM system owner, the government customer, or both. However, all steps leading up to actual acceptance must be addressed for an EVM system owner or agency program to implement an ANSI-compliant EVM system.[74]

Figure 31: The EVM System Acceptance Process



Source: Copyright 2004-2005 National Defense Industrial Association (NDIA) Program Management Systems Committee (PMSC).

The system acceptance process has four phases. In system design and implementation, establishing the EVM policy (which includes documented processes and procedures) is followed by developing and implementing an EVM system. Once complete, the compliance evaluation review can begin. The purpose of this review is to verify that the EVM system meets the ANSI guidelines and has been fully

[74] More information on EVM system acceptance is in NDIA, Program Management Systems Committee, "NDIA PMSC ANSI/EIA 748 Earned Value Management System Acceptance Guide," draft, working release for user comment (Arlington, Va.: November 2006).

implemented on selected contracts, projects, or programs. Data traces are necessary for verifying that lower-level reporting aligns with higher levels and that the data provide accurate management information. Interviews verify that the EVM system is fully implemented and actively used to manage the program. Additionally, the compliance review process and its results should be documented.

The compliance evaluation review is an independent review conducted by an individual or organization that

- has no stake in the EVM system, project, or contract being reviewed;[75]
- has the knowledge, skills, and abilities to fairly evaluate the fitness of the EVM systems implementation or surveillance; and
- relies on the NDIA EVMS intent guide to determine whether the EVM system is compliant with the ANSI guidelines.

Upon successful completion of EVM system acceptance, an acceptance recognition document should be prepared and released. When cross-agency acceptance occurs, this is best accomplished by mutual agreements between agencies and organizations to recognize EVM system ANSI compliant acceptance or recognition documents.

An agency can accept another organization's EVMS acceptance with the understanding that they will need to instill a rigorous surveillance process (see chapter 20) to ensure that the written system description meets the intent of the 32 guidelines and is actively being followed. An alternative acceptance procedure is for a partner agency (or cross-agency) to review the documentation from the EVM system owner's compliance evaluation review.

When no independent entity exists to perform EVM acceptance, the assessment may be performed by a qualified source that is independent from the program's development, implementation, and direct supervision—for example, an agency's inspector general. Moreover, civilian agencies may negotiate an interagency agreement to conduct acceptance reviews to satisfy the criteria for independence. For this arrangement to succeed, staff trained in EVM system reviews are required, and these resources are scarce in the government.

Best practices call for centers of excellence that include staff who are experienced in EVM system design, implementation, and validation and have a strong knowledge of ANSI guidelines. In addition, these staff should have good evaluation skills, including the ability to review and understand EVM data and processes and the ability to interview personnel responsible for the EVM system implementation to determine how well they understand their own system description and processes.

Case studies 44 and 45 highlight what can happen to a program when an EVM system has not been validated as being compliant with the ANSI guidelines.

[75] This criterion does not apply when the EVM system owner conducts a self-evaluation review.

Case Study 44: Validating the EVM System, from *Cooperative Threat Reduction*, GAO-06-692

In September 2004, DOD modified its contract with Parsons Global Services, allocating about $6.7 million and requiring the company to apply EVM to the Shchuch'ye project. Parsons was expected to have a validated EVM system by March 2005, but by April 2006, it had not yet developed an EVM system that provided useful and accurate data to the chemical weapons destruction facility's program managers. In addition, GAO found that the project's EVM data were unreliable and inaccurate: in numerous instances, data had not been added properly for scheduled work. Parsons' EVM reports, therefore, did not accurately capture data that project management needed to make informed decisions about the Shchuch'ye facility.

For example, Parsons' EVM reports from September 2005 through January 2006 contained errors in addition that did not capture almost $29 million in actual project costs. Such omissions and other errors may have caused DOD and Parsons project officials to overestimate the available project funding. GAO also found several instances in which the accounting data were not allocated to the correct cost accounts, causing large cost over- and underruns. Accounting data had been placed in the wrong account or Parsons' accounting system was unable to track costs at all levels of detail within EVM.

GAO concluded that until Parsons fixed its accounting system, manual adjustments would have to be made monthly to ensure that costs were properly aligned with the correct budget. Such adjustments meant that the system would consistently reflect inaccurate project status for Parsons and DOD managers. Parsons' outdated accounting system had difficulty capturing actual costs for the Shchuch'ye project and placing them in appropriate cost categories. Parsons management should have discovered such accounting errors before the EVM report was released to DOD.

The Defense Contract Audit Agency therefore questioned whether Parsons could generate correct accounting data and recommended that it update its accounting system. DOD expected Parsons to use EVM to estimate cost and schedule impacts and their causes and, most importantly, to help eliminate or mitigate identified risks. GAO recommended that DOD ensure that Parsons' EVM system contained valid, reliable data and that the system reflect actual cost and schedule conditions. GAO also recommended that DOD withhold a portion of Parsons' award fee until the EVM system produced reliable data.

However, before GAO issued its report, Parsons had begun to improve its EVM processes and procedures. It had established a new functional lead position to focus on cost management requirements in support of government contracts. In addition, Parsons installed a new EVM focal point to address the lack of progress made in achieving validation of the EVM system for the Shchuch'ye project.

Immediately after GAO's report was issued, Parsons' new EVM focal point was able to identify and correct the system problems that had led to the unreliable and inaccurate EVM data. The new focal point also found that the data integrity problems GAO had identified were not directly related to a need to update Parsons' accounting system. First, the project's work breakdown structure had not been developed to the level of detail required to support a validated EVM system before Parsons received the contract modification to implement the system, and the project's original cost management practices, policies, and procedures had not been robust enough to effectively prevent the historical miscoding of actual costs against the existing WBS. Second, the more recent data quality issues GAO cited resulted from the lack of a reconcilable means of downloading actual cost information from Parsons' accounting system into a cost processor that had not yet been optimized.

Parsons' accounting system was deemed adequate in an August 2006 Defense Contract Audit Agency audit report. DOD chose not to withhold Parsons' award fee, given the progress being made toward improving the data integrity issues GAO had identified. The Shchuch'ye project's EVM system was formally validated in a May 2007 Defense Contract Management Agency letter.

GAO, *Cooperative Threat Reduction: DOD Needs More Reliable Data to Better Estimate the Cost and Schedule of the Shchuch'ye Facility*, GAO-06-692 (Washington, D.C.: May 31, 2006).

Case Study 45: Validating the EVM System, from *DOD Systems Modernization*, GAO-06-215

The Naval Tactical Command Support System (NTCSS) elected to use EVM, but Navy and DOD oversight authorities did not have access to the reliable and timely information they needed to make informed decisions. The EVM system that NTCSS implemented to measure program performance did not provide data for effectively identifying and mitigating risks. According to the NTCSS central design agency's self-assessment of its EVM system, 17 of industry's 32 best practices criteria were not being met. GAO also found 29 of the 32 criteria were not satisfied.

Two NTCSS projects for which EVM activities were reportedly being performed were 2004 Optimized Organizational Maintenance Activity (OOMA) software development and 2004 NTCSS hardware installation and integration. GAO found several examples of ineffective EVM implementation on both projects.

The estimate at completion for the 2004 OOMA software project—a forecast value expressed in dollars representing final projected costs when all work was completed—showed a negative cost for the 6 months November 2003 to April 2004. If EVM had been properly implemented, this amount, which is always a positive number, should have included all work completed.

The cost performance index for the OOMA software project—which was to reflect the critical relationship between the actual work performed and the money spent to accomplish the work—showed program performance during a time when the program office stated that no work was being performed.

The estimate at completion for the OOMA hardware installation project showed that almost $1 million in installation costs had been removed from the total sunk costs, but no reason for doing so was given in the cost performance report.

The cost and schedule indexes for the OOMA hardware installation project showed improbably high program performance when the installation schedules and installation budget had been drastically cut because OOMA software failed operational testing.

GAO concluded that because EVM was ineffectively implemented in these two projects, NTCSS program officials did not have access to reliable and timely information about program status or a sound basis for making informed program decisions. Therefore, GAO recommended that the NTCSS program implement effective program management activities, including EVM.

GAO, *DOD Systems Modernization: Planned Investment in the Naval Tactical Command Support System Needs to Be Reassessed*, GAO-06-215 (Washington, D.C.: Dec. 5, 2005).

15. Best Practices Checklist: Managing Program Costs: Planning

- ☐ A cost estimate was used to measure performance against the original plan, using EVM.
- ☐ EVM and risk management were tightly integrated to ensure better program outcomes.
  - ✓ Strong leadership demands EVM be used to manage programs.
  - ✓ Stakeholders make it clear that EVM matters and hold staff accountable for results.
  - ✓ Management is willing to hear the truth about programs and relies on EVM data to make decisions on how to mitigate risk.
  - ✓ Policy outlines clear expectations for EVM as a disciplined management tool and requires pertinent staff to be continuously trained in cost estimating, scheduling, EVM, and risk and uncertainty analysis.
- ☐ EVM is implemented at the program level so that both government and contractor know what is expected and are held accountable.
  - ✓ EVM relied on the cost of completed work to determine true program status.
  - ✓ EVM planned all work to an appropriate level of detail from the beginning.
  - ✓ It measured the performance of completed work with objective techniques.
  - ✓ It used past performance to predict future outcomes.
  - ✓ It integrated cost, schedule, and performance with a single
  - ✓ management control system.
  - ✓ It directed management to the most critical problems, reducing information overload.
  - ✓ It fostered accountability between workers and management.
- ☐ The EVM system complied with the agency's implementation of ANSI's 32 guidelines.

- ☐ The following steps in the EVM process were taken:
  - ✓ The work's scope was defined with a WBS, and effort was broken into work and planning packages.
  - ✓ The WBS and organizational breakdown structure were cross-walked to identify control accounts that show who will do the work.
  - ✓ An acceptable technique was used to schedule work to resource load activities.
    - o All activities were identified and sequenced, logically networked, clearly showing horizontal and vertical integration.
    - o Activities were resource loaded with labor, material, and overhead and durations were estimated with historical data when available, and float was identified.
    - o Program master schedule and critical path were identified.
    - o A schedule risk analysis was performed based on an 11-point schedule assessement.
    - o Schedule reserve was chosen and prioritized for high-risk activities.
    - o The schedule was updated using logic and durations to determine dates and reflects accomplishments and is continuously analyzed for variances and changes to the critical path and completion date.
  - ✓ Resources were adequate to complete each activity and were estimated to do the work, authorize budgets, and identify management reserve for high-risk efforts.
  - ✓ Objective methods for determining earned value were used.
  - ✓ The performance measurement baseline was developed for assessing program performance; EVM performance data were analyzed and variances from the baseline plan were recorded; the performance measurement baseline was updated.
  - ✓ EACs were forecast using EVM.
  - ✓ An integrated cost-schedule risk analysis was conducted.
  - ✓ EACs from EVM were compared with an EAC from risk analysis.
  - ✓ Management took action to mitigate risk.
  - ✓ A preaward IBR was performed where provided for to verify the performance measurement baseline's realism and compliance with ANSI guidelines.
  - ✓ Award fee criteria were developed to motivate the contractor to manage its contract with EVM to deliver the best possible product, were tied to specific contract events, and did not predetermine specific EVM measures.
  - ✓ A Performance Based Payment contract was considered for fixed price contracts where technical effort and risk are low.
  - ✓ The EVM system implemented was validated for compliance with the ANSI guidelines by independent and qualified staff and therefore can be considered to provide reliable and valid data from which to manage the program.

CHAPTER 19

Managing Program Costs: Execution

Studies of more than 700 defense programs have shown limited opportunity for getting a program back on track once it is more than 15 percent to 20 percent complete.[76] EVM data allow management to quickly track deviations from a program's plan for prompt understanding of problems. Proactive management results in better focus and increases the chance that a program will achieve its goals on time and within the expected cost.

To rely on EVM data, an IBR must be conducted to ensure that the performance measurement baseline accurately captures all the work to be accomplished. Data from the CPR can then be used to assess program status—typically, monthly. Cost and schedule variances are examined and various estimates at completion are developed and compared to available funding. The results are shared with management for evaluating contractor performance. Finally, because EVM requires detailed planning for near-term work, as time progresses, planning packages are converted into detailed work packages. This cycle continues until all work has been planned and the program is complete.

Validating the Performance Measurement Baseline with an IBR

An IBR is an evaluation of the performance measurement baseline to determine whether all program requirements have been addressed, risks identified, and mitigation plans put in place and all available and planned resources are sufficient to complete the work. Too often, programs overrun because estimates fail to account for the full technical definition, unexpected changes, and risks. Using poor estimates to develop the performance measurement baseline will result is an unrealistic baseline for performance measurement.

The IBR concept to ensure comprehensive baselines for managing programs was developed in 1993 as a best practice after numerous DOD programs experienced significant cost and schedule overruns because their baselines were too optimistic. An IBR's goal is to verify that the technical baseline's budget and schedule are adequate for performing the work. Key benefits are that

- it lays a solid foundation for successfully executing the program,
- it gives the program manager and contractor mutual understanding of the risks,
- the program manager knows what to expect at the outset of the program,
- planning assumptions and resource constraints are understood,
- errors or omissions in the baseline plan can be corrected early in the program,

[76] The source of this statement is © 2003, Society of Cost Estimating and Analysis, "Earned Value Management Systems (EVMS) Tracking Cost and Schedule Performance on Projects," p. 7.

- developing variances can be discovered sooner, and
- resources for specific challenges and risks can be identified.

Conducting an IBR increases everyone's confidence that the performance measurement baseline provides reliable cost and schedule data for managing the program and that it projects accurate estimated costs at completion. OMB has endorsed the IBR as a critical process for risk management on major investments and requires agencies to conduct IBRs for all contracts that require EVM.

The IBR is the crucial link between cost estimating and EVM because it verifies that the cost estimate has been converted into an executable program plan. While the cost estimate provides an expectation of what could be, based on a technical description and assumptions, the baseline converts those assumptions into a specific plan for achieving the desired outcome. Once the baseline is established, the IBR assesses whether its estimates are reasonable and risks have been clearly identified.

OMB directs agencies to conduct IBRs in accordance with DOD's *Program Manager's Guide to the Integrated Baseline Review Process*, which outlines four activities to be jointly executed by the program manager and contractor staff: performance measurement baseline development, IBR preparation, IBR execution, and management processes.[77]

Experts agree that it is a best practice is for the government and prime contractor to partner in conducting an IBR on every major subcontractor in conjunction with the prime contractor IBR. This practice cannot be emphasized enough, especially given that many major systems acquisitions are systems of systems with the prime contractor acting as the main integrator. The expert community has seen up to 60 to 70 percent of work being subcontracted out. Pair this risk with the lack of focus on systems engineering, and many risks may go unnoticed until they are realized. Furthermore, the increasing roles and responsibilities assumed by subcontractors in these contracts make the accuracy of subcontractor EVM data that much more important.

Performance Measurement Baseline Development

As the principal element of EVM, the performance measurement baseline represents the time-phased budget plan against which program performance is measured for the life of the program. This plan comes from the total roll-up of work that has been planned in detail through control accounts, summary planning packages, and work packages with their schedules and budgets.

Performance measurement baseline development examines whether the control accounts encompass all contract requirements and are reasonable, given the risks. To accomplish this, the government and contractor management teams meet to understand whether the program plan reflects reality. They ask,

- Have all tasks in the statement of work been accounted for in the baseline?
- Are adequate staff and materials available to complete the work?
- Have all tasks been integrated, using a well-defined schedule?

[77] See DOD, *The Program Manager's Guide to the Integrated Baseline Review Process* (Washington, D.C.: Office of the Secretary of Defense (AT&L), April 2003).

Since it is not always feasible for the IBR team to review every control account, the team often samples control accounts to review. To ensure a comprehensive and value-added review, teams can consider

- medium to high technical risk control accounts,
- moderate to high dollar value control accounts,
- critical path activities,
- elements identified in the program risk management plan, and
- significant material subcontracts and non-firm-fixed-price subcontracts.

The IBR team should ask the contractor for a list of all performance budgets in the contract. The contractor can typically provide a matrix of all control accounts, their managers, and approved budget amounts. Often called a dollarized responsibility assignment matrix, it is a valuable tool in selecting control accounts that represent the most risk.

At the end of the IBR, the team's findings inform the program's risk management plan and should give confidence in the quality of the contractor's performance reports. If no IBR is conducted, confidence is less that monthly EVM reporting will be meaningful or accurate.

IBR Preparation

An IBR is most effective if the focus is on areas of greatest risk to the program. Government and contractor program managers should try for mutual understanding of risks and formulate a plan to mitigate and track them through the EVM and risk management processes. In addition, developing cooperation promotes communication and increases the chance for effectively managing and containing program risks.

Depending on the program, the time and effort in preparing for the IBR varies. Specific activities include

- identifying program scope to review, including appropriate control accounts, and associated documentation needs;
- identifying the size, responsibilities, and experience of the IBR team;
- program management planning, such as providing training, obtaining required technical expertise, and scheduling review dates;
- classifying risks by severity and developing risk evaluation criteria; and
- developing an approach for conveying and summarizing findings.

Program managers should develop a plan for conducting the review by first defining the areas of the program scope the team will review. To do this, they should be familiar with the contract statement of work and request the appropriate documents, including the LCCE and program risk assessment, to decide areas that have the most risk. They should also have a clear understanding of management processes that will be used to support the program, including how subcontractors will be managed.

Each IBR requires participation from specific program, technical, and schedule experts. Staff from a variety of disciplines—program management, systems engineering, software engineering, manufacturing, integration and testing, logistics support—should assist in the review. In addition, experts in functional areas like cost estimating, schedule analysis, EVM, and contracting should be members of the team. In particular, EVM specialists and contract management personnel should be active participants. The IBR team may at times also include subcontractor personnel. The team's size should be determined by the program's complexity and the risk associated with achieving its objectives.

While IBRs have traditionally been conducted by government program offices and their contractors, OMB guidance anticipates that EVM will be applied at the program level. Therefore, program-level IBR teams should include participants from other stakeholder organizations, such as the program's business unit, the agency's EVM staff, and others, as appropriate.

Team members must have appropriate training before the IBR is conducted to ensure that they can correctly identify and assess program risks. Team members should be trained so they understand the cost, schedule, and technical aspects of the performance measurement baseline and the processes that will be used to manage them.

As we stated earlier, identifying potential program risk is the main goal of an IBR. Risks are generally categorized as cost, management process, resource, schedule, and technical (table 34).

Table 34: Integrated Baseline Review Risk Categories

Category	Definition
Cost	Evaluates whether the program can succeed within budget, resource, and schedule constraints as depicted in the performance measurement baseline; cost risk is driven by the quality and reasonableness of the cost and schedule estimates, accuracy of assumptions, use of historical data, and whether the baseline covers all efforts outlined in the statement of work
Management process	Evaluates how well management processes provide effective and integrated technical, schedule, cost planning, and baseline change control; it examines whether management processes are being implemented in accordance with the EVM system description. Management process risk is driven by the need for early view into risks, which can be hampered by inability to establish and maintain valid, accurate, and timely performance data, including subcontractors' data
Resource	Represents risk associated with the availability of personnel, facilities, and equipment needed to perform program-specific tasks; includes staff lacking because of other company priorities, unexpected downtime precluding or limiting the use of specific equipment or facilities when needed
Schedule	Addresses whether all work scope has been captured in the schedule and time allocated to lower-level tasks meets the program schedule; schedule risk is driven by the interdependency of scheduled activities and logic and the ability to identify and maintain the critical path
Technical	Represents the reasonableness of the technical plan for achieving the program's objectives and requirements; deals with issues such as the availability of technology, capability of the software development team, technology, and design maturity

Source: Adapted from DOD, *The Program Manager's Guide to the Integrated Baseline Review Process* (Washington, D.C.: Office of the Secretary of Defense (AT&L), April 2003).

Program managers should also outline the criteria for evaluating risks in table 34 and develop a method for tracking them within the risk management process. In addition, they should monitor the progress of all risks identified in the IBR and develop action plans for resolving them.

IBR Execution

Because an IBR provides a mutual understanding of the performance measurement baseline and its associated risk, identifying potential problems early allows for developing a plan for resolving and mitigating them. Thus, the IBR should be initiated as early as possible—before award, when appropriate, and no later than 6 months after. To be most effective, maturity indicators should be assessed to ensure that a value-added assessment of the performance measurement baseline can be accomplished:

1. Work definition:
   - a WBS should be developed;
   - specifications should flow down to subcontractors;
   - internal statement of work for work package definitions should be defined.
2. Integrated schedule:
   - lowest and master level should be vertically integrated;
   - tasks should be horizontally integrated;
   - product handoffs should be identified;
   - subcontractor schedules should be integrated with the prime master schedule.
3. Resources, labor, and material should be fully planned and scheduled;
   - constrained resources should be identified or rescheduled;
   - staffing resources should be leveled off;
   - subcontractor baselines should be integrated with the prime baseline;
   - schedule and budget baselines should be integrated;
   - work package earned value measures should be defined;
   - the baseline should be validated at the lowest levels and approved by management.

The absence of maturity indicators is itself an indication of risk. An IBR should not be postponed indefinitely; it should begin, with a small team, as soon as possible to clarify plans for program execution.

In executing the IBR, the team assesses the adequacy, realism, and risks of the baseline by examining if:

- the technical scope of work is fully included (an allowance for rework and retesting are considered),
- key schedule milestones are identified,
- supporting schedules reflect a logical flow to accomplish tasks,
- the duration of each task is realistic and the network schedule logic is accurate,
- the program's critical path is identified,
- resources—budgets, facilities, personnel, skills—are available and sufficient for accomplishing tasks,
- tasks are planned to be objectively measured for technical progress,
- the rationale supporting performance measurement baseline control accounts is reasonable, and
- managers have appropriately implemented required management processes.

After it has been determined that the program is defined at an appropriate level, interviewing control account managers is the next key IBR objective. Interviews should focus on areas of significant risk and management processes that may affect the ability to monitor risks. Discussions should take place among a small group of people, addressing how the baseline was developed and the supporting documentation. If the contractor has reasonably developed an integrated baseline, preparing for the IBR should require minimal time.

During the interview process, the IBR team meets with specific control account managers to understand how well they use EVM to manage their work and whether they have expertise in their area of discipline. Typical discussion questions involve how the control account managers receive work authorization, how they ensure that the technical content of their effort is covered, and how they use the schedule to plan and manage their work. In addition, interviews are an excellent way to determine whether a control account manager needs additional training in EVM or lacks appropriate resources. A template gives interviewers a consistent guide to make sure they cover all aspects of the IBR objectives. Figure 32 is a sample template.

Figure 32: IBR Control Account Manager Discussion Template

Baseline discussion starter

Step 1	Introductions	**5 minutes**
Step 2	Overview of control accounts General description, work content	**5 minutes**
Step 3	Describe control account or work packages, briefly describe performance to date	**5 minutes**

No.	Title	Budget at completion	% complete	BCWP method	Discuss?

Step 4	Evaluate baseline for each work package	**90 minutes**

Work scope	Schedule	Budget	BCWP method
All work included? Clear work description? Risk mitigation? Technical risk? Trace from scope of work to WBS to control account or work package descriptions	Realistic? Complete? Subcontractors? Task durations? Network logic? Handoffs? Vertical and horizontal integration? Critical path? Concurrence? Developing schedule variance? Completion variance from schedule? Budget risk?	Basis for estimate? Management challenges? Realistic budget? (focus on hours) Phasing? Developing cost variance? Variance at complete? Budget risk?	Objective measures of work? Level of effort minimized? Subcontractor performance? Milestones defined? Method for calculating percentage complete?
Documents to review Statement of work, contractor WBS dictionary, work package descriptions, risk plans	**Documents to review** IMS, work package schedules, staffing plans	**Documents to review** Control account plan, basis of estimate, variance reports, purchase order for material	**Documents to review** Control account plan, back-up worksheets for BCWP, subcontractor reports

Step 5	Document. Complete control account risk evaluation sheet, reach concurrence on risk and action items.	**10 minutes**

Source: DCMA.

After completing the IBR, the program managers assess whether they have achieved its purpose—they report on their understanding of the performance measurement baseline and their plan of action for handling risks. They should develop a closure plan that assigns staff responsibility for each risk identified in the IBR. Significant risks should then be included in the program's risk management plan, while lower-level risks are monitored by responsible individuals. An overall program risk summary should list each risk by category and severity in order to determine a final risk rating for the program. This risk assessment should be presented to senior management—government and contractors—to promote awareness.

The IBR team should document how earned value will be assessed and whether the measurements are objective and reasonable. It should discuss whether management reserve will cover new risks identified in the IBR. Finally, if the team found deficiencies in the EVM system, it should record them in a corrective action request and ask the EVM specialist to monitor their status.

Although a formal IBR report is not usually required, a memorandum for the record describing the findings with all backup documentation should be retained in the official program management files. And, while the IBR is not marked with an official pass or fail, a determination should be made about whether the performance measurement baseline is reliable and accurate for measuring true performance.

Management Processes

When the IBR is complete, the focus should be on the ongoing ability of management processes to reveal actual program performance and detect program risks. The IBR risk matrix and risk management plan should give management a better understanding of risks facing the program, allowing them to manage and control cost and schedule impacts. The following management process should continue after the IBR is finished:

- the baseline maintenance process should continue to ensure that the performance measurement baseline reflects a current depiction of the plan to complete remaining work and follows a disciplined process for incorporating changes, and
- the risk management process should continue to document and classify risks according to the probability that they will occur, their consequences, and their handling.

Other typical business processes that should continue to support the management of the program involve activities like scheduling, developing estimates to complete, and EVM analysis so that risks may be monitored and detected throughout the life of the program. (Appendix XIV has a case study example on IBRs.)

Contract Performance Reports

The IBR completed and the PMB validated, now EVM data can be used to assess performance and project costs at completion. EVM data are typically summarized in a standard CPR. This report becomes the primary source for program cost and schedule status and provides the information needed for effective program control. The CPR provides cost and schedule variances, based on actual performance against the plan, which can be further examined to understand the causes of any differences. Management can rely on these data to make decisions regarding next steps. For example, if a variance stems from an incorrect assumption in the program cost estimate, management may decide to obtain more funding or reduce the scope.

Reviewing CPR data regularly helps track program progress, risks, and plans for activities. When variances are discovered, CPR data identify where the problems are and the degree of their impact on the program. Therefore, the ANSI guidelines specify that, at least monthly, cost and schedule variance data should be generated by the EVM system to give a view into causes and allow action. Since management may not be able to review every control account, relying on CPR data enables management to quickly assess problems and focus on the most important issues.

CPR data come from monthly assessment of and reports on control accounts. Control account managers summarize the data to answer the following questions:

- How much work should have been completed by now—or what is the planned value or BCWS?
- How much work has been done—or what is the earned value or BCWP?
- How much has the completed work cost—or what is the actual cost or ACWP?
- What is the planned total program cost—or what is the BAC?
- What is the program expected to cost, given what has been accomplished—or what is the EAC?

Figure 33 is an example of this type of monthly assessment. It shows that the performance measurement baseline is calculated by summarizing the individual planned costs (BCWS) for all control accounts scheduled to occur each month. Earned value (BCWP) is represented by the amount of work completed for each active control account. Finally, actual costs (ACWP) represent what was spent to accomplish the completed work.

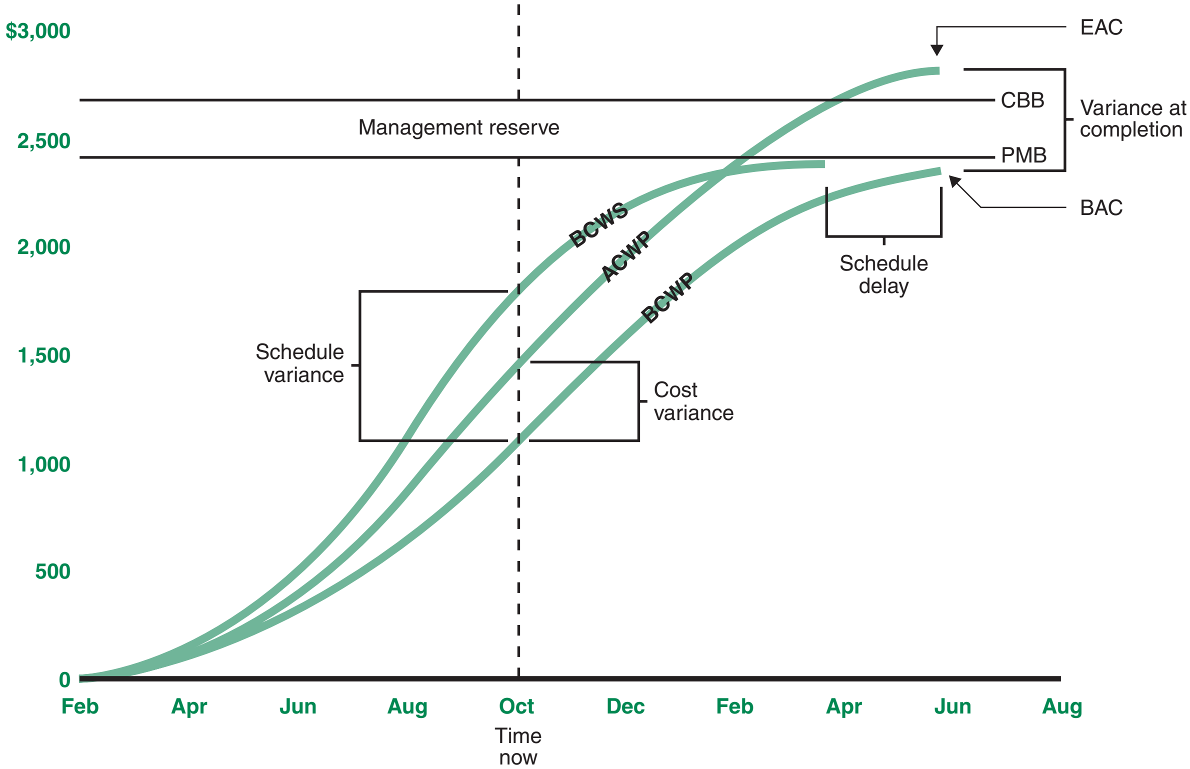
Figure 33: Monthly Program Assessment Using Earned Value

Task description	J	F	M	A	M	J	J	A	S	O	N	D	Budgeted	% Complete	Earned
Concrete	3,000	5,000	2,000										$10,000	100%	$10,000
Framing		5,000	10,000	5,000									20,000	60	12,000
Roofing			1,000	8,000	6,000								15,000	30	5,000
Electrical					10,000	15,000	15,000						40,000		
Plumbing							6,000	12,000	12,000	5,000			35,000		
Interior										8,000	12,000	15,000	35,000		
Monthly budget	$3,000	$10,000	$13,000	$13,000	$16,000	$15,000	$21,000	$12,000	$12,000	$13,000	$12,000	$15,000			
Cum budget (PMB)	3,000	13,000	26,000	39,000	55,000	70,000	91,000	103,000	115,000	128,000	140,000	155,000			
Earned value (BCWP)	1,000	5,000	15,000	27,000											$27,000
Actual cost (ACWP)	2,000	7,000	19,000	33,000											

Source: Naval Air Systems Command (NAVAIR).

According to the data in figure 33, by the end of April the control account for concrete has been completed, while the framing and roofing control accounts are only partially done—60 percent and 30 percent complete, respectively. Examining what was expected to be done by the end of April—$39,000 worth of work—with what was actually accomplished—$27,000 worth of work—one can determine that $12,000 worth of work is behind schedule. Likewise, by assessing what was accomplished—$27,000 worth of work—with what was spent—$33,000—one can see that the completed work cost $6,000 more than planned. These data can also be graphed to quickly obtain an overall program view, as in figure 34.

Figure 34: Overall Program View of EVM Data



Source: © 2003 SCEA, "Earned Value Management Systems."

Note: ACWP = actual cost of work performed; BAC = budget at completion; BCWP = budgeted cost for work performed; BCWS = budgeted cost for work scheduled; CBB = contract budget baseline; EAC = estimate at completion; PMB = performance measurement baseline.

Figure 34 shows that in October, the program is both behind schedule and overrunning cost. The EAC shows projected performance and expected costs at completion. Cost variance is calculated by taking the difference between completed work (BCWP) and its cost (ACWP), while schedule variance is calculated by taking the difference between completed work (BCWP) and planned work (BCWS). Positive variances indicate that the program is either underrunning cost or performing more work than planned. Conversely, negative variances indicate that the program is either overrunning cost or performing less work than planned.

It is important to understand that variances are neither good nor bad. They are merely measures that indicate that work is not being performed according to plan and that it must be assessed further to understand why. From this performance information, various estimates at completion can be calculated. The difference between the EAC and the budget at completion (BAC) is the variance at completion, which represents either a final cost overrun or an underrun.

Management should use the EVM data captured by the CPR data to (1) integrate cost and schedule performance data with technical performance measures, (2) identify the magnitude and impact of actual and potential problem areas causing significant cost and schedule variances, and (3) provide valid and timely program status to higher management. As a management report, the CPR provides timely, reliable summary EVM data with which to assess current and projected contract performance.

The primary value of the report is its ability to reflect current contract status and reasonably project future program performance. When the data are reliable, the report can facilitate informed, timely decisions by a variety of program staff—engineers, cost estimators, and financial management personnel, among others. CPR data are also used to confirm, quantify, and track known or emerging problems and to communicate with the contractor. As long as the CPR data accurately reflect how work is being planned, performed, and measured, they can be relied on for analyzing actual program status. The five formats within a CPR are outlined in figure 35.

Figure 35: A Contract Performance Report's Five Formats

Format 1	Format 2	Format 3	Format 4	Format 5
Work breakdown structure	**Functional categories**	**Baseline**	**Staff loading**	**Explanation of variances**
• WBS level 2 • WBS level 3		• Changes • Undistributed budget • Management reserve		Identify: • Nature of the problem • Reason for cost or schedule variance • Impact on total program • Corrective action taken • Amounts attibuted to rate changes • Undistributed budget application • Management reserve application • Baseline changes

Source: Naval Air Systems Command (NAVAIR).

All five formats in a CPR should be tailored to ensure that only information essential to management on cost and schedule is required from contractors. Format 1 provides cost and schedule data for each element in the program's product-oriented WBS—typically, hardware, software, and other services necessary for completing the program. Data in this format are usually reported to level three of the WBS, but high-cost or high-risk elements may be reported at lower levels to give management an appropriate view of problems.

Format 2 provides the same cost and schedule data as format 1 but breaks them out functionally, using the contractor's organizational breakdown structure. Format 2 may be optional for agencies other than DOD. It need not be obtained, for example, when a contractor does not manage along functional lines.

Format 3 shows the budget baseline plan, against which performance is measured, as well as any changes that have occurred. It also displays cumulative, current, and forecasted data, usually in detail for the next 6 months and in larger increments beyond 6 months. This format forecasts the time-phased budget baseline cost to the end of the program—in other words, the reported data primarily looks forward—and should be correlated with the cost estimate.

Format 4 forecasts the staffing levels by functional category required to complete the contract, and an essential component to evaluating the EAC. This format—also forward looking—allows the analyst to correlate the forecast staffing levels with contract budgets and cost and schedule estimates.

Format 5 is a detailed, narrative report explaining significant cost and schedule variances and other contract problems and topics.

The majority of EVM analysis comes from the CPR's format 1—that is, from examining lower-level control account status to determine lower-level variances—and format 5—that is, from explanations for what is causing the variances in format 1. Table 35 describes some of the major data elements in format 1.

Table 35: Contract Performance Report Data Elements: Format 1

Data element	Description
Contract data	
Contract budget base	Includes the negotiated contract cost plus the estimated cost of any authorized, unpriced work
Negotiated cost	Includes the dollar value (excluding fee or profit) of the contractually agreed-to program cost, typically the definitized contract target cost for an incentive-type contract;[a] excludes costs for changes that have not been priced and incorporated into the contract through a modification or supplemental agreement
Estimated cost of authorized, unpriced work	Excludes fee or profit; represents work that has been authorized but the contract price for it has not been definitized by either a contract change order or supplemental agreement[a]
Budget at completion (BAC)	The sum of all estimated budgets, representing at the program level the cumulative value of BCWS over the life of the program; at lower-levels, such as a control account or WBS element, it represents a roll-up of total estimated cost for the individual element (within a contract, the summary BAC is, in effect, the official spend plan for the contract)
Estimated cost at completion (EAC)	Represents a range of estimated costs at completion so that management has flexibility to analyze possible outcomes and should be as accurate as possible, consider known or anticipated risks, and be reported without regard to the contract ceiling cost; it is derived by adding to actual costs the forecasted cost of work remaining (budgeted cost for work remaining), using a statistically based forecasting method
Variance at completion	Representing the entire program overrun or underrun, it is calculated by taking the difference between the BAC and EAC
Performance data	
Budgeted cost for work scheduled (BCWS)	Representing the amount of work set aside for a specific effort over a stated period of time, it specifically describes the detailed work that was planned to be accomplished according to the program schedule; it is the sum of the budgets for all the work packages, planning packages, etc., scheduled to be accomplished within a given time period; it is the monthly spread of the BAC at the performance measurement level
Budgeted cost for work performed (BCWP)	Representing the earned value for the work accomplished; it is the prime schedule item in the CPR; as earned value, it is the sum of the budgets for completed work packages and completed portions of open work packages, plus the applicable portion of the budgets for apportioned effort and level of effort; BCWP represents that portion of BCWS earned
Actual cost of work performed (ACWP)	Represents actual or accrued costs of the work performed
Cost variance	The difference between BCWP and ACWP represents the cost position—a positive number means that work cost less than planned, a negative number that it cost more

Data element	Description
Schedule variance	The difference between BCWP and BCWS represents the schedule status—a positive number means that planned work was completed ahead of schedule, a negative number that it was not completed as planned. Although it is expressed in dollars and not time, one needs to consider that work takes time to complete and requires resources such as money; therefore, schedule variance is reported as a dollar amount to reflect the fact that scheduled work has a budget; it does not always translate into an overall program schedule time delay; if it is caused by activities on the critical path, then it may cause a time delay in the program
Budgeted cost for work remaining	Represents the planned work that still needs to be done; its value is determined by subtracting budgeted cost for work performed from budget at completion

Source: DOD and SCEA.

[a]Definitized cost or price = contract cost or contract price that has been negotiated.

Using the measures in format 1 at the control account level, management can easily detect problems. The sooner a problem is detected, the easier it will be to reduce its effects or avoid it in future. However, it is not enough just to know there is a problem. It is also critical to know what is causing it. The purpose of format 5 of the CPR is to provide necessary insight into problems. This format focuses on how the control account manager will make corrections to avoid future cost overruns and schedule delays or change cost and schedule forecasts when corrective action is not possible. In addition, format 5 reports on what is driving past variances and what risks and challenges lie ahead. It is an option, though, to focus the format 5 analyses on the top problems of the program instead of looking at each significant variance found in format 1 or 2. Thus, to be useful for providing good insight into problems, the format 5 variance report should discuss

- changes in management reserve;
- differences in various EACs;
- performance measurement milestones that are inconsistent with contractual dates, perhaps indicating an over-target schedule;
- formal reprogramming or over-target baseline;
- significant staffing estimate changes; and
- a summary analysis of the program.

It should also discuss in detail significant problems for each cost or schedule variance, including their nature and reason, the effect on immediate tasks and the total program, corrective actions taken or planned, the WBS number of the variance, and whether the variance is driven primarily by labor or material.

That is, the format 5 variance report should provide enough information for management to understand the reasons for variances and the contractor's plan for fixing them. Good information on what is causing variances is critical if EVM data are to have any value. If the format 5 is not prepared in this manner, then the EVM data will not be meaningful or useful as a management tool, as case study 46 illustrates.

Case Study 46: Cost Performance Reports, from *Defense Acquisitions*, GAO-05-183

The quality of the Navy's cost performance reports, whether submitted monthly or quarterly, was inadequate in some cases—especially with regard to the variance analysis section describing the shipbuilder's actions on problems. The Virginia class submarine and the Nimitz class aircraft carrier variance analysis reports discussed the root causes of cost growth and schedule slippage and described how the variances were affecting the shipbuilders' projected final costs. However, the remaining ship programs tended to report only high-level reasons for cost and schedule variances, giving little to no detail regarding root cause analysis or mitigation efforts. For example, one shipbuilder did not provide written documentation on the reasons for variances, making it difficult for managers to identify risk and take corrective action.

Variance analysis reporting was required and being conducted by the shipbuilders, but the quality of the reports differed greatly. DOD rightly observed that the reports were one of many tools the shipbuilders and DOD used to track performance. To be useful, however, the reports should have contained detailed analyses of the root causes and impacts of cost and schedule variances. CPRs that consistently provided a thorough analysis of the causes of variances, their associated cost impacts, and mitigation efforts would have allowed the Navy to more effectively manage, and ultimately reduce, cost growth.

Therefore, to improve management of shipbuilding programs and promote early recognition of cost issues, GAO recommended that the Navy require shipbuilders to prepare variance analysis reports that identified root causes of reported variances, associated mitigation efforts, and estimated future cost impacts.

GAO, *Defense Acquisitions: Improved Management Practices Could Help Minimize Cost Growth in Navy Shipbuilding Programs*, GAO-05-183 (Washington, D.C.: Feb. 28, 2005).

The level of detail for format 5 is normally determined by specific variance analysis thresholds, which, if exceeded, require problem analysis and narrative explanations. Therefore, each program has its own level of detail to report. Thresholds should be periodically reviewed and adjusted to ensure that they continue to provide management with the necessary view on current and potential problems. In addition, because the CPR should be the primary means of documenting ongoing communication between program manager and contractor, it should be detailed enough that cost and schedule trends and their likely effect on program performance are transparent.

Monthly EVM Analysis

EVM data should be analyzed and reviewed at least monthly so that problems can be addressed as soon as they occur and cost and schedule overruns can be avoided or at least their effect can be lessened. Some labor intensive programs review the data weekly, using labor hours as the measurement unit, to spot and proactively address specific problems before they get out of control.

Using data from the CPR, a program manager can assess cost and schedule performance trends. This information is useful because trends can be difficult to reverse. Studies have shown that once programs are 15 percent complete, performance indicators can predict the final outcome. For example, a CPR showing an early negative trend for schedule status would mean that work is not being accomplished and the program is probably behind schedule. By analyzing the CPR and the schedule, one could determine the cause of the schedule problem, such as delayed flight tests, changes in requirements, or test problems. A negative schedule variance can be a predictor of later cost problems, because additional spending is often necessary to resolve problems. CPR data also provide the basis for independent assessments of a program's cost and schedule status and can be used to project final costs at completion, in addition to determining when a program should be completed.

Analyzing past performance provides great insight into how a program will continue to perform and can offer important lessons learned. Effective analysis involves communicating to all managers and stakeholders what is causing significant variances and developing trends and what corrective action plans are in place so informed decisions can be made. Analysis of the EVM data should be a team effort that is fully integrated into the program management process so results are visible to everyone. Finally, while the analysis focuses on the past and what can be learned from variances, it also projects into the future by relying on historical performance to predict where a program is heading. The principal steps for analyzing EVM data are

1. Analyze performance:
   - check data to see if they are valid,
   - determine what variances exist,
   - probe schedule variances to see if activities are on the critical path,
   - develop historical performance data indexes,
   - graph the data to identify any trends, and
   - review the format 5 variance analysis for explanations and corrective actions.
2. Project future performance:
   - identify the work that remains,
   - calculate a range of EACs and compare the results to available funding,
   - determine if the contractor's EAC is feasible, and
   - calculate an independent date for program completion.
3. Formulate a plan of action and provide analysis to management.

These steps should be taken in sequence, since each step builds on findings from the previous one. Skipping the analysis steps to start off with projecting independent EACs would be dangerous if the EVM data have not been checked to see if they are valid. In addition, it is important to understand what is causing problems before making projections about final program status. For example, if a program is experiencing a negative schedule variance, it may not affect the final completion date if the variance is not associated with an activity on the critical path or if the schedule baseline represents an early "challenge" date. Therefore, it is a best practice to follow the analysis steps in the right order so that all information is known before making independent projections of costs at completion.

Analyze Performance

Check to See If the Data Are Valid

It is important to make sure that the CPR data make sense and do not contain anomalies that would make them invalid. If errors are not detected, then the data will be skewed, resulting in bad decision-making. To determine if the data are valid, they should be checked at all levels of the WBS, focusing on whether there are errors or data anomalies such as

- negative values for ACWP, BAC, BCWP, BCWS, or EAC;
- unusually large performance swings (BCWP) from month to month;
- BCWP and BCWS data with no corresponding ACWP;
- BCWP with no BCWS;
- BCWP with no ACWP;
- ACWP with no BCWP;
- ACWP that is way above or below the planned value;
- inconsistency between EAC and BAC—for example, no BAC but an EAC or a BAC with no EAC;
- ACWP exceeds EAC;
- BCWP or BCWS exceed BAC.

If the CPR data contain anomalies, the performance measurement data will be distorted. For example, a CPR reporting actual costs (ACWP) with no corresponding earned value (BCWP) could indicate that unbudgeted work is being performed but not captured in the CPR. When this happens, the performance measurement data will not reflect true status.

In addition to checking the data for anomalies, the EVM analyst should check whether the CPR data are consistent. For instance, the analyst should review whether the data reported at the bottom line in format 1 match the total in format 2. The analyst should also assess whether program cost is consistent with the authorized budget.

Determine What Variances Exist

Cost and schedule deviations from the baseline plan give management at all levels information about where corrective actions are needed to bring the program back on track or to update completion dates and EACs. While variances are often perceived as something bad, they provide valuable insight into program risk and its causes. Variances empower management to make decisions about how best to handle risks. For example, management may decide to allocate additional resources or hire technical experts, depending on the nature of the variance.

Because negative cost variances are predictive of a final cost overrun if performance does not change, management needs to focus on containing them as soon as possible. A negative schedule variance, however, does not automatically mean program delay; it means that planned work was not completed.

To know whether the variance will affect the program's completion date, the EVM analyst also needs to analyze the time-based schedule, especially the critical path. Because EVM data cannot provide this information, data from the contractor's scheduling system are needed. Therefore, EVM data alone cannot provide the full picture of program status. Other program management tools and information are also needed to better understand variances.

Probe Schedule Variances for Activities on the Critical Path

Schedule variances should be investigated to see if the effort is on the critical path. If it is, then the whole program will be delayed. And, as we mentioned before, any delay in the program will result in additional cost unless other measures are taken. The following methods are often used to mitigate schedule problems:

- consuming schedule reserve if it is available,
- diverting staff to work on other tasks while dealing with unforeseen delays,
- preparing for follow-on activities early so that transition time can be reduced,
- consulting with experts to see if process improvements can reduce task time,
- adding more people to speed up the effort, and
- working overtime.

Caution should be taken with adding more people or working overtime, since these options cost money. In addition, when too many people work on the same thing, communication tends to break down. Similarly, working excessive overtime can make staff less efficient. Therefore, careful analysis should precede adding staff or instituting overtime.

A good network schedule that is kept current is a critical tool for monitoring program performance. Carefully monitoring the contractor's network schedule will allow for quickly determining when forecasted completion dates differ from the planned dates. Tasks may be resequenced or resources realigned to reduce the schedule condition. It is also important to determine whether schedule variances are affecting downstream work. For example, a schedule variance may compress remaining activities' duration times or cause "stacking" of activities toward the end of the program, to the point at which it is no longer realistic to predict success. If this happens, then an over target schedule may be necessary (discussed in chapter 20).

Various schedule measures should be analyzed to better understand the impact of schedule variances. For example, the amount of float, as well as the number of tasks with lags, constraints, or lack of progress, should be examined each month. Excess float usually indicates that the schedule logic is flawed, broken, or absent. Large float values should be checked to determine if they are real or a consequence of incomplete scheduling. Similarly, a large number of tasks with constraints (such as limitations on when an activity can start or finish), typically are substitutes for logic and can mean that the schedule is not well planned. Lags are often reserved for time that is unchanging, does not require resources and cannot be avoided (as in waiting for concrete to cure), but lags are often inappropriately used instead of logic to put activities on a specified date. Similarly, if open work packages are not being statused regularly, it may be that the schedule and EVM are not really being used to manage the program. Analyzing these issues can help assess the schedule's progress.

In addition to monitoring tasks on the critical path, close attention should be paid to near-critical tasks and near-term critical path effort, as these may alert management to potential schedule problems. If a task is not on the critical path but is experiencing a large schedule variance, the task may be turning critical. Therefore, schedule variances should be examined for their causes. For instance, if material is arriving late and the variance will disappear once the material is delivered, its effect is minimal. But if the late material is causing tasks to slip, then its effect is much more significant.

Remember that while a negative schedule variance eventually disappears when the full scope of work is ultimately completed, a negative cost variance is not corrected unless work that has been overrunning begins to underrun—a highly unlikely occurrence. Schedule variances are usually followed by cost variances; as schedule increases, costs such as labor, rented tools, and facilities increase. Additionally, management tends to respond to schedule delays by adding more resources or authorizing overtime.

Develop Historical Performance Data Indexes

Performance indexes are necessary for understanding the effect a cost or schedule variance has on a program. For example, a $1 million cost variance in a $500 million program is not as significant as it is in a $10 million program. Because performance indexes are ratios, they provide a level of program efficiency that easily shows how a program is performing.

The cost performance index (CPI) and schedule performance index (SPI) in particular can be used independently or together to forecast a range of statistical cost estimates at completion. They also give managers early warning of potential problems that need correcting to avoid adverse results. Table 36 explains what the values of three performance indexes indicate about program status.

Table 36: EVM Performance Indexes

Index	Formula	Indicator
Cost performance index (CPI), the ratio of work performed (or earned value) to actual costs for work performed	CPI = BCWP / ACWP	Like a negative cost variance, a CPI less than 1 is unfavorable, because work is being performed less efficiently than planned; a CPI greater than 1 is favorable, implying that work is being performed more efficiently than planned. CPI can be expressed in dollars: 0.9 means that for every dollar spent, the program has received 90 cents worth of completed work
Schedule performance index (SPI), the ratio of work performed (or earned value) to the initial planned schedule	SPI = BCWP / BCWS	Like a negative schedule variance, an SPI less than 1 indicates that work is not being completed as planned and the program may be behind schedule if the incomplete work is on the critical path; an SPI greater than 1 means work has been completed ahead of the plan. An SPI can be thought of as describing work efficiency: 0.9 means that for every dollar planned, the program is accomplishing 90 cents worth of work
To complete performance index (TCPI), cost performance to be achieved if remaining work is to meet contractor EAC	TCPI = BCWR/ (EAC – ACWP))[a]	CPI takes into account what the contractor has done and can be compared to TCPI to test the EAC's reasonableness; if TCPI is higher than CPI, the contractor expects productivity to improve, which may not be feasible given past performance

Source: DOD and SCEA.

[a]BCWR = budgeted cost for work remaining.

Just like variances, performance indexes should be investigated. An unfavorable CPI—one less than 1.0—may indicate that work is being performed less efficiently or that material is costing more than planned. Or it could mean that more expensive labor is being employed, unanticipated travel was necessary, or technical problems were encountered. Similarly, a mistake in how earned value was taken or improper accounting could cause performance to appear to be less efficient. The bottom line: more analysis is needed to know what is causing an unfavorable condition. Likewise, favorable cost or schedule performance may stem from errors in the EVM system, not necessarily from work's taking less time than planned or overrunning its budget. Thus, not assessing the full meaning behind the indexes runs the risk of basing estimates at completion on unreliable data.

Further, when using the CPI as a sanity check against the TCPI, if the TCPI is much greater than the current or cumulative CPI, then the analyst should discover whether this gain in productivity is even possible. If not, then the contractor is most likely being optimistic. A rule of thumb is that if the TCPI is more than 5 percent higher than the CPI, it is too optimistic. In addition, a CPI less than 1 is a cause for concern, because without exception, the cumulative CPI tends not to improve but, rather, declines after a program is 15 percent complete.

An SPI different from 1.0 warrants more investigation to determine what effort is behind or ahead of schedule. To do this, one needs to examine the WBS to identify issues at the activity level associated with completing the work. Using this information, management could decide to reallocate resources, where possible, from activities that might be ahead of schedule (SPI greater than 1.10) to help activities that are struggling (SPI less than 0.90) to get back on track. There also should be a discussion on analyzing the free-float of activities that are slipping to see if proactive actions should take place so resources are not lost in future activities.

Performance reported early in a program tends to be a good predictor of how the program will perform later, because early control account budgets tend to have a greater probability of being achieved than those scheduled to be executed later. DOD's contract analysis experience suggests that all contracts are front-loaded to some degree, simply because more is known about near-term work than far-term. To the extent possible, the IBR should check for this condition.

In addition to the performance indexes, three other simple and useful calculations for assessing program performance are

- % planned = BCWS/BAC,
- % complete = BCWP/BAC, and
- % spent = ACWP/BAC.

Examining these formulas, one can see quickly whether a program is doing well or is in trouble. For example, if percent planned is much greater than percent complete, the project is significantly behind schedule. Similarly, if percent spent is much greater than percent complete, the project is significantly overrunning its budget. Moreover, if the percent of management reserve consumed is much higher than percent complete, the program is likely not to have sufficient budget to mitigate all risks. For example, if a program is 25 percent complete but has spent more than 50 percent of its management reserve, there may not be enough management reserve budget to cover remaining risks because, this early in the program, it is being consumed at twice the rate at which work is being accomplished.

Graph the Data to Discover Trends

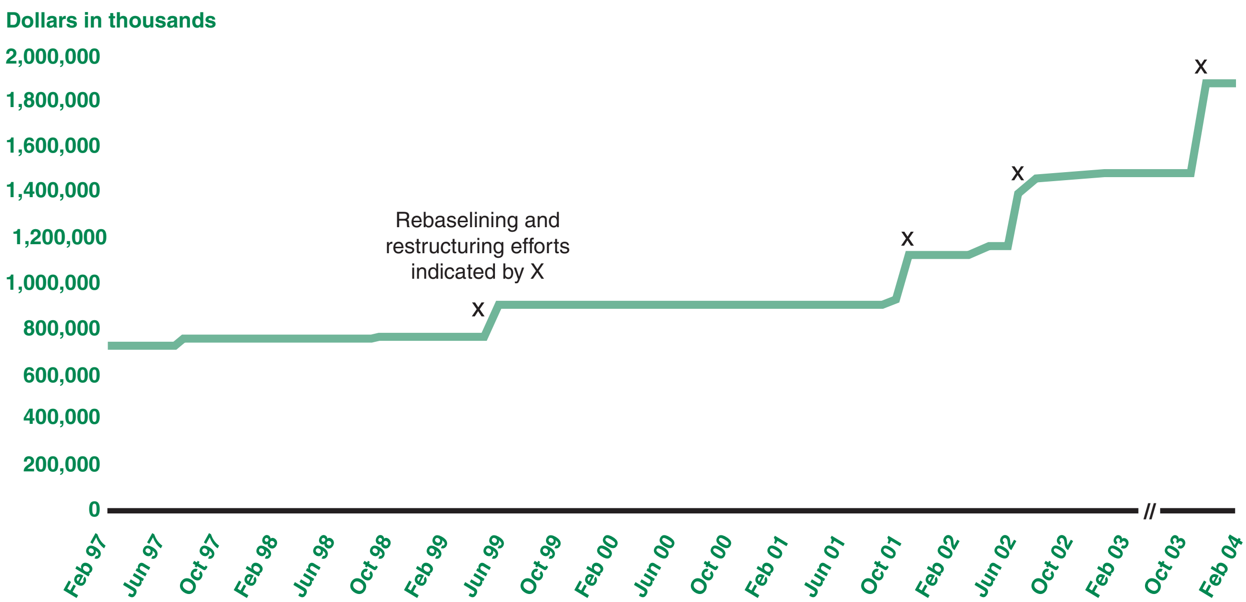
For reasons we discussed in chapter 10, EVM data should be analyzed graphically to see what trends are apparent. Performance trends provide valuable information about how a program has been doing in terms of cost and schedule. They also help in understanding performance, important for accurately predicting costs at completion. Knowing what has caused problems in the past can help determine whether they will continue in the future.

Trend analysis should plot current and cumulative EVM data and track the use of management reserve for a complete view of program status and an indication of where problems exist. Typical EVM data trend plots that can help managers know what is happening in their programs are

- BAC and contractor EAC over the life of the contract;
- historical, cumulative and current, cost, and schedule variance trends;
- CPI and SPI (cumulative and current), monthly burn rate, or current ACWP;
- TCPI versus CPI (cumulative and current), format 3 baseline data;
- projected versus actual staffing levels from format 4; and
- management reserve allocations and burn rate.

Plotting the BAC over the life of the contract will quickly show any contract rebaselines or major contract modifications. BACs that follow a stairstep trend mean that the program is experiencing changes or major overruns. Both should be investigated to see if the EVM data are still reliable. For example, if the contract has been modified, then an IBR may be necessary to ensure that the changes were incorporated and flowed down to the right control accounts. In figure 36, BAC for an airborne laser program has been plotted over time to show the effect of major contract modifications and program rebaselines.

Figure 36: Understanding Program Cost Growth by Plotting Budget at Completion Trends



Source: GAO.

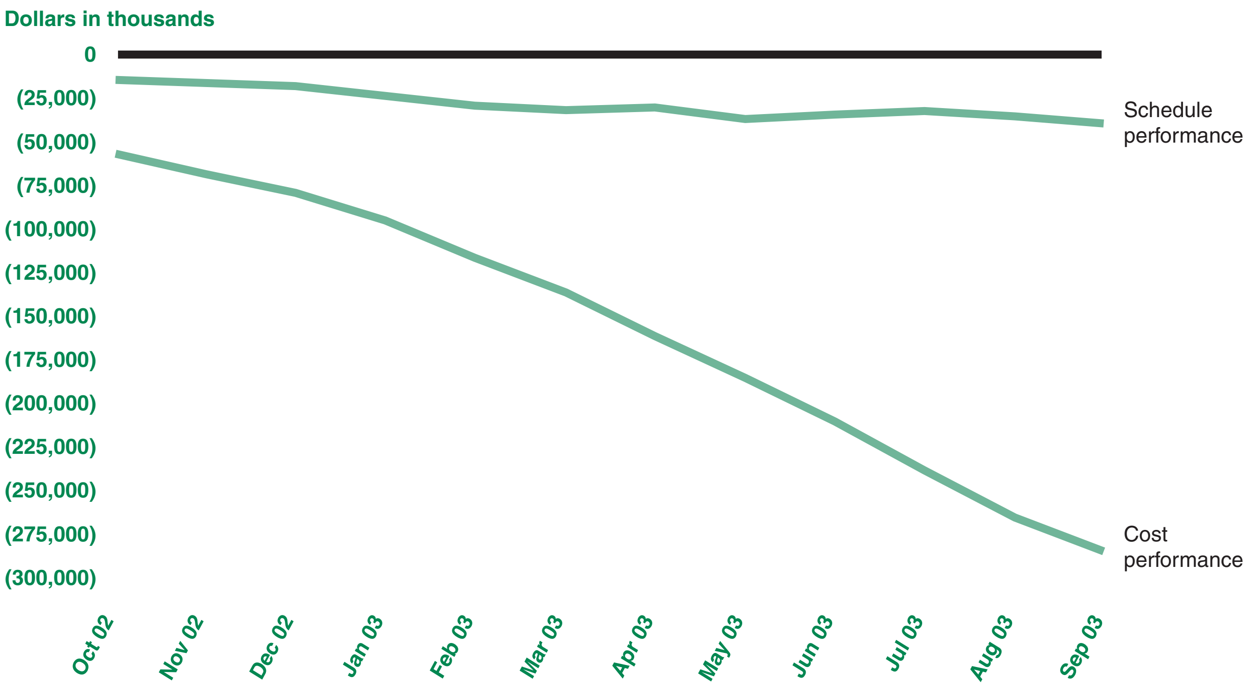
Note: The trend examples in figures 36–38, shown for learning purposes, are drawn from GAO, *Uncertainties Remain Concerning the Airborne Laser's Cost and Military Utility*, GAO-04-643R (Washington, D.C.: May 17, 2004), pp. 17–20.

The figure reveals a number of contract modifications, program restructurings, and rebaselines in the airborne laser program over the 7 years 1997 to 2004. Looking at the plot line, one can quickly see that the program more than doubled in cost. The trend data also show instances of major change, making it easy to pinpoint exactly which CPRs should be examined to best understand the circumstances.

In this example, cost growth occurred when the program team encountered major problems with manufacturing and integrating advanced optics and laser components. Initial cost estimates underestimated the complexity in developing these critical technologies, and funding was insufficient to cover these risks. To make matters worse, the team was relying on rapid prototyping to develop these technologies faster, and it performed limited subcomponent testing. These shortcuts resulted in substantial rework when parts failed during integration.

Besides examining BAC trends, it is helpful to plot cumulative and current cost and schedule variances for a high-level view of how a program is performing. If downward trends are apparent, the next step is to isolate where these problems are in the WBS. Figure 37 shows trends of increasing cost and schedule variance associated with the airborne laser program.

Figure 37: Understanding Program Performance by Plotting Cost and Schedule Variances



Source: GAO.

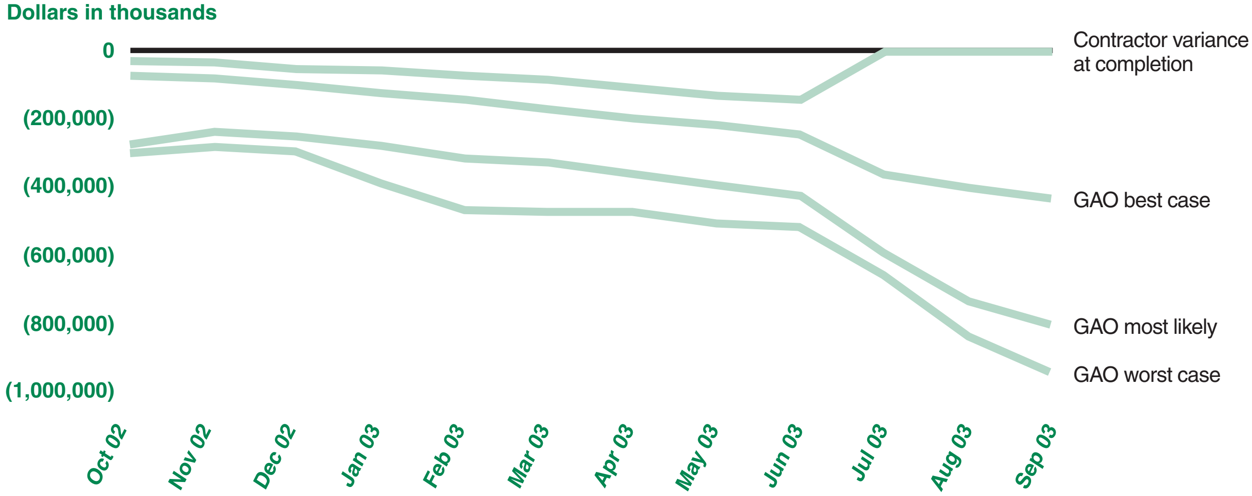
Note: The trend examples in figures 36–38, shown for learning purposes, are drawn from GAO, Uncertainties Remain Concerning the Airborne Laser's Cost and Military Utility, GAO-04-643R (Washington, D.C.: May 17, 2004), pp. 17–20.

In figure 37, cost variance steadily declined over fiscal year 2003, from an unfavorable $50 million to an almost $300 million overrun. At the same time, schedule variance also declined, but during the first half of the year it leveled off, after the program hired additional staff in March to meet schedule objectives. While the additional staff helped regain the schedule, they also caused the cost variance to worsen.

Plotting both cost and schedule variances makes a wealth of information visible. Management can rely on this information to discover where attention is needed most.

Plotting various EACs along with the contractor's estimate at completion is a very good way to see if the contractor's estimate is reasonable. Figure 38, for example, shows expected cost overruns at contract completion for the airborne laser program.

Figure 38: Understanding Expected Cost Overruns by Plotting Estimate at Completion



Source: GAO.

Note: The trend examples in figures 37 and 38, shown for learning purposes, are drawn from GAO, Uncertainties Remain Concerning the Airborne Laser's Cost and Military Utility, GAO-04-643R (Washington, D.C.: May 17, 2004), pp. 17–20.

Figure 38 plots various EACs that GAO generated from the contractor's EVM data. GAO's independent EACs showed that an overrun between $400 million and almost $1 billion could be expected from recent program performance. The contractor, in contrast, was predicting no overrun at completion—despite the fact that the program had already incurred a cost overrun of almost $300 million, as shown in figure 37.

That the program was facing huge technology development problems made it highly unlikely that the contractor could finish the program with no additional cost variances. In fact, there was no evidence that the contractor could improve its performance enough to erase the almost $300 million cumulative cost variance. Knowing this, the reasonable conclusion was that the contractor's estimate at completion was not realistic, given that it was adding more personnel to the contract and still facing increasing amounts of uncompleted work from prior years.

Another way to check the reasonableness of a contractor's estimate at completion is to compare the CPI, current and cumulative, with the TCPI to see if historical trends support the contractor's EAC.

Other trends that can offer insight into program performance include plotting the monthly burn rate, or ACWP. If the plotting shows a rate of increase, the analyst needs to determine whether the growth stems from the work's becoming more complex as the program progresses or from overtime's being initiated to make up for schedule delays. Reviewing monthly ACWP and BCWP trends can also help determine what is being accomplished for the amount spent. In the data in figures 37 and 38, for example, it was evident that the program was paying a large staff to make a technological breakthrough rather than paying its staff overtime just to meet schedule goals. It is important to know the reasons for variances, so management can make decisions about the best course of action. For the program illustrated in the figures, we recognized that since the airborne laser program was in a period of technology discovery that could not be forced to a specific schedule, any cost estimate would be highly uncertain. Therefore, we recommended that the agency develop a new cost estimate for completing technology development and perform an uncertainty analysis to quantify its level of confidence in that estimate.

Other trend analyses include plotting CPR format 3 data over time to show whether budget is being moved to reshape the baseline. Comparing planned to actual staffing levels—using a waterfall chart to analyze month-to-month profiles—can help determine whether work is behind schedule for lack of available staff.[78] This type of trend analysis can also be used to determine whether projected staffing levels shown in CPR format 4 represent an unrealistic expectation of growth in labor resources.

Finally, plotting the allocation and burn rate of management reserve is helpful for tracking and analyzing risk. Since management reserve is a budget tool to help manage risks, analyzing its rate of allocation is important because when management reserve is consumed, any further risk that is realized can only be manifested as unfavorable cost variance. Accordingly, risks from the cost estimate uncertainty analysis should be compared against the management reserve allocation to understand where in the WBS risks are turning into issues. This analysis is a best practice because it further ties the cost estimating risk analysis with EVM. It can also prevent the handing out of budget whenever a program encounters a problem, ensuring that as more complicated tasks occur later in the program, management reserve will be available to mitigate any problems. Therefore, to meet this best practice, risks in the cost estimate should be identified up front and conveyed to the EVM analysts, so they can keep a look out for risks in specific WBS elements. Thus, it is absolutely necessary to integrate cost estimating and EVM in order to have the right information to make good judgments about when to allocate management reserve.

Review the Format 5 Variance Analysis

After determining which WBS elements are causing cost or schedule variances, examining the format 5 variance analysis can help determine the technical reasons for variances, what corrective action plans are in place, and whether or not the variances are recoverable. Corrective action plans for cost and schedule variances should be tracked through the risk mitigation process. In addition, favorable cost variances should be evaluated to see if they are positive as a result of performance without actual cost having been recorded. This can happen when accounting accruals lag behind invoice payments. Finally, the variance analysis report should discuss any contract rebaselines and whether any authorized unpriced work exists and what it covers.

Examining where management reserve has been allocated within the WBS is another way to identify potential issues early on. An alarming situation arises if the CPR shows that management reserves are being used faster than the program is progressing toward completion. For example, management should be concerned if a program has used 80 percent of its management reserves but has completed only 40 percent of its work. EVM experts agree that a program's management reserves should be sufficient to mitigate identified program risk so that budget will always be available to cover unexpected problems.

[78] A waterfall chart is made up of floating columns that typically show how an initial value increases and decreases by a series of intermediate values leading to a final value; an invisible column keeps the increases and decreases linked to the heights of the previous columns. Waterfall charts can be created by applying widely available add-in tools to Microsoft Excel.

This is especially important toward the latter half of a program, when adequate management reserve is needed to cover problems during testing and evaluation. When management reserve is gone, any work that could have been budgeted from it can only manifest as additional cost overrun. And, when it is gone, the analyst should be alert to contractor requests to increase the contract value to avoid variances.

Project Future Performance

Identify the Work That Remains

Two things are needed to project future performance: the actual costs spent on completed work and the cost of remaining work. Actual costs spent on completed work are easy to determine because they are captured by the ACWP. The remaining work is determined by subtracting BCWP from BAC to derive the budgeted cost of work remaining. However, to be accurate, the EAC should take into account performance to date when estimating the cost of the remaining work.

Calculate a Range of EACs and Compare to Available Funding

It is a best practice to develop more than one EAC, but determining an accurate EAC is difficult because EVM data can be used to develop a multitude of EACs. Picking the right EAC is challenging since the perception is that bad news about a contract's performance could put a program and its management in jeopardy. By calculating a range of EACs, management can know a likely range of costs for completing the program and take action in response to the results.

While plenty of EACs can be generated from the EVM data, each EAC is calculated with a generic index-based formula, similar to

EAC = ACWP (cumulative) + (BAC – BCWP (cumulative)) / efficiency index

The difference in EACs is driven by the efficiency index that is used to adjust the remaining work according to the program's past cost and schedule performance. The idea in using the efficiency index is that how a program has performed in the past will indicate how it will perform in the future. The typical performance indexes include the CPI and SPI, but these could represent cumulative, current, or average values over time. In addition, the indexes could be combined to form a schedule cost index—as in CPI x SPI—which can be weighted to emphasize either cost or schedule impact. Further, EACs can be generated with various regression analyses in which the dependent variable is ACWP and the independent value is BCWP, a performance index, or time. Thus, many combinations of efficiency indexes can be applied to adjust the cost of remaining work.

Table 37 summarizes findings from studies in which EACs make the best predictors, depending on where the program is in relation to its completion. The findings are based on extensive research that compared efficiency factors that appeared to best predict program costs. The conclusion was that no one factor was superior. Instead, the best EAC efficiency factor changes by the stage of the program. For example, the research found that assigning a greater weight to SPI is appropriate for predicting costs in the early stage of a program but not appropriate later on. SPI loses its predictive value as a program progresses and eventually returns to 1.0 when the program is complete. The research also found that averaging performance over a shorter period of time—3 months, for example—was more accurate for predicting costs than longer periods of time—such as 6 to12 months—especially in the middle of a program, when costs are being spent at a greater rate.

Table 37: Best Predictive EAC Efficiency Factors by Program Completion Status

EAC efficiency factor		Percent complete: Early: 0%–40%	Middle: 20%–80%	Late: 60%–100%	Comment
CPI	Cumulative	x	x	x	Assumes the contractor will operate at the same efficiency for remainder of program; typically forecasts the lowest possible EAC
	3-month average	x	x	x	Weights current performance more heavily than cumulative past performance
	6-month average		x	x	
	12-month average		x	x	
CPI x SPI	Cumulative	x	x		Usually produces the highest EAC
	6-month average		x	x	A variation of this formula (CPI_6 x SPI), also proven accuratea
SPI	Cumulative	x			Assumes schedule will affect cost also but is more accurate early in the program than later
Regression		x			Using CPI that decreases within 10% of its stable value can be a good predictor of final costs and should be studied further
Weighted		x		x	Weights cost and schedule based on .x(CPI) + .x(SPI); statistically the most accurate, especially when using 50% CPI x 50% SPI [a]

Source: Industry.

[a]Per DOD comments based on the work of David S. Christensen.

Other methods, such as the Rayleigh model, rely on patterns of manpower build-up and phase-out to predict final cumulative cost. This model uses a nonlinear regression analysis of ACWP against time to predict final cumulative cost and duration and has been known to be a high-end EAC forecast. One benefit of using this model is that as long as actual costs are available, they can be used to forecast cumulative cost at completion and to assess overall cost and schedule risk.

Relying on the CPI and SPI performance factors usually results in higher EACs if their values are less than 1.0. How much the cost will increase depends on the specific index and how many months are included in determining the factor. Research has also shown that once a program is 20 percent complete, the cumulative CPI does not vary much from its value (less than 10 percent) and most often tends to get worse as completion grows nearer. Therefore, projecting an EAC by using the cumulative CPI efficiency factor tends to generate a best case EAC.

In contrast, the schedule cost index—some form of CPI x SPI—takes the schedule into account to forecast future costs. This index produces an even higher EAC by compounding the effect of the program's being behind schedule and over cost. The theory behind this index is that to get back on schedule will require more money because the contractor will either have to hire more labor or pay for overtime. As a result, the schedule cost index forecast is often referred to as a worst case predictor.

A more sophisticated EAC method relies on using actual costs to date plus the remaining work with a cost growth factor applied plus a cost impact for probable schedule delays. Using this method takes into account cost, schedule, and technical risks that can result from test failures or other external factors that have occurred in other past programs and relies on simulation to determine the probability effect. Finally, an integrated schedule can be used, in combination with risk analysis data and Monte Carlo simulation software, to estimate schedule risk and the EAC (chapter 18, step 10, has more details).

EACs should be created not only at the program level but also at lower levels of the WBS. By doing this, areas that are performing poorly will not be masked by other areas doing well. If the areas performing worse represent a large part of the BAC, then this method will generate a higher and more realistic EAC. Once a range of EACs has been developed, the results should be analyzed to see if additional funding is required. Independent EACs provide a credible rationale for requesting additional funds to complete the program, if necessary. Their information is critical for better program planning and avoiding a situation in which work must be stopped because funds have been exhausted. Early warning of impending funding issues enables management to take corrective action to avoid any surprises.

Determine Whether the Contractor's EAC Is Feasible

While EVM data are useful for predicting independent EACs, the contractor should also look at other information to develop its EAC. In particular, the contractor should

- evaluate its performance on completed work and compare it to the remaining budget,
- assess commitment values for material needed to complete remaining work, and
- estimate future conditions to generate the most accurate EAC,

Further, the contractor should periodically develop a comprehensive EAC, using all information available to develop the best estimate possible. This estimate should also take into account an assessment of risk based on technical input from the team. Once the EAC is developed, it can be compared for realism against other independent EACs and historical performance indexes.

A case in point is the Navy's A-12 program, cancelled in January 1991 by the Secretary of Defense because estimates based on EVM of the cost to complete it showed substantial overruns. Many estimates had been developed for the program. The program manager had relied on the lower EAC, even though higher EACs had been calculated. The inquiry into the A-12 program cancellation concluded that management tended to suppress bad news and that this was not a unique problem but common within DOD.

Since a contractor typically uses methods outside EVM to develop an EAC, EVM and risk analysis results can be used to assess the EAC's reliability. While the contractor's EAC tends to account for special situations and circumstances that cannot be accurately captured by looking only at statistics, it also tends to include optimistic views of the future. One way to assess the validity of the EAC is to compare the TCPI to the CPI. Because the TCPI represents the ratio of remaining work to remaining funding and indicates the level of performance the contractor must achieve and maintain to stay within funding goals, it can be a good benchmark for assessing whether the EAC is reasonable. Therefore, if the TCPI is greater than the CPI, this means that the contractor expects productivity to be higher in the future. To determine whether this is a reasonable assumption, analysts should look for supporting evidence that backs up this claim.

A typical rule of thumb is that if the CPI and TCPI differ by more than 5 percent to 10 percent, and the program is more than 20 percent complete, the contractor's EAC is too optimistic. For example, if a program's TCPI is 1.2 and the cumulative CPI is 0.9, it is not statistically expected that the contractor can improve its performance that much through the remainder of the program. To meet the EAC cost, the contractor must produce $1.20 worth of work for every $1.00 spent. Given the contractor's historical performance of $0.90 worth of work for every $1.00 spent, it is highly unlikely that it can improve its performance that much. One could conclude that the contractor's EAC is unrealistic and that it underestimates the final cost.

Another finding from more than 500 studies is that once a contract is more than 15 percent complete, the overrun at completion will usually be more than the overrun already incurred.[79] Looking again at the example of the airborne laser program discussed around figures 37–38, we see that while the contractor predicted no overrun at completion, there was a cumulative unfavorable cost variance of almost $300 million. According to this research statement, one could conclude that the program would overrun by $300 million or more. Using EVM data from the program, we predicted that the final overrun could be anywhere between $400 million and almost $1 billion by the time the program was done.

Calculate an Independent Date for Program Completion

Dollars can be reallocated to future control accounts by management, but time cannot. If a cost underrun occurs in one cost account, the excess budget can be transferred to a future account. But if a control account is 3 months ahead and another is 3 months behind, time cannot be shifted from the one account to the other to fix the schedule variance. Given this dynamic, the schedule variance should be examined in terms of the network schedule's critical and near-critical paths to determine what specific activities are behind schedule, and a schedule risk analysis should determine which activities may cause the schedule to extend in the future.

In the simplest terms, the schedule variance describes what was or was not accomplished but does not provide an accurate assessment of schedule progress. To project when a program will finish, management must know whether the activities that are contributing to a schedule variance are on the critical path or may ultimately be on the path, if mitigation is not pursued. If they are, then any slip in the critical path activities will result in a slip in the program, and sufficient slippage in near-critical paths may ultimately have the same result. Therefore, the program manager should analyze the activities undergoing delay to see if they may ultimately delay the program. If they are, then the program may be in danger of not finishing on schedule and an analysis, generally a schedule risk analysis, should be conducted to determine the most likely completion date. In addition, a schedule risk analysis (described in appendix X) should be made periodically to assess changes to the critical path and explain schedule reserve erosion and mitigation strategies for keeping the program on schedule.

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[79] David S. Christensen, *Determining an Accurate Estimate at Completion* (Cedar City: Southern Utah University, 1993), p. 7.

Provide Analysis to Management

The ability to act quickly to resolve program problems depends on having an early view of what is causing them. Management's having accurate progress assessments makes for a better picture of program status and leads to better decisions. When problems are identified, they should be captured within the program's risk management process so that someone can be assigned responsibility for tracking and correcting them.

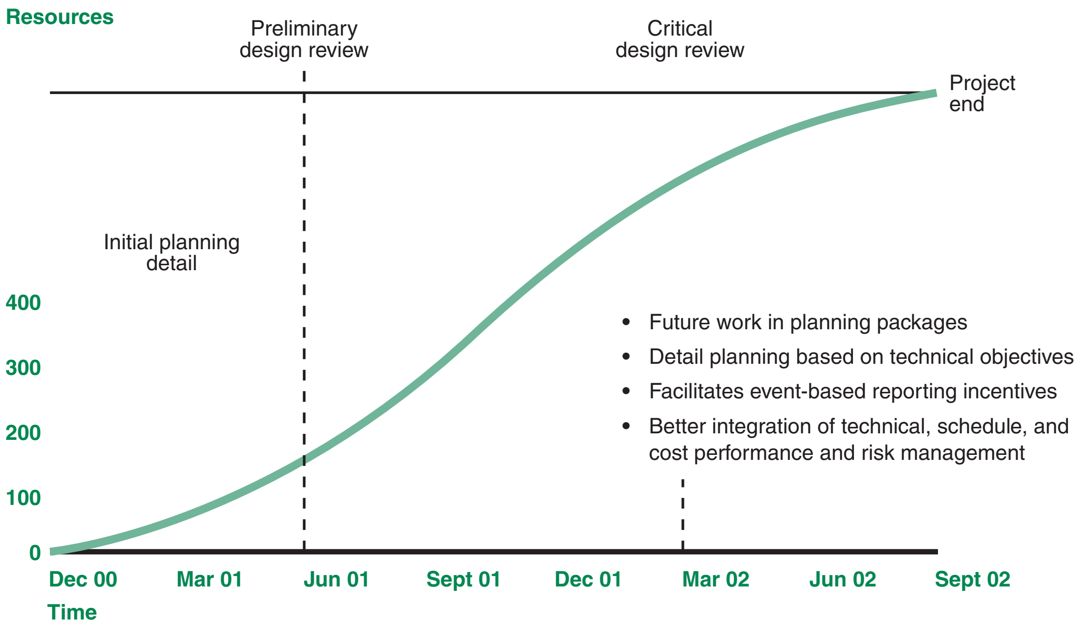
In addition, using information from the independent EACs and the contractor's EAC, management should decide whether additional program funding should be requested and, if so, make a convincing case for more funds. Management should also be sure to link program outcomes to award-fee objectives. For example, management can look back to earlier CPRs to see if they objectively depicted contract status and predicted certain problems. This approach supports performance-based reporting and rewards contractors for managing effectively and reporting actual conditions, reducing the need for additional oversight.

Continue EVM Until the Program is Complete

EVM detail planning is never ending and continues until the program is complete. Converting planning packages into detailed work packages so that near-term effort is always detailed is called "rolling wave" planning. This approach gives the contractor flexibility for planning and incorporating lessons learned.

Rolling-wave planning that is based solely on calendar dates is an arbitrary practice that may result in insufficient detail. When this approach is used, work is planned in 6-month increments; all effort beyond a 6-month unit is held in a planning package. Each month, near-term planning packages are converted to detailed work packages to ensure that 6 months of detailed planning are always available to management. This continues until all work has been planned in detail and the program is complete. A better method is to plan in detail a significant technical event, such as the preliminary design review. By using technical milestones rather than calendar dates, better cost, schedule, and technical performance integration can be achieved, as depicted in figure 39.

Figure 39: Rolling Wave Planning



Source: Abba Consulting.

The unwritten rule that 1 month of detailed planning should be added to previously detailed planning is related more to creating than managing to a baseline, which is the heart of EVM. Therefore, managing to a technical event is the best practice and yields the best EVM benefits.

Continually planning the work supports an EVM system that will help management complete the program within the planned cost and proposed schedule. This is important, since EVM data are essential to effective program management and can be used to answer basic program management questions such as those in table 38.

Table 38: Basic Program Management Questions That EVM Data Help Answer

Question	Answer
How much progress has the program made so far?	Percent complete
What are the significant deviations from the plan?	▪ Cost variance ▪ Schedule variance ▪ Variance at completion
How efficiently is the program meeting cost and schedule objectives?	▪ Cost performance index (CPI) ▪ Schedule performance index (SPI)
Are cost and schedule trends getting better or worse?	Plotting cost and schedule variance, CPI, SPI, etc.
Will the program be completed within the budget?	To complete performance index (TCPI) for the budget at completion (BAC)
Is the contractor's estimate at completion (EAC) reasonable?	TCPI for the contractor's EAC
What other estimates are reasonable for completing the authorized scope of work?	Independent EACs using statistical forecasting techniques based on various efficiency factors
What action will bring the program back on track?	Acting on format 5 variance analysis information

Source: © 2003, Society of Cost Estimating and Analysis (SCEA), "Earned Value Management Systems"

From questions such as those in table 38, reliable EVM data can help inform the most basic program management needs. The questions also provide an objective way of measuring progress so that accurate independent assessments of EACs can be developed and presented to stakeholders.

16. Best Practices Checklist: Managing Program Costs: Execution

- ☐ An IBR verified that the baseline budget and schedule captured the entire scope of work, risks were understood, and available and planned resources were adequate.
  - ✓ Separate IBRs were conducted at the prime contractor and all major subcontractors.
  - ✓ A performance measurement baseline assessment made a comprehensive and value-added review of control accounts.
    - o Before award, or not more than 6 months after, an IBR categorized risks by severity and provided team training.
    - o Work definition (including provisions for rework and retesting), schedule integration, resource identification, earned value measures, and baseline validation were matured and reviewed.

- o Interviewers used a template in discussions with control account managers and identified where additional training was needed.
- o An action plan for assigning responsibility for handling risks was developed, and a final program risk rating was based on a summary of all risks identified risks.
- o Management reserve was set aside that covered identified risks and care was taken to include risks identified during the IBR in the risk management plan.
- o An EVM analyst monitored corrective action requests for closure.
- o A memorandum for the record described the IBR findings.

☐ A contract performance report summarized EVM data.

- ✓ The data were reviewed monthly to track program progress, risks, and plans.
- ✓ Management used the data to
  - o integrate cost and schedule performance data with technical measures;
  - o identify the magnitude and effect of problems causing significant variances;
  - o inform higher management of valid and timely program status and project future performance.
- ✓ Format 1 of the CPR reported data to at least level 3 of the WBS, and format 5 explained variances and the contractor's plans for fixing them.

☐ Program managers analyzed EVM data monthly and sequentially for variances and EACs.

- ✓ The EVM data were checked for validity and anomalies.
- ✓ Performance indexes were analyzed and plotted for trends and variances.
- ✓ Schedule variances were analyzed against the most recently statused schedule to see if problems were occurring on or near the critical path.
- ✓ Management reserve allocations in the WBS were examined and compared against risks identified in the cost estimate.
- ✓ A range of EACs was developed, using a generic index-based formula or relying on probable cost growth factors on remaining work, combined with an integrated cost schedule risk analysis.
- ✓ An independent date for program completion was determined, using schedule risk analysis that identifies which activities need to be closely monitored.
- ✓ Senior management used EVM data to answer basic program questions.

CHAPTER 20

Managing Program Costs: Updating

Programs should be monitored continuously for their cost effectiveness by comparing planned and actual performance against the approved program baseline. In addition, the cost estimate should be updated with actual costs so that it is always relevant and current. The continual updating of the cost estimate as the program matures not only results in a higher-quality estimate but also gives opportunity to incorporate lessons learned. Future estimates can benefit from the new knowledge. For example, cost or schedule variances resulting from incorrect assumptions should always be thoroughly documented so as not to repeat history. Finally, actual cost and technical and historic schedule data should be archived in a database for use in supporting future estimates.

Most programs, especially those in development, do not remain static; they tend to change in the natural evolution of a program. Developing a cost estimate should not be a one-time event but, rather, a recurrent process. Before changes are approved, however, they should be examined for their advantages and effects on the program cost. If changes are deemed worthy, they should be managed and controlled so that the cost estimate baseline continuously represents the new reality. Effective program and cost control requires ongoing revisions to the cost estimate, budget, and projected estimates at completion.

Incorporating Authorized Changes into the Performance Measurement Baseline

While the 32 ANSI guidelines are for the overarching goal of maintaining the integrity of the baseline and resulting performance measurement data, changes are likely throughout the life of the program, so that the performance measurement baseline should be updated to always reflect current requirements or changes in scope. Some changes may be simple, such as modifying performance data to correct for accounting errors or other issues that can affect the accuracy of the EVM data. Other changes can be significant, as when major events or external factors beyond the program manager's control result in changes that will greatly affect the performance measurement baseline. Key triggers for change include

- contract modifications, including engineering change proposals;
- shifting funding streams;
- restricting funding levels;
- major rate changes, including overhead rates;
- changes to program scope or schedule;
- revisions to the acquisition plan or strategy; and
- executive management decisions.

Since the performance measurement baseline should always reflect the most current plan for accomplishing authorized work, incorporating changes accurately and in a timely manner is especially important for maintaining the effectiveness of the EVM system. Table 39 describes the ANSI guidelines with regard to correctly revising the performance measurement baseline.

Table 39: ANSI Guidelines Related to Incorporating Changes in an EVM System

Guideline	Description
Incorporate authorized changes in a timely manner, recording their effects in budgets and schedules; in the directed effort before negotiating a change, base the changes on the amount estimated and budgeted to the program organizations	Incorporating authorized changes quickly maintains the performance measurement baseline's effectiveness for managing and controlling the program; therefore, authorized changes in the baseline should be incorporated in a documented, disciplined, and timely manner so that budget, schedule, and work remain coupled for true performance measurement. The contractor will develop its best estimate for planning and budgeting into changes not yet negotiated; when changes are incorporated, existing cost and schedule variances should not be arbitrarily eliminated, but economic price and rate adjustments may be made as appropriate
Reconcile current budgets to prior budgets in terms of changes to the authorized work and plan the effort in the detail needed by management for effective control	When budget revisions can be reconciled, the integrity of the performance measurement baseline can be verified; budget changes should be controlled and understood in terms of scope, resources, and schedule so the baseline reflects current levels of authorized work. Budget revisions should also be traceable to authorized control account budgets; if additional in-scope work has been identified, management reserve can augment existing control account budgets
Control retroactive changes to records pertaining to work performed that would change previously reported amounts for actual costs, earned value, or budgets	To avoid masking historic variance trends needed to project estimates at completion, retroactive changes need to be controlled; retroactive adjustments to costs should happen only as a result of routine accounting adjustments—e.g., change orders that have not been priced, rate changes, and economic price adjustments—customer-directed changes, or data entry corrections. Limiting retroactive changes to these conditions ensures baseline integrity and accurate performance measurement data
Prevent revisions to the program budget except for authorized changes	If changes are not made within a controlled process, the integrity of performance trend data may be compromised and understanding of overall program status will be delayed; to maintain baseline integrity, unauthorized revisions to the performance measurement baseline should be prevented. All changes must be approved and implemented following a well-defined baseline management control process; this avoids implementing a budget baseline that is greater than the program budget. Only in the situation of an overtarget baseline should the performance budget or schedule objectives exceed the program plan
Document changes to the performance measurement baseline	Properly maintaining the performance measurement baseline enables control account managers to accurately measure performance; it should always reflect the most current plan for accomplishing the work. All authorized changes should be quickly incorporated; before any new work begins, all planning documents should be updated to maintain the EVM system's integrity

Source: Adapted from National Defense Industrial Association (NDIA) Program Management Systems Committee (PMSC), *ANSI/EIA-748-A Standard for Earned Value Management Systems Intent Guide* (Arlington, Va.: January 2005).

It is also important to note that a detailed record of the changes made to the performance measurement baseline should be established and maintained. Doing so makes it easy to trace all changes to the program and lessens the burden on program personnel when compiling this information for internal and external program audits, EVMS surveillance reviews, and updates to the program cost estimate. If changes are not recorded and maintained, the program's performance measurement baseline will not reflect reality. The performance measurement baseline will become outdated and the data from the EVM system will not be meaningful. Case study 47 highlights a program in which this occurred.

Case Study 47: Maintaining Performance Measurement Baseline Data, from *National Airspace System*, GAO-03-343

The Federal Aviation Administration (FAA) obtained monthly cost performance reports from the contractor on the Standard Terminal Automation Replacement System (STARS). The agency should have been able to use the reports for overseeing the contractor's performance and estimating the program's remaining development costs. FAA did not use these reports, however, because they were not current. Their central component—the performance measurement baseline, which established performance, cost, and schedule milestones for the contract—had not been updated since May 2000 and therefore did not incorporate the effects of later contract modifications.

For example, the September 2002 cost performance report did not reflect FAA's March 2002 reduction in STARS' scope from 188 systems to 74 systems, and it did not include the cost of new work that FAA authorized between May 2000 and September 2002. Consequently, the report indicated that STARS was on schedule and within 1 percent of budget, even though—compared to the program envisioned in May 2000—FAA was now under contract to modernize fewer than half as many facilities at more than twice the cost per facility,

FAA had not maintained and controlled the baseline because, according to program officials, the program was "schedule driven." Without a current, valid performance management baseline, FAA could not compare what the contractor had done with what the contractor had agreed to do. And, because the baseline had not been maintained and was not aligned with the program's current status, the reports were not useful for evaluating the contractor's performance or for projecting the contract's remaining costs. Therefore, FAA lacked accurate, valid, current data on the STARS program's costs and progress. Without such data, FAA was limited in its ability to effectively oversee the contractor's performance and reliably estimate future costs,

GAO, *National Airspace System: Better Cost Data Could Improve FAA's Management of the Standard Terminal Automation Replacement System*, GAO-03-343 (Jan. 31, 2003).

The performance measurement baseline should be the official record of the current program plan. If it is updated in a timely manner to reflect inevitable changes, it can provide valuable management information that yields all the benefits discussed in chapter 18.

Using EVM System Surveillance to Keep The Performance Measurement Baseline Current

Surveillance is reviewing a contractor's EVM system as it is applied to one or more programs. Its purpose is to focus on how well a contractor is using its EVM system to manage cost, schedule, and technical performance. For instance, surveillance checks whether the contractor's EVM system

- summarizes timely and reliable cost, schedule, and technical performance information directly from its internal management system;
- complies with the contractor's implementation of ANSI guidelines;
- provides timely indications of actual or potential problems by performing spot checks, sample data traces, and random interviews;
- maintains baseline integrity;
- gives information that depicts actual conditions and trends;
- provides comprehensive variance analyses at the appropriate levels, including corrections for cost, schedule, technical, and other problem areas;
- ensures the integrity of subcontractors' EVM systems;
- verifies progress in implementing corrective action plans to mitigate EVM system deficiencies; and
- discusses actions taken to mitigate risk and manage cost and schedule performance.

Effective surveillance ensures that the key elements of the EVM process are maintained over time and on subsequent applications. The two goals associated with EVM system surveillance ensure that the contractor is following its own corporate processes and procedures and confirm that the contractor's processes and procedures continue to satisfy the ANSI guidelines.

OMB has endorsed the NDIA surveillance guide we listed in tables 3 and 32 to assist federal agencies in developing and implementing EVMS surveillance practices, which include[80]

- establishing a surveillance organization,
- developing an annual corporate-level surveillance plan,
- developing a program-level surveillance plan,
- executing the program surveillance plan, and
- managing system surveillance based on program results.

Establishing a Surveillance Organization

An organization must have designated authority and accountability for EVM system surveillance to assess how well a contractor applies its EVM system relative to the ANSI guidelines. Surveillance organizations should be independent of the programs they assess and should have sufficient experience in EVM. These requirements apply to all surveillance organizations, whether internal or external to the agency, such as consultants. Table 40 further describes the elements of an effective surveillance organization.

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[80] NDIA, *National Defense Industrial Association (NDIA) Program Management Systems Committee (PMSC) Surveillance Guide* (Arlington, Va.: October 2004).

Table 40: Elements of an Effective Surveillance Organization

Element	Description
Independent organizational level	The surveillance organization reports to a management structure different from the programs it surveys; it is independent to ensure that its findings are objective and that it will identify systemic issues on multiple programs; it has sufficient authority to resolve issues and typically rests at an agency's higher levels
Organizational charter	The organization's charter is defined through agency policy, outlining its role, responsibilities, resolution process, and membership; responsibilities include developing annual surveillance plans, appointing surveillance review team leaders, assigning resources for reviews, communicating surveillance findings, tracking findings to closure, developing and maintaining databases of surveillance measures, and recommending EVM system process and training to fix systemic findings
Membership consistent with chartered responsibilities	The organization's staff are consistent with its chartered responsibilities; their key attributes include multidisciplinary knowledge of the agency and its programs, practical experience in using EVM, good relationships with external and internal customers, and strong support of EVM systems compliance

Source: Adapted from National Defense Industrial Association (NDIA) Program Management Systems Committee (PMSC), NDIA PMSC *Surveillance Guide* (Arlington, Va.: October 2004).

OMB states that full implementation of EVM includes performing periodic system surveillance reviews to ensure that the EVM system continues to meet the ANSI guidelines. Periodic surveillance therefore subjects contractors' EVM systems to ongoing government oversight.

DCMA, a DOD support agency that provides a range of acquisition management services, monitors contractor performance through data tracking and analysis, onsite surveillance, and tailored support to program managers. DCMA also leads EVM system validation reviews before contract award, supports programs with monthly predictive EVM analysis, and participates in IBRs as requested.

Unlike DOD, however, nonmilitary agencies do not have the equivalent of a DCMA, and since DCMA does not have enough staff to cover all DOD demands, it is not possible for all nonmilitary agencies to ask DCMA to provide their surveillance. Therefore, they often hire outside organizations or establish an independent surveillance function, such as an inspector general. Without an independent surveillance function, agencies' abilities to use EVM as intended may be hampered, since surveillance monitors problems with the performance measurement baseline and EVM data. If these kinds of problems go undetected, EVM data may be distorted and may not be meaningful for decision making.

Developing a Corporate Surveillance Plan

An annual corporate-level surveillance plan should contain a list of programs for review. The plan's objective is to address, over the course of the year, the question of whether the contractor is applying the full content of its EVM system relative to the 32 ANSI guidelines. The surveillance organization therefore should have the utmost flexibility to schedule its reviews so as not interfere with major program events. Surveillance findings may also rely on the results of other related reviews, such as reviews by DCMA or DCAA or other external organizations. Table 41 lists the key processes for each of the 32 ANSI guidelines.

Table 41: Key EVM Processes across ANSI Guidelines for Surveillance

Process	Applicable ANSI guideline
Organizing	1, 2, 3, 5
Scheduling	6, 7
Work and budget authorization	8, 9, 10, 11, 12, 14, 15
Accounting	16, 17, 18, 20, 22, 30
Indirect management	4, 8, 13, 19, 24, 27
Managerial analysis	22, 23, 25, 26, 27
Change incorporation	28, 29, 30, 31, 32
Material management	21 (9, 10, 12, 22, 23, 27)
Subcontract management	(2, 9, 10, 12, 16, 22, 23, 27)

Source: DCMA.

Note: Guidelines in parentheses are cross process guidelines.

In addition to addressing the 32 ANSI guidelines, senior management may ask the surveillance organization to focus its review on specific procedures arising from government program office concerns, interest in a particular process application, or risks associated with remaining work. This enables the surveillance organization to concentrate on processes that are the most relevant to the program phase. For example,

- a surveillance review of the change incorporation process would be more appropriate for a program in which a new baseline had recently been implemented than for a program that had just started and had not undergone any changes (reviewing the work authorization process would be more beneficial);
- a surveillance review of the EAC process would yield better insight to a development program in which technological maturation was the force behind growing EAC trends than it would to a production program that had stable EAC trends;
- although the goal is to review all 32 ANSI guidelines each year, if a program were almost complete, it would not make sense to focus on work authorization, since this process would not then be relevant.

In line with the approach for selecting EVM processes to concentrate on, the surveillance organization should select candidate programs by the risk associated with completing the remaining work, so that surveillance can be value-added. To facilitate selection, it is important to evaluate the risks associated with each program. Table 42 outlines some risk factors that may warrant program surveillance.

Table 42: Risk Factors That Warrant EVM Surveillance

Risk factor	Description
Baseline resets	Programs experiencing frequent baseline resets need additional monitoring, since they often result from poor planning or a change in work approach that is causing significant schedule or technical challenges; surveillance of change control and EAC benefits such programs by ensuring that changes are correctly implemented and EVM data are reliable for making EAC projections

Risk factor	Description
Contract phase and type	Development contracts tend to be higher-risk and are therefore often good candidates for surveillance; production or follow-on contracts are usually lower-risk and therefore benefit less from surveillance
Contract value	The higher the contract dollar value, the more appropriate the program for frequent EVM surveillance
Significant cost or schedule variance	Programs with significant, unfavorable cost or schedule variances should be reviewed often; surveillance can help identify problems with baseline planning that may give valuable insight into how to take effective corrective action
Nature of remaining work	The technical content of remaining work should be reviewed to ensure that the most value-added EVM processes and guidelines are selected for surveillance
Volume or amount of remaining work	New efforts tend to benefit more from surveillance than those that are near completion
Program office experience	Program office experience in implementing and using EVM processes may influence its selection of programs to survey; program offices lacking experience may implement the processes incorrectly, increasing the risk of generating unreliable program data
Time since last review	If it has been a long time since the last surveillance review, the program should be selected for surveillance
Findings or concerns from prior reviews	Results from prior surveillance reviews may justify additional monitoring
Effectiveness of suppliers' and subcontractors' surveillance process	How well a program's supplier or subcontractor implements its EVM process may influence the selection of programs to review.

Source: © 2004 National Defense Industrial Association (NDIA) Program Management Systems Committee (PMSC), NDIA PMSC Surveillance Guide (October 2004 edition).

Using an algorithm that assigns relative weights and scales to each risk area and classifies risk as low, medium, or high can help determine which programs would most benefit from surveillance. Table 43 shows how an algorithm can be used to evaluate a candidate program.

Table 43: A Program Surveillance Selection Matrix

Risk factor	Weight	Risk level			Risk score
		High = 3	Medium = 2	Low = 1	
Contract value	0.05	More than 20% of business base	5%–20%	Less than 5%	3
Nature of work	0.05	High-risk, many unknowns		Low-risk content	3
Program office experience	0.05	Inexperienced staff		Very experienced staff	1
Program type	0.05	Development	Production	Operations and maintenance	3
Baseline resets	0.10	Many per year	Once a year	Less than one a year	3
Historic trends	0.10	Worsening		Trends are improving	3
Previous findings	0.10	Many unresolved		Few or easily closed	1

Risk factor	Weight	Risk level			Risk score
		High = 3	Medium = 2	Low = 1	
Variance percent	0.10	Worse than –10%	–5% to –10%	Better than –5%	3
Management interest	0.40	High visibility		Low visibility	3
Total					2.6

Source: © 2004 National Defense Industrial Association (NDIA) Program Management Systems Committee (PMSC), *NDIA PMSC Surveillance Guide* (October 2004 edition).

For the sample program assessed in the algorithm in table 43, we can quickly determine that it is a high-risk program because it received a risk score of 2.6 of a possible 3.0. This risk is determined by the fact that the program has high contract value, the work is high-risk, and high variances had led to several baseline resets. Once a risk score has been calculated for all candidate programs, the scores can be used to decide which programs should be reviewed more often. The number of programs that can be reviewed each year, however, depends on available resources.

Developing a Program Surveillance Plan

The surveillance team designated to perform program reviews should consist of a few experienced staff who fully understand the contractor's EVM system and the processes being reviewed. The surveillance organization should appoint the team leader and ensure that all surveillance team members are independent. This means that they should not be responsible for any part of the programs they assess.

Key activities on the surveillance team's agenda include reviewing documents, addressing government program office concerns, and discussing prior surveillance findings and any open issues. Sufficient time should be allocated to all these activities to complete them. The documents for review should give the team an overview of the program's implementation of the EVM process. Recommended documents include

- at least 2 months of program EVM system reports;
- EVM variance analyses and corrective actions;
- program schedules;
- risk management plan and database;
- program-specific instructions or guidance on implementing the EVM system;
- WBS with corresponding dictionary;
- organizational breakdown structure;
- EAC and supporting documentation;
- correspondence related to the EVM system;
- contract budget baseline, management reserve, and undistributed budget log;
- responsibility assignment matrix identifying control account managers;
- work authorization documentation;
- staffing plans;

- rate applications used; and
- findings from prior reviews and status.

Additionally, it is recommended that if there are any concerns regarding the validity of the performance data, the government program office be notified. Finally, inconsistencies identified in prior reviews should be discussed to ensure that the contractor has rectified them and continues to comply with its EVM system guidelines.

Executing the Program Surveillance Plan

Surveillance should be approached in terms of mentoring or coaching the contractor on where there are deficiencies or weaknesses in its EVM process and offering possible solutions. The contractor can then view the surveillance team as a valuable and experienced asset to determine whether it can demonstrate that it is continuing to use the accepted EVM system to manage the program.

Successful surveillance is predicated on access to objective information that verifies that the program team is using EVM effectively to manage the contract and complies with company EVM procedures. Objective information includes program documentation created in the normal conduct of business. Besides collecting documentation, the surveillance team should interview control account managers and other program staff to see if they can describe how they comply with EVM policies, procedures, or processes. During interviews, the surveillance team should ask them to verify their responses with objective program documentation such as work authorizations, cost and schedule status data, variance analysis reports, and back-up data for any estimates at completion. Finally, to ensure a common exposure to the program's content and quicker consolidation of findings, the surveillance team should stay together as much as possible.

The interview is a key review effort because it enables the surveillance team to gauge the EVM knowledge of the program staff. This is especially important because control account managers are the source of much of the information on the program's EVM system. Interviews also enable the surveillance team to monitor program personnel's awareness of and practice in complying with EVM guidelines. In particular, interviews help the surveillance team determine whether the control account managers see EVM as an effective management tool. The following subjects should be covered in an interview:

- work authorization;
- organization;
- EVM methodologies, knowledge of the EVM process, use of EVM information, and EVM system program training;
- scheduling and budgeting, cost and schedule integration, and cost accumulation;
- EACs;
- change control process;
- variance analysis;
- material management;
- subcontract management and data integration; and
- risk assessment and mitigation.

When all the documentation has been reviewed and interviews have been conducted, the surveillance team should provide appropriate feedback to the program team. Specifically, surveillance team members and program personnel should clarify any questions, data requests, and responses to be sure everything is well understood. The surveillance team leader should present all findings and recommendations to the program staff so that any misunderstandings can be clarified and corrected. In addition, a preliminary report should be prepared, once program personnel have provided their preliminary feedback, that addresses findings and recommendations:

Findings fall into two broad categories: compliance with the accepted EVM system description and consistency with EVM system guidelines. Local practices may be compliant with the system description, while others may fall short of the intent of an EVM guideline because of discrepancies in the system description. If findings cannot be resolved, confidence in program management's ability to effectively use the EVM system will be lowered, putting the program at risk of not meeting its goals and objectives. Open findings may also result in withdrawing advance agreements and acceptance of the company's EVM system.

Team members may recommend EVM implementation enhancements, such as sharing successful practices or tools. Unlike findings, however, recommendations need not be tracked to closure.

In addition to findings and recommendations, the final team report should outline an action plan that includes measurable results and follow-up verification, to resolve findings quickly. It should present the team's consensus on the follow-up and verification required to address findings resulting from the surveillance review. An effective corrective action plan must address how program personnel should respond to each finding and it must set realistic dates for implementing corrective actions. The surveillance review is complete when the leader confirms that all findings have been addressed and closed.

Managing System Surveillance Based on Program Results

After a program's surveillance is complete, the results are collected and tracked in a multiprogram database. This information is transformed into specific measures for assessing the overall health of a contractor's EVM system process. They should be designed to capture whether the EVM data are readily available, accurate, meaningful, and focused on desirable corrective action. The types of measure may vary from contractor to contractor, but each one should be well defined, easily understood, and focused on improving the EVM process and surveillance capability. They should have the following characteristics:

- surveillance results measures identify where there are deviations from documented EVM application processes and
- system surveillance measures are EVM system process measures that indicate whether the surveillance plan is working by resolving systemic issues.

To develop consistent measures, individual program results can be summarized by a standard rating system that uses color categories to identify findings. Table 44 shows a standard color-category rating system.

Table 44: A Color-Category Rating System for Summarizing Program Findings

Related to	EVM system rating		
	Low = green	Moderate = yellow	High = red
Organization			
1	One WBS used and authorized for the program	One WBS used for the program	More than one WBS used for the program
2	WBS dictionary available and traceable to the contract WBS and statement of work	WBS dictionary available but cannot be traced to the contract WBS and is inconsistent with the statement of work	WBS dictionary not developed
3	Organizational breakdown system, including major subcontractors, defined	More than one organizational breakdown system used; not all are identified or some contain errors or omissions	Organizational breakdown system not defined
4	Program WBS and organizational breakdown system integrated and identified by the responsibility assignment matrix	Program WBS and organizational breakdown system identified but the responsibility assignment matrix is incomplete or outdated	Responsibility assignment matrix process is not implemented
Budget			
1	Budgets for authorized work identified	Budgets for authorized work have omissions	Budgets for authorized work not developed
2	Sum of work package budgets equals control account budgets; appropriate EVM techniques deployed	Sum of work package budgets equals control account budgets, but appropriate EVM techniques not applied	Sum of work package budgets does not equal control account budgets
3	Management reserve and undistributed budget identified; management reserve not used for cost growth or contract changes	Management reserve and undistributed budget identified but do not adequately cover existing program scope and risk	Management reserve used for cost growth or contract changes
4	Time-phased budget established, against which performance can be measured	Not applicable	Baseline cannot be used for accurate performance measurement
5	Authorized work identified in measurable units	Authorized work identified in measurable units but has omissions	Authorized work not identified in measurable units

Source: © 2004 National Defense Industrial Association (NDIA) Program Management Systems Committee (PMSC), NDIA PMSC Surveillance Guide (October 2004 edition).

Summarizing individual program findings by a standard measure can help pinpoint systemic problems in a contractor's EVM system and can therefore be useful for highlighting areas for correction. This may result in more training or changing the EVM system description to address a given weakness by improving a process. Without the benefit of standard measures, it would be difficult to diagnose systemic problems; therefore, it is a best practice to gather them and review them often.

Overtarget Baselines and Schedules

At times, an organization may conclude that the remaining budget and schedule targets for completing a program are significantly insufficient and that the current baseline is no longer valid for realistic performance measurement. The purpose of an overtarget baseline or overtarget schedule is to restore management's control of the remaining effort by providing a meaningful basis for performance management. Working to an unrealistic baseline could make an unfavorable cost or schedule condition worse.

For example, if variances become too big, they may obscure management's ability to discover newer problems that could still be mitigated. To quickly identify new variances, an overtarget baseline normally eliminates historic variances and adds budget for future work. The contractor then prepares and submits a request to implement a recovery plan—in the form of an overtarget baseline or overtarget schedule—that reflects the needed changes to the baseline.

The Rebaseline Rationale

The focus during a rebaseline is ensuring that the estimated cost of work to complete is valid, remaining risks are identified and tracked, management reserve is identified, and the new baseline is adequate and meaningful for future performance measurement.

An overtarget baseline is established by formally reprogramming the performance measurement baseline to include additional budget that is above and beyond the contract's negotiated cost.[81] This additional budget is believed necessary to finish work that is in process and becomes part of the recovery plan for setting new objectives that are achievable.

An overtarget baseline does not always affect all remaining work in the baseline; sometimes only a portion of the WBS needs more budget. Similarly, an overtarget baseline may or may not reset cost and schedule variances, although in most cases the variances are eliminated.

An overtarget baseline or overtarget schedule should be rare. Therefore, if a program is experiencing recurrent overtarget baselines, it may be that the scope is not well understood or simply that program management lacks effective EVM discipline and is unable to develop realistic estimates.

Moreover, a program that frequently changes its baseline can appear to be trying to "get well" by management's hiding its real performance, leading to distorted EVM data reporting. When this happens, decision makers tend to lose confidence in the program, as evidenced in case study 48.

[81] This action is not to be confused with reprogramming of agency appropriations. In that context, reprogramming is a shifting of funds within an appropriation or fund account to use them for purposes other than those contemplated at the time of the appropriation. (See GAO, *A Glossary of Terms Used in the Federal Budget Process*, GAO-05-734SP (Washington, D.C.: Sept. 1, 2005), p. 85.) The overtarget baseline action should also not be confused with replanning—that is, the replanning of actions for remaining work scope, a normal program control process accomplished within the scope, schedule, and cost objectives of the program.

Case Study 48: Maintaining Realistic Baselines, from *Uncertainties Remain*, GAO-04-643R

From the contract's award in 1996 to 2003, the cost of the Airborne Laser's (ABL) research and development contract increased from about $1 billion to about $2 billion. In fiscal year 2003 alone, work the contractor completed cost about $242 million more. Besides these cost overruns, the contractor was unable to complete $28 million worth of work planned for the fiscal year. GAO estimated from the contractor's 2003 cost and schedule performance that the prime contract would overrun by $431 million to $943 million.

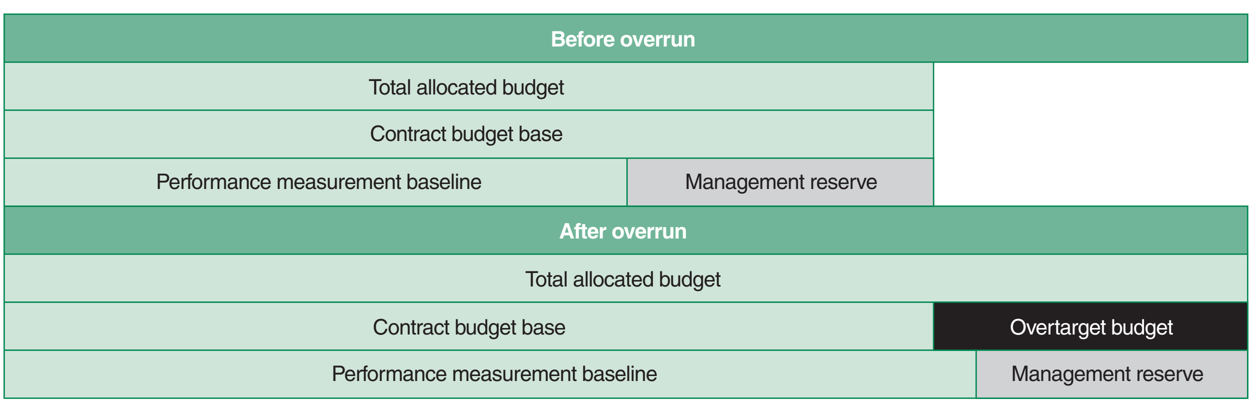
The program had undergone several major restructurings and contract rebaselines from 1996 on, primarily because of unforeseen complexity in manufacturing and integrating critical technology. According to program officials, rapid prototyping resulted in limited subcomponent testing, causing rework and changing requirements. At the time of GAO's review, the program faced massively increasing amounts of incomplete work from previous years, even though the prime contractor had increased the number of people devoted to the program and had added shifts to bring the work back on schedule. In addition, unanticipated difficulties in software coding and integration, as well as difficulty in manufacturing advanced optics and laser components, caused cost growth.

Good investment decisions depend on understanding the total funds needed to obtain an expected benefit, but the Missile Defense Agency (MDA) had been unable to assure decision makers that its cost projections to complete technology development could be relied on. Decision makers would have been able to make more informed decisions about further program investments if they had understood the likelihood and confidence associated with MDA's cost projections. Therefore, GAO recommended that MDA complete an uncertainty analysis of the contractor's new cost estimate.

GAO, *Uncertainties Remain Concerning the Airborne Laser's Cost and Military Utility*, GAO-04-643R (Washington, D.C.: Mar. 17, 2004).

The end result of an overtarget baseline is that its final budget always exceeds the contract budget base, which includes the negotiated contract cost plus any authorized, unpriced work. In EVM system terminology, the sum of all budgets (performance measurement baseline, undistributed budget, and management reserve) that exceed the contract budget base is known as total allocated budget, and the difference between the total allocated budget and contract budget base is the overtarget baseline. Figure 40 illustrates the effect an overtarget baseline has on a contract.

Figure 40: The Effect on a Contract of Implementing an Overtarget Budget



Source: DCMA.

Like an overtarget budget, an overtarget schedule occurs when the schedule and its associated budgets are spread over time and work ends up being scheduled beyond the contract completion date. The new schedule becomes the basis for performance measurement. Typically, an overtarget schedule precipitates the need for an overtarget budget, because most increases in schedule also require additional budget.

As mentioned above, the contractor submits an overtarget budget and overtarget schedule request to the government program office for evaluation. It should contain the following key elements:

- an explanation of why the current plan is no longer feasible, identifying the problems that led to the need to make a new plan of the remaining work and discussing measures in place to prevent recurrence;
- a bottoms-up estimate of remaining costs and schedule that accounts for risk and includes management reserve;
- a realistic schedule for remaining work that has been validated and spread over time to the new plan;
- a report on the overtarget budget in the CPR—the government program office needs to come to an agreement with the contractor on how it is to be reported in the CPR, how decisions are to be made on handling existing cost and schedule variances, and how perspectives on new budget allocations will be reported (whether variances are to be retained or eliminated or both);
- the overtarget budget's implementation schedule, to be accomplished as soon as possible once approved; usually, it is established in one to two full accounting periods, with reporting continuing against the existing baseline in the meantime.

In determining whether implementing an overtarget budget and overtarget schedule is appropriate, the program office should consider the program's health and status and should decide whether the benefits outweigh the costs. An overtarget budget should be planned with the same rigor as planning for the original program estimate and performance measurement baseline. While overtarget budget and overtarget schedule can restore program confidence and control by establishing an achievable baseline, with meaningful performance metrics, the time and expense required must be carefully considered.

Contract type is a key factor to consider when rebaselining a program, because each contract has its own funding implications when an overtarget budget is implemented. Table 45 describes two common types of contracts and considerations for overtarget budget implementation.

Table 45: Overtarget Budget Funding Implications by Contract Type

Contract type	Description	Considerations
Fixed price incentive	Negotiated target cost plus estimated cost of authorized unpriced work equals the cost of the contract budget base; government program office liability is established up to a specified ceiling price	▪ Although additional performance budget is allocated to the performance measurement baseline, the overtarget budget does not change the customer's funding liability or any contract terms; the contractor has liability for a portion of costs above target and all actual costs over the ceiling price, because the work's scope has not changed and the contract has not been modified ▪ An overtarget budget is established on a fixed price incentive contract without regard to profit, cost sharing, or ceiling implications

Contract type	Description	Considerations
Cost reimbursement	Provides for payment of allowable incurred costs to the contractor to the extent provided in the contract and, where included, for contractor's fee or profit; the new contract budget base is based on the updated cost target	▪ The customer must be notified of the need for an overtarget budget, having agreed to pay for actual costs incurred to the extent provided in the contract; he may have to commit or seek additional funds to address the changing program condition and must therefore be aware of and involved in the overtarget budget implementation ▪ While the government normally has full cost responsibility if this is a cost plus incentive fee contract, the contractor may lose the fee ▪ A cost growth contract modification results in obligating additional funds to cover in-scope effort; this involves real dollars, so the performance measurement budget does not increase and the cost growth variance continues to be reported in the CPR; when a contract modification includes a new scope, the modification should clearly state the portion of the new estimated cost that is for new scope and the portion that is to provide funds for an acknowledged cost overrun

Source: GAO and Ivan Bembers and others, Over Target Baseline and Over Schedule Handbook (n.p., n.p.: May 7, 2003), p. 7.

The program office and the contractor should also consider whether losing valuable historic performance variances and trends is worth the effort and time to reset the baseline. Table 46 identifies common problems and indicators that may be warning signs that a program may need an overtarget budget or schedule.

Table 46: Common Indicators of Poor Program Performance

Indicator	Description
Cost	▪ Significant difference between estimated cost to complete and budget for remaining work ▪ Significant difference between cumulative CPI and TCPI ▪ Significant lack of confidence in the EAC ▪ Frequent allocation of management reserve to the PMB for newly identified in-scope effort ▪ Inadequate control account budgets for remaining work ▪ Work packages with no budget left ▪ No reasonable basis for achieving the EAC ▪ EACs that are too optimistic and do not adequately account for risks
Schedule	▪ High level of concurrent activities in the integrated schedule ▪ Significant negative float in the integrated schedule's critical path ▪ Unrealistic activity durations ▪ Unrealistic logic and relationships between tasks ▪ Significant number of activities with constrained start or finish dates ▪ No horizontal or vertical integration in the schedule ▪ No basis for schedule reserve reductions except to absorb the effect of schedule delays
Project execution risk	▪ Risk management analysis that shows significant changes in risk levels ▪ Lack of correlation between budget phases and baseline schedule ▪ No correlation between estimate to complete time periods and current program schedule ▪ Program management's reliance on ineffective performance data

Indicator	Description
Data accuracy	■ Frequent or significant current or retroactive changes ■ Actual costs exceeding the EAC ■ Work scope transferred without associated budget ■ An apparently front-loaded performance measurement baseline ■ Inadequate planning for corrective action ■ Repetitive reasons for variances ■ No reflection of progress in earned value ■ Late booking of actual costs that cause lagging variances ■ Frequent data errors

Source: Ivan Bembers and others, *Over Target Baseline and Over Schedule Handbook* (n.p., n.p.: May 7, 2003).

Establishing a revised performance measurement baseline to incorporate significant variances should be a major wake-up call for program management, sending a serious message about the amount of risk a program is undertaking. Therefore, in conjunction with evaluating the indicators in table 46, program management should consider other aspects before deciding to implement an overtarget budget and schedule.

Work Completion Percentage

The contract should typically be 20 percent to 85 percent complete. A contract that is less than 20 percent complete may not be mature enough yet to benefit from the time and expense of implementing overtarget budget and schedule. A contract that is more than 85 percent complete gives management limited time to significantly change the program's final cost.

Projected Growth

A projected growth of more than 15 percent may warrant an overtarget budget and schedule. The projection is made by comparing the estimated time of completion with the budget allocated for the remaining work. An overtarget budget's most important criterion is whether it is necessary to restore meaningful performance measurement.

Remaining Schedule

If less than a year is required to complete the remaining work, the benefit of overtarget budget and schedule will most likely be negligible because of the time it typically takes to implement the new baseline.

Benefit Analysis

A benefit analysis should determine whether the ultimate goal of implementing overtarget budget and overtarget schedule gives management better control and information. With this analysis, the government program office and contractor should ensure that the benefits will outweigh the cost in both time and resources. If better management information is expected and the program team is committed to managing within the new baseline, then they should be implemented.

Rebaselining History

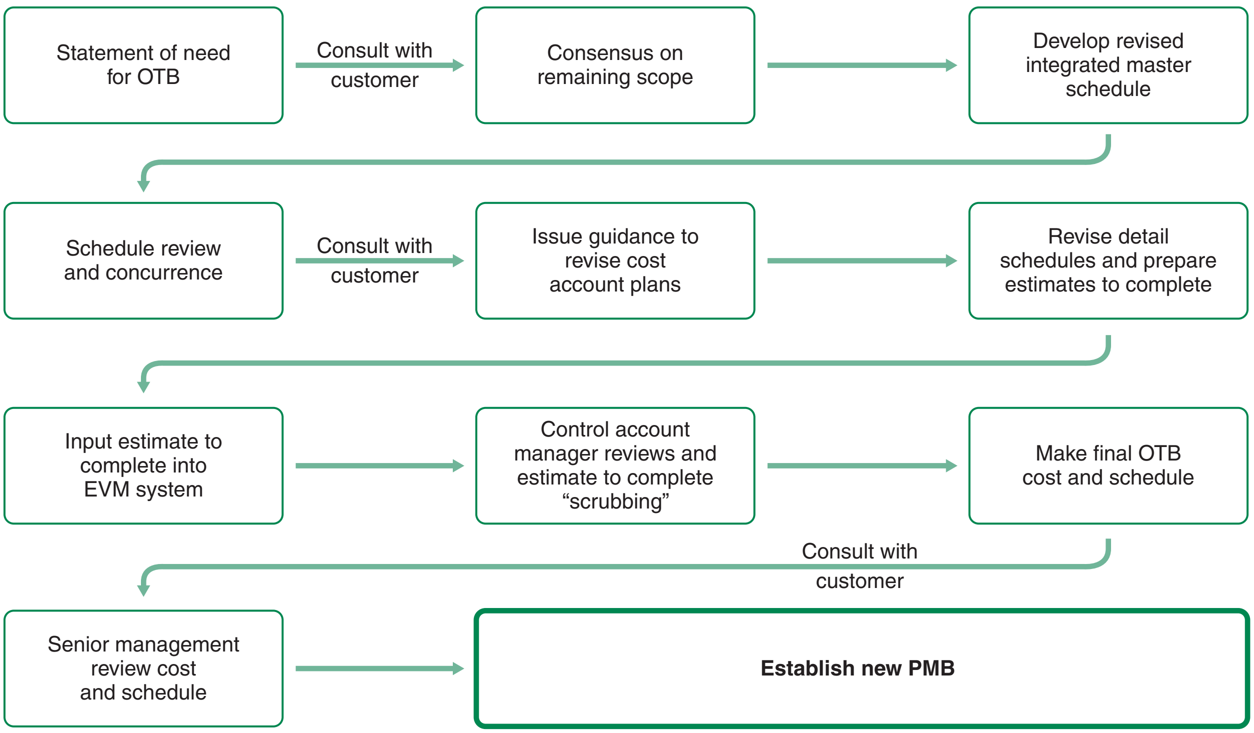
Several overtarget budget requests have suggested severe underlying management problems. These should be investigated before implementing a new budget.

Key Steps of the Overtarget Budget–Overtarget Schedule Process

While it is the primary responsibility of the contractor to ensure that a meaningful performance measurement baseline is established, every control account manager must develop new work plans that can be reasonably executed. The program manager and supporting business staff must have open lines of communication and a clear review process to ensure that the baseline is reasonable and accurate, reflecting known risks and opportunities.

Thus, the overtarget budget–overtarget schedule implementation process involves multiple steps and processes, illustrated in figure 41.

Figure 41: Steps Typically Associated with Implementing an Overtarget Budget



Source: "Ivan Bembers and others. "Over Target Baseline and Over Schedule Handbook," n.p., n.p., 2003."

The key steps we describe here include (1) planning the approach, (2) developing the new schedule and making new cost account plans, and (3) senior management's reviewing the costs and schedule. Each step assumes early involvement and frequent interaction between the contractor and government program office,

Planning the Overtarget Budget–Overtarget Schedule Approach

When developing a plan for an overtarget budget, certain factors should be considered:

- What issues or problems resulted in the need for one? How will the new plan address them?
- Can the overtarget budget be accomplished within the existing schedule? If not, then an overtarget schedule must also be performed. Conversely, does an overtarget schedule require an overtarget budget or can the schedule be managed within the existing budget?

- How realistic is the estimate to complete? Does it need to be updated?
- Are cost and schedule variances being eliminated or retained? Will future reporting include historical data or begin again when the new plan is implemented?
- What is the basis for the overtarget budget management reserve account? Is it adequate for the remaining work?
- To what extent are major subcontractors affected by the overtarget budget? How will it affect their target cost and schedule dates?
- Were any EVM system discipline issues associated with the need for an overtarget budget? If so, how were they resolved?

If the new baseline is to provide management with better program status, a decision about whether to eliminate variances will have to be made. A single point adjustment—that is, eliminating cumulative performance variances, replanning the remaining work, and reallocating the remaining budget to establish a new performance measurement baseline—results in a new performance measurement baseline that reflects the plan of the remaining work and budget. Since existing variances can significantly distort progress toward the new baseline, a single point adjustment is a common and justifiable adjunct to an overtarget budget. Table 47 describes options for treating historical cost and schedule variances when performing a single point adjustment.

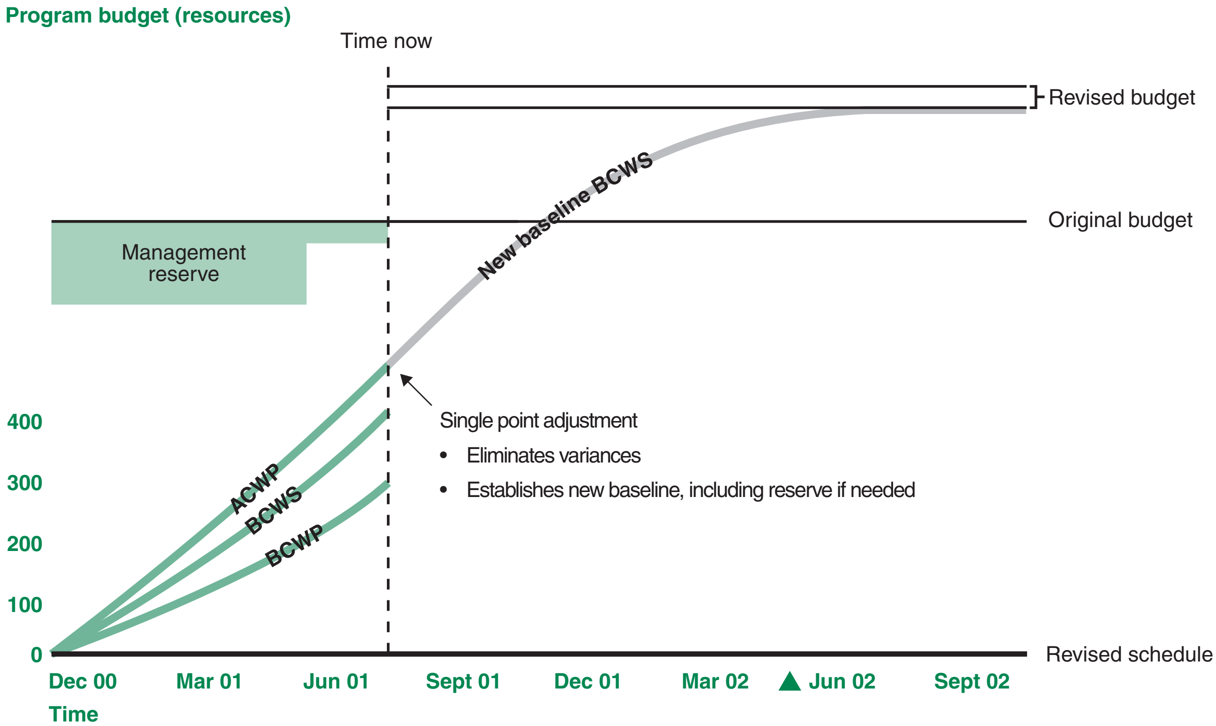
Table 47: Options for Treating Variances in Performing a Single Point Adjustment

Variance option	Description
Eliminate	
All variances	Eliminate cost and schedule variances for all WBS elements by setting BCWS and BCWP equal to ACWP; the most common type of variance adjustment, this normally generates an increase in BCWP and sometimes results in an adjustment to BCWS
Schedule variance only	Cost variance is considered a valid performance measurement; the new performance measurement baseline retains the cost variance history but eliminates schedule variance by setting BCWS equal to BCWP, allowing revised planning for the remaining work and budgets
Cost variance only	When, infrequently, cost variance impels an overtarget budget but schedule information is valid, variance is eliminated by setting BCWP equal to ACWP; the cumulative BCWP value is adjusted to match the cumulative cost variance. To preserve the existing schedule variance, the cumulative BCWS should be changed by the same amount as the BCWP; the CPR will reflect positive adjustments to both in the current period following the overtarget budget
Selected variances	If one WBS element or a subcontractor shows performance out of line with the baseline, management may implement an overtarget budget for only that portion of the contract; all other variances remain intact
Retain	
All variances	A contractor may have been performing fairly well to the baseline plan with no significant variances, but additional budget is necessary to complete the work; or the contractor has large variances warranting an overtarget budget, but management wants to retain them. In both situations, cost and schedule variances are left alone but budget is added to cover future work in the overtarget budget process

Source: Ivan Bembers and others. *Over Target Baseline and Over Schedule Handbook* (n.p., n.p.: May 7, 2003).

It is important to understand that while cost and schedule variances can be adjusted in various ways, under no circumstances should the value of ACWP be changed in the overtarget budget process. The value of ACWP should always be reconcilable to the amount shown in the contractor's accounting records. In addition, management reserve to be included in the final overtarget budget should be addressed in the overtarget budget planning step: The amount will depend on how much work and risk remain. Historic management reserve consumption before the overtarget budget may offer important insights into the amount to set aside. The bottom line is that a realistic management reserve budget should be identified and available for mitigating future risks. These two issues—keeping ACWP integrity and setting aside adequate management reserve—must be considered in making the new plan, regardless of whether the single point adjustment option is used. Figure 42 shows how a single point adjustment results in a change to the performance measurement baseline.

Figure 42: Establishing a New Baseline with a Single Point Adjustment



Source: Abba Consulting.

In figure 42, the performance measurement baseline—that is, BCWS—is shifted upward to align with actual costs to date—that is, with ACWP. The new baseline continues from this point forward, and all new work performed and corresponding actual costs will be measured against this new baseline. The revised budget is also at a higher level than the original budget; the schedule has slipped 4 months from May to September. Finally, all variances up to the overtarget budget date have been eliminated and the management reserve amount has risen above the new performance measurement baseline.

As work is performed against this new baseline, reliable performance indicators can be used to identify problems and implement corrective actions. However, because all variances have been eliminated, it may take several months after the single point adjustment for trends to emerge against the new baseline.

During the next few months, monitoring the use of management reserve can help show whether realistic budgets were estimated for the remaining work or new risks occurred after the overtarget budget.

A note of caution: single point adjustments should not be made regularly and not solely to improve contract performance metrics—especially when attempting to meet OMB's "Get to Green" capital planning initiative to show favorable program performance status. Because a single point adjustment masks true performance, frequent use tends to cause varied and significant problems such as

- distorting earned value cost and schedule metrics, resulting in unreliable index-based EAC calculations;
- turning attention away from true cost and schedule variances; and
- hindering the ability of EVM data to predict performance trends.

In other words, single point adjustments should be used sparingly in order not to inhibit successful use of EVM information to manage programs.

Planning the New Schedule and Control Accounts

Even if only an overtarget budget is required, some level of schedule development or analysis should always be performed. The revised schedule should be complete, integrated, realistic in length, and coordinated among key vendors and subcontractors. Further, the schedule logic and activity durations should be complete and should represent the effort associated with the remaining work. Any effect on government-furnished equipment schedules or availability of government test ranges should also be considered before the schedule is validated and considered realistic.

The government program office and the contractor should review, and come to a mutual understanding of, the remaining scope, resources, and risk in the new schedule. They should agree that it is integrated vertically and horizontally, task durations are backed by historic data, schedule reserve is adequate, and achieving the overall schedule is likely.

Once the revised schedule for the remaining work has been established, it is used to determine the budget for the remaining cost accounts. A detailed estimate to complete the remaining work should be based on a bottom-up estimate to reflect all costs—staffing, material, travel. Control account managers should also consider the remaining cost and schedule risk and their probability.

Senior Management Review of Cost and Schedule

While an overriding goal of the overtarget budget–overtarget schedule process is to allow the contractor to implement an effective baseline in a timely manner, the government program office plays a key role in determining whether the contract can be executed within the constraints of program funding and schedule. Three key activities the government program office should consider in the final review of the new baseline are

1. perform an IBR to verify that the value and associated schedule determined in the overtarget budget–overtarget schedule process have been established in the new baseline;
2. determine to what extent EVM reporting requirements will be suspended or reduced, given the time needed to implement the new baseline; a best practice is to continue reporting against the old

baseline until the new one is established, keeping EVM reporting rhythm in place and maintaining a record of the final change;

3. select meaningful performance indicators (such as those in table 46) to monitor contractor efforts to implement and adhere to the new baseline.

One key indicator, management reserve usage, should not be used to a great extent in the near term; another is EVM performance trends, although the government program office should be aware of its effect on subsequent trend chart if a single point adjustment was made.

Update the Program Cost Estimate With Actual Costs

Regardless of whether changes to the program result from a major contract modification or an overtarget budget, the cost estimate should be regularly updated to reflect all changes. Not only is this a sound business practice; it is also a requirement outlined in OMB's Capital Programming Guide.[82] The purpose of updating the cost estimate is to check its accuracy, defend the estimate over time, shorten turnaround time, and archive cost and technical data for use in future estimates. After the internal agency and congressional budgets are prepared and submitted, it is imperative that cost estimators continue to monitor the program to determine whether the preliminary information and assumptions remain relevant and accurate.

Keeping the estimate fresh gives decision makers accurate information for assessing alternative decisions. Cost estimates must also be updated whenever requirements change, and the results should be reconciled and recorded against the old estimate baseline. Several key activities are associated with updating the cost estimate:

- documenting all changes that affect the overall program estimate so that differences from past estimates can be tracked;
- updating the estimate as requirements change, or at major milestones, and reconciling the results with the program budget and EVM system;
- updating the estimate with actual costs as they become available during the program's life cycle;
- recording reasons for variances so that the estimate's accuracy can be tracked;
- recording actual costs and other pertinent technical information—source line of code sizing, effort, schedule, risk items—so they can be used for estimating future programs; and
- obtaining government program office feedback, assessing lessons learned on completion, and recording the lessons so they are available for the next version of the estimate.

After these activities are completed, the estimator should document the results in detail, including reasons for all variances. This critical step allows others to track the estimates and to identify when, how much, and why the program cost more or less than planned. Further, the documented comparison between the current estimate (updated with actual costs) and old estimate allows the cost estimator to determine the level of variance between the two estimates. In other words, it allows estimators to see how well they are estimating and how the program is changing over time.

[82] OMB, *Capital Programming Guide: Supplement to Circular A-11, Part 7, Preparation, Submission, and Execution of the Budget*.

Keep Management Updated

Part of agency capital planning and investment control is reporting updated program EACs to management during senior executive program reviews. With EVM data, a variety of EACs can be generated solely for this purpose. In addition, continuous management reviews of the EVM data not only allow insight into how a specific program is performing but also help depict a company's financial condition accurately for financial reporting purposes.

EVM data provide a clear picture of what was scheduled, accomplished, and spent in a given month so that program status can be known at any time. Likewise, cost and schedule performance trends derived from the CPR are objective data that allow management to identify where potential problems and cost overruns can occur. This information should be presented at every program manager review, since it is essential for managing a program effectively.

DOD requires in addition that contractors submit a quarterly contract funds status report that provides time-phased funding requirements and execution plans and identifies requirements for work agreed-to but not yet under contract. Other agencies require a similar document. For example, NASA requires form 533 that reports data necessary for projecting costs and hours to ensure that resources realistically support program schedules. It also evaluates contractors' actual cost and fee data and compares them to the negotiated contract value, estimated costs, and budget forecast data.

Data from the DOD report or a similar report are important for knowing whether the government has adequate funding to complete the program, based on the contractor's historic performance trends. Therefore, both that report and the CPR should be used regularly to monitor contractor performance and update the cost estimate. Doing so will provide valuable information about problems early on, when there is still time to act. It also makes everyone more accountable and answerable to basic program management questions, such as

- Can the EVM data be trusted?
- Is there really a problem?
- How much risk is associated with this program?
- What is causing a problem and how big is it?
- Are other risks associated with this problem?
- What is likely to happen?
- What are the alternatives?
- What should the next course of action be?
- Who is responsible for major parts of the contract?
- What were the major changes since the contract began?
- How long have similar programs taken?
- How much work has been completed and when will the program finish?
- When should results start materializing?

While EVM offers many benefits, perhaps the greatest benefit of all is the discipline of planning the entire program before starting any work. This planning brings forth better visibility and accountability, which add clarity to risks as well as opportunities. Further, EVM offers a wealth of data and lessons that can be used to project future program estimates. To reap these benefits, however, EVM requires strong partnership between the government program office and the contractor to make for a sense of ownership and responsibility on both sides. This shared accountability is a major factor in bringing programs to successful completion and makes good program management possible.

17. Best Practices Checklist: Managing Program Costs: Updating

- ☐ The cost estimate was updated with actual costs, keeping it current and relevant.
  - ✓ Actual cost, technical, and schedule data were archived for future estimates.
- ☐ Authorized changes to the EVM performance measurement baseline were incorporated in a timely manner.
  - ✓ It reflected current requirements.
  - ✓ These changes were incorporated in a documented, disciplined, and timely manner so that budget, schedule, and work stayed together for true performance measurement.
  - ✓ Changes were approved and implemented in a well-defined baseline control process.
- ☐ Regular EVM system surveillance ensured the contractor's effective management of cost, schedule, and technical performance and compliance with ANSI guidelines.
  - ✓ The surveillance organization was independent and had authority to resolve issues.
  - ✓ Surveillance staff had good knowledge about EVM and agency programs.
  - ✓ An annual surveillance plan was developed and programs were chosen objectively.
  - ✓ Findings and recommendations were presented to the program team for clarification, and the final surveillance report had an action plan to resolve findings quickly.
- ☐ The contractor's overtarget baseline or over target schedule was detailed, reasonable, and realistic; planned for costs, schedule, and management review; and described measures in place to prevent another OTB.
- ☐ Updated EACs and other EVM data were continually reported to management.
- ☐ EVM and CFSR–like data were examined regularly to identify problems and act on them quickly.

AUDITING AGENCIES AND THEIR WEB SITES

GAO frequently contacts the audit agencies in this appendix at the start of a new audit. This list does not represent the universe of audit organizations in the federal government.

Auditing agency	Agency's Web site
Air Force Audit Agency	
Defense Contract Audit Agency	
District of Columbia, Office of the Inspector General	
Federal Trade Commission, Office of Inspector General	
National Aeronautics and Space Administration, Office of Inspector General	
National Archives, Office of the Inspector General	
Navy Inspector General	
Social Security Administration, Office of the Inspector General	
U.S. Army Audit Agency	
U.S. Department of Commerce, Office of Inspector General	
U.S. Department of Defense, Office of Inspector General	
U.S. Department of Education, Office of Inspector General	
U.S. Department of Health and Human Services, Office of Inspector General	
U.S. Department of Housing and Urban Development, Office of Inspector General	
U.S. Environmental Protection Agency, Office of Inspector General	
U.S. General Services Administration, Office of Inspector General	
U.S. House of Representatives, Office of Inspector General	
United States Postal Service, Office of Inspector General	

CASE STUDY BACKGROUNDS

We drew the material in the guide's 48 case studies from the 16 GAO reports described in this appendix. Table 48 shows the relationship between reports, case studies, and the chapters they illustrate. The table is arranged by the order in which we issued the reports, earliest first. Following the table, paragraphs that describe the reports are ordered by the numbers of the case studies in this Cost Guide.

Table 48: Case Studies Drawn from GAO Reports Illustrating This Guide

Case study	GAO report	Chapters illustrated
2, 5, 18, 30, 35	GAO/AIMD-99-41: Customs Service Modernization	1, 2, 4, 9, 11
47	GAO-03-343: National Airspace System	20
17	GAO-03-645T: Best Practices	5
1, 3, 4, 11, 13, 23	GAO-04-642: NASA	1, 2, 5, 8
48	GAO-04-643R: Uncertainties Remain	20
8, 10, 14, 27, 28, 33, 36, 38, 40, 46	GAO-05-183: Defense Acquisitions	2, 4, 9–11, 13, 14, 19
19, 21, 45	GAO-06-215: DOD Systems Modernization	5, 7, 18
24	GAO-06-296: Homeland Security	8
9	GAO-06-327: Defense Acquisitions	2
7	GAO-06-389: Combating Nuclear Smuggling	2
20	GAO-06-623: United States Coast Guard	7
12, 32, 44	GAO-06-692: Cooperative Threat Reduction	2, 10, 18
6, 16, 25, 26, 29, 31, 34, 37, 39, 42	GAO-07-96: Space Acquisitions	2, 4, 9–12, 14, 15
15	GAO-07-133R: Combating Nuclear Smuggling	4
41	GAO-07-240R: Chemical Demilitarization	15
43	GAO-07-268, Telecommunications	16
22	GAO-08-756: Air Traffic Control	8

Note: Full bibliographic data for the reports in this table (listed in the order in which GAO issued them) are given below their headings in this appendix and in the case studies in the text.

Case Studies 1, 3, 4, 11, 13, and 23: From NASA, GAO-04-642, May 28, 2004

For more than a decade, GAO has identified the National Aeronautics and Space Administration's (NASA) contract management as a high-risk area. Because of NASA's inability to collect, maintain, and report the full cost of its programs and projects, it has been challenged to manage its programs and control program costs. The scientific and technical expectations inherent in NASA's mission create even greater challenges—especially if meeting those expectations requires NASA to reallocate funding from existing programs to support new efforts.

Because cost growth has been a persistent problem in a number of NASA's programs, GAO was asked to examine NASA's cost estimating for selected programs, assess its cost-estimating processes and methods, and describe any barriers to improving its cost-estimating processes. Accordingly, in NASA: Lack of Disciplined Cost-Estimating Processes Hinders Effective Program Management (May 28, 2004), GAO reported its analysis of 27 NASA programs, 10 of which it reviewed in detail.

Case Studies 2, 5, 18, 30, and 35: From Customs Service Modernization, GAO/AIMD-99-41, February 26, 1999

Title VI of the 1993 North American Free Trade Agreement Implementation Act, Public Law 103-182, enabled the U.S. Customs Service to speed the processing of imports and improve compliance with trade laws. Customs refers to this legislation as the Customs Modernization and Informed Compliance Act, or "Mod Act." The act's primary purpose was to streamline and automate Customs' commercial operations. According to Customs, modernized commercial operations would permit it to more efficiently handle its burgeoning import workloads and expedite the movement of merchandise at more than 300 ports of entry. Customs estimated that the volume of import trade would increase from $761 billion in 1995 to $1.1 trillion through 2001, with the number of commercial entries processed increasing in those years from 13.1 million to 20.6 million.

The Automated Commercial Environment (ACE) program was Customs' system solution to a modernized commercial environment. In November 1997, Customs estimated that it would cost $1.05 billion to develop, operate, and maintain ACE between fiscal year 1994 and fiscal year 2008. Customs planned to develop and deploy ACE in increments. The first four were known collectively as the National Customs Automation Program (NCAP). The first increment, NCAP 0.1, was deployed for field operation and evaluation in May 1998. At the end of fiscal year 1998, Customs reported that it had spent $62.1 million on ACE. GAO issued its report on these programs, Customs Service Modernization: Serious Management and Technical Weaknesses Must Be Corrected, on February 26, 1999.

Case Studies 6, 16, 25, 26, 29, 31, 34, 37, 39, and 42: From Space Acquisitions, GAO-07-96, November 17, 2006

Estimated costs for major space acquisition programs in the Department of Defense (DOD) have increased about $12.2 billion—or nearly 44 percent—above initial estimates for fiscal years 2006–2011. In some cases, current estimates of costs are more than double the original estimates. For example, the Space Based Infrared System High program was originally estimated to cost about $4 billion but is now estimated to cost over $10 billion. The National Polar-orbiting Operational Environmental Satellite System program was originally estimated to cost almost $6 billion but is now over $11 billion. Such growth has had a dramatic effect on DOD's overall space portfolio.

To cover the added costs of poorly performing programs, DOD has shifted scarce resources away from other programs, creating cascading cost and schedule inefficiencies. As a result, GAO was asked to examine (1) in what areas space system acquisition cost estimates have been unrealistic and (2) what incentives and pressures have contributed to the quality and usefulness of cost estimates for space system acquisitions. GAO reported its findings on November 17, 2006, in Space Acquisitions: DOD Needs to Take More Action to Address Unrealistic Initial Cost Estimates of Space Systems.

Case Study 7: From Combating Nuclear Smuggling, GAO-06-389, March 22, 2006

Since September 11, 2001, combating terrorism has been one of the nation's highest priorities. Preventing the smuggling of radioactive material into the United States—perhaps for use by terrorists in a nuclear weapon or in a radiological dispersal device (a dirty bomb)—has become a key national security objective. The Department of Homeland Security (DHS) is responsible for providing radiation detection capabilities at U.S. ports of entry. In September 2003, GAO reported on the department's progress in completing domestic deployments. In particular, GAO found that certain aspects of its installation and use of equipment diminished its effectiveness and that agency coordination on long-term research issues was limited.

After GAO issued that report, questions arose about the deployed detection equipment's efficacy—in particular, its purported inability to distinguish naturally occurring radioactive materials from a nuclear bomb. GAO was asked to review DHS's progress in (1) deploying radiation detection equipment, (2) using radiation detection equipment, (3) improving the equipment's capabilities and testing, and (4) increasing cooperation between DHS and other federal agencies in conducting radiation detection programs. GAO reported these findings on March 22, 2006, in Combating Nuclear Smuggling: DHS Has Made Progress Deploying Radiation Detection Equipment at U.S. Ports-of-Entry, but Concerns Remain.

Case Studies 8, 10, 14, 27, 28, 33, 36, 38, 40, and 46: From Defense Acquisitions, GAO-05-183, February 28, 2005

The U.S. Navy makes significant investments to maintain the technological superiority of its warships. It devoted $7.6 billion in 2005 alone to new ship construction in six ship classes: 96 percent of this was allocated to the Arleigh Burke class destroyer, Nimitz class aircraft carrier, San Antonio class amphibious transport dock ship, and Virginia class submarine. Cost growth in the Navy's shipbuilding programs has been a long-standing problem. Over the few preceding years, the Navy had used "prior year completion" funding—that is, additional appropriations for ships already under contract—to pay for cost overruns. Responding to a congressional request, GAO's review—Defense Acquisitions: Improved Management Practices Could Help Minimize Cost Growth in Navy Shipbuilding Programs (Feb. 28, 2005)—(1) estimated the current and projected cost growth on construction contracts for eight case study ships, (2) broke down and examined the components of the cost growth, and (3) identified funding and management practices that contributed to cost growth.

Case Study 9: From Defense Acquisitions, GAO-06-327, March 15, 2006

DOD has spent nearly $90 billion since 1985 to develop a Ballistic Missile Defense System. The developer, the Missile Defense Agency (MDA), plans to invest about $58 billion more in the next 6 years. MDA's overall goal is to produce a system that can defeat enemy missiles launched from any range during any phase of their flight. Its approach is to field new capabilities in 2-year blocks. Block 2004, the first block, was to provide some protection by December 2005 against attacks out of North Korea and the Middle East.

The Congress requires GAO to assess MDA's progress annually. Its 2006 report assessed (1) MDA's progress during fiscal year 2005 and (2) whether capabilities fielded under Block 2004 met their goals. In Defense Acquisitions: Missile Defense Agency Fields Initial Capability but Falls Short of Original Goals (Mar. 15, 2006), GAO identified reasons for shortfalls and discussed corrective actions that should be taken.

Case Studies 12, 32, and 44: From Cooperative Threat Reduction, GAO-06-692, May 31, 2006

Until Russia's stockpile of chemical weapons is destroyed, it will remain not only a proliferation threat but also vulnerable to theft and diversion. The U.S. Congress has authorized DOD since 1992 to provide more than $1 billion for the Cooperative Threat Reduction program to help the Russian Federation build a chemical weapons destruction facility at Shchuch'ye to eliminate about 14 percent of its stockpile. DOD has faced numerous challenges over the past several years that have increased the facility's estimated cost from about $750 million to more than $1 billion and that delayed its operation from 2006 to 2009. DOD has attributed these increases to a variety of factors. Asked to assess the facility's progress, schedule, and cost and to review the status of Russia's efforts to destroy all its chemical weapons, GAO reported its findings in Cooperative Threat Reduction: DOD Needs More Reliable Data to Better Estimate the Cost and Schedule of the Shchuch'ye Facility (May 31, 2006).

Case Study 15: From Combating Nuclear Smuggling, GAO-07-133R, October 17, 2006

DHS is responsible for providing radiation detection capabilities at U.S. ports of entry. Current portal monitors, costing about $55,000 each, detect the presence of radiation. They cannot distinguish between harmless radiological materials, such as naturally occurring radiological material in some ceramic tile, and dangerous nuclear material, such as highly enriched uranium. Portal monitors with new identification technology designed to distinguish between the two types of material currently cost $377,000 or more. In July 2006, DHS announced that it had awarded contracts to three vendors to further develop and purchase $1.2 billion worth of new portal monitors over 5 years.

GAO's report on these developments is in Combating Nuclear Smuggling: DHS's Cost-Benefit Analysis to Support the Purchase of New Radiation Detection Portal Monitors Was Not Based on Available Performance Data and Did Not Fully Evaluate All the Monitors' Costs and Benefits (Oct. 17, 2006).

Case Study 17: From Best Practices, GAO-03-645T, April 11, 2003

DOD's modernizing its forces competes with health care, homeland security, and other demands for federal funds. Therefore, DOD must manage its acquisitions as cost efficiently and effectively as possible. As of April 2003, DOD's overall investments to modernize and "transition" U.S. forces were expected to average $150 billion a year through 2008.

In 2003, DOD's newest acquisition policy emphasized evolutionary, knowledge-based concepts that had produced more effective and efficient weapon system outcomes. However, most DOD programs did not employ such concepts and, as a result, experienced cost increases, schedule delays, and poor product quality and reliability.

In a hearing before the Subcommittee on National Security, Emerging Threats, and International Relations of the House Committee on Government Reform, GAO's testimony—Best Practices: Better Acquisition Outcomes Are Possible If DOD Can Apply Lessons from F/A-22 Program (Apr. 11, 2003)—compared best practices for developing new products with the experiences of the F/A-22 program.

Case Studies 19, 21, and 45: From DOD Systems Modernization, GAO-06-215, December 5, 2005

The Naval Tactical Command Support System (NTCSS) was started in 1995 to help U.S. Navy personnel effectively manage ship, submarine, and aircraft support activities. The Navy expected to spend $348 million on the system between fiscal years 2006 and 2009. As of December 2005, about $1 billion had been spent to partially deploy NTCSS to about half its intended sites. It is important that DOD adhere to disciplined information technology acquisition processes to successfully modernize its business systems. Therefore, GAO was asked to determine whether NTCSS was being managed according to DOD's acquisition policies and guidance, as well as other relevant acquisition management best practices. GAO issued its report on December 5, 2005, under the title, DOD Systems Modernization: Planned Investment in the Naval Tactical Command Support System Needs to Be Reassessed.

Case Study 20: From United States Coast Guard, GAO-06-623, May 31, 2006

Search and rescue is one of the U.S. Coast Guard's oldest missions and highest priorities. The search and rescue mission includes minimizing the loss of life, injury, and property damage by aiding people and boats in distress. The National Distress and Response System is the legacy communications component of the Coast Guard's search and rescue program. However, the 30-year-old system had several deficiencies and was difficult to maintain, according to agency officials. In September 2002, the Coast Guard contracted to replace its search and rescue communications system with a new system known as Rescue 21. However, the acquisition and initial implementation of Rescue 21 had resulted in significant cost overruns and schedule delays. Therefore, GAO was asked to assess the (1) reasons for the significant cost overruns and implementation delays, (2) viability of the revised cost and schedule estimates, and (3) impact of the implementation delays. GAO issued its report on May 31, 2006, under the title, United States Coast Guard: Improvements Needed in Management and Oversight of Rescue System Acquisition.

Case Study 22: From Air Traffic Control, GAO-08-756, July 18, 2008

In fiscal year 2008, the Federal Aviation Administration (FAA) planned to spend over $2 billion on information technology (IT) investments—many of which support FAA's air traffic control modernization. To more effectively manage such investments, in 2005 the Office of Management and Budget (OMB) required agencies to use earned value management (EVM). If implemented appropriately, EVM is a project management approach that provides objective reports of project status, produces early warning signs of impending schedule delays and cost overruns, and provides unbiased estimates of a program's total costs.

Among other objectives, GAO was asked to assess FAA's policies for implementing EVM on its IT investments, evaluate whether the agency is adequately using these techniques to manage key IT acquisitions, and assess the agency's efforts to oversee EVM compliance. To do so, GAO compared agency policies with best practices, performed four case studies, and interviewed key FAA officials. GAO issued its report, FAA Uses Earned Value Techniques to Help Manage Information Technology Acquisitions, but Needs to Clarify Policy and Strengthen Oversight, on July 18, 2008.

Case Study 24: From Homeland Security, GAO-06-296, February 14, 2006

DHS's U.S. Visitor and Immigrant Status Indicator Technology (US-VISIT) program was designed to collect, maintain, and share information, including biometric identifiers, on selected foreign nationals entering and exiting the United States. US-VISIT uses the identifiers—digital finger scans and photographs—to match persons against watch lists and to verify that a visitor is the person who was issued a visa or other travel documents. Visitors are also to have their departure confirmed by having their visas or passports scanned and by undergoing finger scanning at selected air and sea ports of entry. GAO has made many recommendations to improve the program's management, all of which DHS has agreed to implement. GAO was asked to report in February 2006 on DHS's progress in responding to 18 of those recommendations. Homeland Security: Recommendations to Improve Management of Key Border Security Program Need to Be Implemented (Feb. 14, 2006) was the result.

Case Study 41: From Chemical Demilitarization, GAO-07-240R, January 26, 2007

The U.S. stockpile of 1,269 tons of a lethal nerve agent (called VX) stored at the Newport Chemical Depot (Newport), Indiana, is one of nine stockpiles that DOD must destroy in response to congressional direction and the requirements of the Chemical Weapons Convention. The stockpile at Newport will be destroyed by neutralization—mixing hot water and sodium hydroxide with VX to change the chemical composition to a less toxic form. The resulting by-product is a liquid wastewater commonly referred to as hydrolysate that consists mostly of water but needs further treatment for disposal. At the time of GAO's review, none of the generated hydrolysate—which was expected to be about 2 million gallons at the completion of the neutralization process—had been treated. Instead, the hydrolysate was being stored on-site until a post-treatment plan could be implemented.

The House Committee on Armed Services Report on the National Defense Authorization Act for Fiscal Year 2006 (H.R. Rep. No. 109-89) directed the Secretary of the Army to conduct and provide the congressional defense committees with a detailed cost-benefit analysis to include an analysis comparing the proposed off-site treatment option with eight on-site options. In response, the Army published its cost-benefit report in April 2006, which concluded that only three of the eight technologies were feasible for treating Newport's hydrolysate. In the cost-effectiveness analysis contained in the report, the Army determined that the cost of off-site treatment of the hydrolysate would be less expensive than the on-site options. The Army also concluded that the off-site treatment option would allow the disposal to be accomplished in the shortest amount of time and would minimize the amount of time that the hydrolysate must be stored at Newport. GAO was asked to (1) assess the reasonableness of the Army's rational to eliminate five of the eight technologies for treating Newport's hydrolysate; (2) determine what other options the Army considered, such as incineration; and (3) evaluate the adequacy of the cost comparison analysis presented for the three remaining technologies considered as alternatives to the Army's proposed plan. GAO issued its report on Jan. 26, 2007, under the title, Chemical Demilitarization: Actions Needed to Improve the Reliability of the Army's Cost Comparison Analysis for Treatment and Disposal Options for Newport's VX Hydrolysate.

Case Study 43: From Telecommunications, GAO-07-268, February 23, 2007

The mission of General Services Administration (GSA) technology programs is to provide federal agencies with acquisition services and solutions at best value including offering agencies options for acquiring needed telecommunications services. With the current set of governmentwide telecommunications contracts approaching expiration, GSA and its customer agencies will have to see the services acquired under these contracts through their transition to their replacements, known collectively as Networx. GSA will incur program management costs associated with planning and executing this transition. It has also made a commitment to absorb certain agency transition costs. To ensure that it would have the funds necessary to pay for these costs, GSA estimated that it would need to set aside about $151.5 million. GAO was asked to determine (1) the soundness of GSA's analysis in deriving the estimate of funding that would be required for the transition and (2) whether GSA will have accumulated adequate funding to pay for its transition management costs. GAO issued its report on February 23, 2007, under the title, Telecommunications: GSA Has Accumulated Adequate Funding for Transition to New Contracts but Needs Cost Estimation Policy.

Case Study 47: From National Airspace System, GAO-03-343, January 31, 2003

The Standard Terminal Automation Replacement System (STARS) was to replace outdated computer equipment used to control air traffic within 5 to 50 nautical miles of an airport. At the time of this review, FAA's plan was to procure 74 STARS systems, including 70 for terminal facilities and 4 for support facilities. With STARS, air traffic controllers at these facilities would receive new hardware and software that would produce color displays of aircraft position and flight information. In the future, FAA would be able to upgrade the software to provide air traffic control tools to allow better spacing of aircraft as they descend into airports. STARS was complex, costly, and software-intensive. Since 1996, when FAA initiated STARS, the number of systems scheduled to be procured ranged from as many as 188 to as few as 74, and the program's cost and schedule also varied considerably. GAO's report, covering cost and performance issues related to this procurement, is in National Airspace System: Better Cost Data Could Improve FAA's Management of the Standard Terminal Automation Replacement System (Jan. 31, 2003).

Case Study 48: From Uncertainties Remain, GAO-04-643R, May 17, 2004

In 1996, the Air Force launched an acquisition program to develop and produce a revolutionary laser weapon system, the Airborne Laser (ABL), capable of defeating an enemy ballistic missile during the boost phase of its flight. Over the 8 years preceding GAO's review, the program's efforts to develop this technology resulted in significant cost growth and schedule delays. The prime contractor's costs for developing ABL nearly doubled from the Air Force's original estimate and cost was growing. The cost growth occurred primarily because the program did not adequately plan for and could not fully anticipate the complexities of developing the system. The Missile Defense Agency continued to face significant challenges in developing the ABL's revolutionary technologies and in achieving cost and schedule stability. From 1996 through 2003, the value of the prime contract, which accounted for the bulk of the program's cost, increased from about $1 billion to $2 billion. According to our analysis, costs could increase between $431 million to $943 million more through the first full demonstration of the ABL system. GAO's report, covering cost and performance issues related to this procurement, is in Uncertainties Remain Concerning the Airborne Laser's Cost and Military Utility, GAO-04-643R (May 17, 2004).

EXPERTS WHO HELPED DEVELOP THIS GUIDE

The two lists in this appendix name the experts in the cost estimating community, with their organizations, who helped us develop this guide. This first list names significant contributors to the Cost Guide. They attended and participated in numerous expert meetings, provided text or graphics, and submitted comments.

Organization	Expert
ABBA Consulting	Wayne Abba
BAE Systems	Shobha Mahabir
David Consulting Group	Michael Harris
Defense Contract Management Agency	Bob Keysar
Defense Acquisition University	David Bachman Todd Johnston
Department of Defense	Debbie Tomsic
Department of Treasury	Kimberly Smith
Federal Aviation Administration	Lewis Fisher Wayne Hanley Fred Sapp
Fleming Management Consultancy	Quentin Fleming
Galorath Incorporated	Dan Galorath
Hulett & Associates LLC	David Hulett
Independent Consultant	John Pakiz
Internal Revenue Service	Donald Moushegian
KM Systems Group	Kim Hunter
Lockheed Martin Corporation	Jamie Fieber
Ludwig Consulting Services, LLC	Joyce Ludwig
Management Concepts	Gregory T. Haugan
MCR Federal LLC	Neil Albert
Missile Defense Agency	David Melton Peter Schwarz
MITRE	David Crawford
MITRE and National Oceanic and Atmospheric Administration	Richard Riether
National Aeronautics and Space Administration	Glenn Campbell David Graham
PRICE Systems	Bruce Fad William Mathis
Project and Program Management Systems, International	Eric Marantoni
Social Security Administration	Otto Immink
The Analytical Sciences Corporation	Peter Braxton Greg Hogan
Technomics	Rick Collins Robert Meyer Jack Smuck

Organization	Expert
Tecolote Research, Incorporated	Lew Fichter Greg Higdon Bill Rote Alf Smith
United Kingdom Ministry of Defense	Andy Nicholls
U.S. Air Force, Air Force Cost Analysis Agency	John Cargill Rich Hartley John Peterson William Seeman Wilson Rosa
U.S. Army, Army Cost Center	Sean Vessey
U.S. Army, Corps of Engineers	Kim Callan
U.S. Navy, Center for Cost Analysis	Susan Wileman
U.S. Navy, Naval Air Systems Command	Brenda Bizier Susan Blake Fred Meyer John Scapparo
U.S. Navy, Naval Sea Systems Command	Hershel Young

This second list names those who generously donated their time to review the Cost Guide in its various stages and to provide feedback.

Organization	Expert
Association for the Advancement of Cost Engineering	Osmund Belcher Bill Kraus
Business Growth Solutions Ltd.	Keith Gray
Center for Naval Analyses	Dan Davis Richard Sperling
CGI Federal	Sameer Rohatgi
Comcast	Tamara Garcia
Data Systems Analysts Inc.	Aubrey Jones
Department of Defense	John Leather
Department of Homeland Security	Jim Manzo Michael Zaboski
Department of Homeland Security, Domestic Nuclear Detection Office	Richard Balzano Lisa Bell Andrew Crisman
Federal Aviation Administration	Scott Allard Dan Milano William Russell
Hutchins & Associates	Pam Shepherd
Independent Consultant	Steven Deal Dee Dobbins Jan Kinner David Muzio Max Wideman

Organization	Expert
Lockheed Martin Corporation	Walt Berkey Bill Farmer Kathleen McCarter Chitra Raghu Tony Stemkowski
MITRE	Raj Agrawal
National Geospatial Intelligence Agency	Ivan Bembers
Northrop Grumman	Gay Infanti Beverly Solomon
Office of Management and Budget	Patricia Corrigan
Parsons	Karen Kimball Michael Nosbisch Jon Tanke Sandy Whyte
PRICE Systems	Didier Barrault
PT Mitratata Citragraha (PTMC)	Paul D. Giammalvo
Robbins Gioia	Wei Tang
Social Security Administration	Alan Deckard
SRA International	David Lyons
SRS Technologies	Tim Sweeney
The Analytical Sciences Corporation	Samuel Toas
University of Colorado	Shekhar Patil
UQN and Associates	Ursula Kuehn
U.S. Air Force	Harold Parker
U.S. Army	Robert Dow
U.S. Army, Army Cost Center	Mort Anvari
U.S. Navy	Mark Gindele
U.S. Navy, Naval Air Systems Command	Jeff Scher
Wyle Labs	Katrina Brown

THE FEDERAL BUDGET PROCESS

Each year in January or early February, the president submits budget proposals for the year that begins October 1. They include data for the most recently completed year, the current year, the budget year, and at least the 4 years following the budget year.

The budget process has four phases: (1) executive budget formulation, (2) congressional budget process, (3) budget execution and control, and (4) audit and evaluation. Budget cycles overlap—the formulation of one budget begins before action has been completed on the previous one. Tables 49 and 50 present information from OMB's Circular A-11 about the main phases of the budget cycle and the steps—and time periods—within each phase.

Table 49: Phases of the Budget Process

Phase	Description
Executive budget formulation	OMB and the federal agencies begin preparing one budget almost as soon as the president has sent the last one to the Congress. OMB officially starts the process by sending planning guidance to executive agencies in the spring. The president completes this phase by sending the budget to the Congress on the first Monday in February, as specified in law
Congressional budget process	Begins when the Congress receives the president's budget. The Congress does not vote on the budget but prepares a spending and revenue plan that is embedded in the Congressional Budget Resolution; the Congress also enacts regular appropriations acts and other laws that control spending and receipts
Budget execution	This phase lasts for at least 5 fiscal years and has two parts: ▪ Apportionment pertains to funds appropriated for that fiscal year and to balances of appropriations made in prior years that remain available for obligation. At the beginning of the fiscal year, and at other times as necessary, OMB apportions funds to executive agencies; that is, it specifies the amounts they may use by time period, program, project, or activity. Throughout the year, agencies hire people, enter into contracts, enter into grant agreements, and so on, to carry out their programs, projects, and activities. These actions use up the available funds by obligating the federal government to make immediate or future outlays ▪ Reporting and outlay last until funds are canceled (1-year and multiple-year funds are canceled at the end of the fifth year, after the funds expire for new obligations) or until funds are totally disbursed (for no-year funds)
Audit and evaluation	▪ While OMB does not specify times, each agency is responsible for ensuring that its obligations and outlays adhere to the provisions in the authorizing and appropriations legislation, as well as other laws and regulations governing the obligation and expenditure of funds. OMB provides guidance for, and federal laws are aimed at, controlling and improving agency financial management. Agency inspectors general give policy direction for, and agency chief financial officers oversee, all financial management activities related to agency programs and operations. ▪ The 1993 Government Performance and Results Act requires each agency to submit an annual performance plan and performance report to OMB and the Congress; the report must establish goals defining the level of performance each program activity in the agency*s budget is to achieve and describing the operational processes and resources required to meet those goals. The Congress oversees agencies through the legislative process, hearings, and investigations. GAO audits and evaluates government programs and reports its findings and recommendations for corrective action to the Congress, OMB, and the agencies

Source: GAO and OMB.

Table 50: The Budget Process: Major Steps and Time Periods

Phase	Major step	Time
Formulation	OMB issues planning guidance to executive agencies. OMB's Director issues to agency heads policy guidance for budget requests; if no more specific guidance is given, the previous budget's out-year estimates serve as the starting point for the next budget. This begins the process of formulating the budget the president will submit next February	Spring
	OMB issues Circular No. A–11 to all federal agencies, providing detailed instructions for submitting budget data and materials	July
	Executive agencies, except those not subject to review, submit budgets; OMB provides specific deadlines	Sept.
	The fiscal year begins. The just completed budget cycle focused on this fiscal year, the budget year in that cycle, and the current year in this cycle	Oct. 1
	OMB conducts its fall review, analyzing agency budget proposals in light of presidential priorities, program performance, and budget constraints	Oct.–Nov.
	OMB informs executive agencies of decisions on their budget requests	Late Nov.
	Agencies enter computer data and submit printed material and additional data; this begins immediately after passback and continues until OMB "locks" agencies out of the database to meet the printing deadline	Late Nov. to early Jan.
	Agencies prepare, and OMB reviews, the justification materials they need to explain their budget requests to congressional subcommittees	Jan.
	The president transmits the budget to the Congress	First Mon. in Feb.
Congressional	The Congressional Budget Office (CBO) reports to budget committees on the economic and budget outlook	Jan.
	CBO reestimates the President's Budget, based on its economic and technical assumptions	Feb.
	Committees submit "views and estimates" to House and Senate budget committees, indicating preferences on matters they are responsible for	Within 6 weeks of budget transmittal
	The Congress completes action on the concurrent resolution on the budget and commits to broad spending and revenue levels by passing a budget resolution	Apr. 15
	The Congress completes action on appropriations bills for the coming fiscal year or passes a continuing resolution (stop-gap appropriations)	Sept. 30
Execution	The fiscal year begins	Oct. 1
	OMB apportions funds made available in the annual appropriations process and other available funds. Agencies submit to OMB apportionment requests for each budget account by August 21 or within 10 calendar days after the approval of the appropriation, whichever is later. OMB approves or modifies apportionments, specifying the funds agencies may use by time period, program, project, or activity	Sept. 10, or within 30 days after approval of a spending bill
	Agencies incur obligations and make outlays for funded programs, projects, and activities, hiring people and entering into contracts and agreements. They record obligations and outlays according to control procedures, report to Treasury, and prepare financial statements	Throughout the fiscal year
	The fiscal year ends	Sept. 30
	Agencies disburse against obligated balances and adjust them to reflect actual obligations, continuing to record obligations and outlays, report to Treasury, and prepare financial statements	Until Sept. 30, fifth year after funds expire.

Source: OMB.

FEDERAL COST ESTIMATING AND EVM LEGISLATION, REGULATIONS, POLICIES, AND GUIDANCE

The material in this appendix, keyed to table 3 in the body of the Cost Guide, describes criteria related to cost estimating and EVM.

Legislation and Regulations

1968: DOD Selected Acquisition Reports

Before selected acquisition reports (SAR) were introduced, with DOD Instruction 7000.3 in 1968, no recurring reports on major acquisitions summarized cost, schedule, and performance data for comparison with earlier and later estimates. The original purpose of SARs was to keep the Assistant Secretary of Defense (Comptroller) informed of the progress of selected acquisitions and to compare this progress with the planned technical, schedule, and cost performance. When the Secretary of Defense and the Congress began to require regular reports early in 1969, SARs became key recurring summaries advising the Congress on the progress of major acquisition programs.[1]

For the purpose of oversight and decision making, legislation (10 U.S.C. § 2432 (2006)) now requires DOD to submit SARs annually to the Congress. The reports present the latest cost and schedule estimates and technical status for major defense programs. The comprehensive annual SARs are prepared in conjunction with the president's budget.

Quarterly exception reports are required only for programs with unit cost increases of at least 15 percent or schedule delays of at least 6 months. They are also submitted for initial reports, final reports, and programs that are rebaselined at major milestone decisions.

For each major defense acquisition program, an SAR contains program quantities; program acquisition cost and acquisition unit cost; current procurement cost and procurement unit cost; reasons for any changes in these costs from the previous SAR; reasons for any significant changes from the previous SAR in total program cost, software schedule milestones, or performance; any major contract changes and reasons for cost or schedule variances since the last SAR; and program highlights for current reporting period.

1982: DOD Unit Cost Reports

Recognizing the need to establish a cost growth oversight mechanism for DOD's major defense acquisition programs, the Congress requires DOD to report on program cost growth that exceeds certain thresholds. This requirement is commonly called Nunn-McCurdy, after the congressional leaders responsible for it. It became permanent law in 1982 with the Department of Defense Authorization Act, 1983. The law (10 U.S.C. § 2433 (2006)) now provides for oversight of cost growth in DOD's major defense acquisition programs by requiring DOD to notify the Congress when a program's unit cost growth exceeds (or breaches) the original or the latest approved acquisition program baseline by certain thresholds.[2] If the cost growth has increased by certain percentages over the baseline, the Secretary of Defense must carry out an assessment that includes the projected costs of completing the program if

[1] See Comptroller General of the United States, *How to Improve the Selected Acquisition Reporting System: Department of Defense*, PSAD-75-63 (Washington, D.C.: GAO, Mar. 27, 1975), p. 2.

[2] See 10 U.S.C.S. § 2433 (2002 & Supp. 2007).

current requirements are not modified, as well as based on reasonable modification of such requirements. The assessment is also to include a rough order of magnitude of the costs of any reasonable alternative system of capability. Further, the Secretary of Defense is to certify to the Congress that

1. the program is essential to national security,
2. no alternatives will provide equal or greater military capability at less cost,
3. new program acquisition or procurement unit cost estimates are reasonable, and
4. the management structure is adequate to control unit cost.

1983: DOD Independent Cost Estimates

Section 2434 of title 10 of the U.S. Code requires the Secretary of Defense to consider an independent life-cycle cost estimate (LCCE) before approving system development and demonstration, or production and deployment, of a major defense acquisition program. Under DOD's acquisition system policy, this function is delegated to a program's milestone decision authority. The statute requires that DOD prescribe regulations governing the content and submission of such estimates and that the estimates be prepared

1. by an office or other entity not under the supervision, direction, or control of the military department, agency, or other component directly responsible for the program's development or acquisition or
2. if the decision authority has been delegated to an official of a military department, agency, or other component, by an office or other entity not directly responsible for the program's development or acquisition.

The statute specifies that the independent estimate is to include all costs of development, procurement, military construction, and operations and support, without regard to funding source or management control.

1993: Government Performance and Results Act

The Government Performance and Results Act of 1993 (GPRA), Pub. L. No. 103-62, requires agencies to prepare multiyear strategic plans that describe mission goals and methods for reaching them. It also requires agencies to develop annual performance plans that OMB uses to prepare a federal performance plan that is submitted to the Congress, along with the president's annual budget submission. The agencies' plans must establish measurable goals for program activities and must describe the methods for measuring performance toward those goals. The act also requires agencies to prepare annual program performance reports to review progress toward annual performance goals.

1994: Federal Acquisition Streamlining Act

The Federal Acquisition Streamlining Act of 1994 (Pub. L. No. 103-355, §§ 5001(a)(1), 5051(a), as amended) established a congressional policy that the head of each executive agency should achieve, on average, 90 percent of cost, performance, and schedule goals established for major acquisition programs of the agency. The act requires an agency to approve or define cost, performance, and schedule goals for its major acquisition programs. To implement the 90 percent policy, the act requires agency heads to determine whether there is a continuing need for programs that are significantly behind schedule, over budget, or not in compliance with performance or capability requirements and to identify suitable actions to be taken, including termination, with respect to such programs. This provision is codified at 41 U.S.C. § 263 (2000) for civilian agencies. A similar requirement in 10 U.S.C. § 2220 applied to the DOD but was amended to remove the 90 percent measure. DOD has its own major program performance oversight requirements, such as the Nunn-McCurdy cost reporting process at 10 U.S.C. § 2433. OMB incorporated the 90 percent measure into the *Capital Programming Guide* Supplement to Circular A-11.[3]

1996: Clinger-Cohen Act

The Clinger-Cohen Act of 1996 (codified, as relevant here, at 40 U.S.C. §§ 11101–11704 (Supp. V 2005)) is intended to improve the productivity, efficiency, and effectiveness of federal programs by improving the acquisition, use, and disposal of information technology resources. Among its provisions, it requires federal agencies to

1. establish capital planning and investment control processes to maximize the value and manage the risks of information technology acquisitions, through quantitative and qualitative assessment of investment costs, benefits, and risks, among other ways;
2. establish performance goals and measures for assessing and improving how well information technology supports agency programs, by benchmarking agency performance against public and private sector best practices;
3. appoint chief information officers to be responsible for carrying out agency information resources management activities, including the acquisition and management of information technology, to improve agency productivity, efficiency, and effectiveness; and
4. identify in their strategic information resources management plans any major information technology acquisition program, or any phase or increment of such a program, that has significantly deviated from the cost, performance, or schedule goals established for the program.

2006: DOD Major Automated Information System Programs

Section 816 of the John Warner National Defense Authorization Act for Fiscal Year 2007 (Pub. L. No. 109-364) added new oversight requirements for DOD's major automated information system (MAIS) programs. These requirements, codified at 10 U.S.C. §§ 2445a–2445d (2006), include estimates of development costs and full life-cycle costs, as well as the establishment of a program baseline, variance reporting, and reports on significant or critical changes in the program (these include estimated program cost increases over certain thresholds).

2006: Federal Acquisition Regulation—EVM Policy Added

The government's earned value management system policy is spelled out in subpart 34.2 of the Federal Acquisition Regulation (FAR, 48 C.F.R.). The Civilian Agency Acquisition Council and the Defense Acquisition Regulations Council promulgated a final rule amending the FAR to implement EVM policy on July 5, 2006.[4] The rule was necessary to help standardize EVM use across the government where

[3] OMB, *Capital Programming Guide: Supplement to Circular A-11, Part 7, Preparation, Submission, and Execution of the Budget* (Washington, D.C.: Executive Office of the President, June 2006). www.whitehouse.gov/omb/circulars/index.html.

[4] See Federal Acquisition Circular 2005-11, July 5, 2006, Item I—Earned Value Management System (EVMS) (FAR Case 2004-019).

developmental effort under a procurement contract is required. It implements EVM system policy in accordance with OMB Circular A–11, Part 7, and its supplement, the *Capital Planning Guide*.[5]

It requires that EVM be used for major acquisitions for development. The rule defines an EVM system as a project management tool that effectively integrates the project's scope of work with cost, schedule, and performance elements for optimum project planning and control (see FAR, 48 C.F.R. § 2.101). It also states that the qualities and characteristics of an EVM system are described in ANSI/EIA Standard 748, Earned Value Management Systems.[6]

The rule stipulates that when an EVM system is required, the government is to conduct an integrated baseline review (IBR) to verify the technical content and realism of the related performance budgets, resources, and schedules. Through the IBR, agencies are to attain mutual understanding of the risks inherent in contractors' performance plans and the underlying management control systems. The rule contemplates that the IBR results in the formulation of a plan to handle these risks.

2008: Defense Federal Acquisition Regulation Supplement

DOD issued a final rule (73 Fed. Reg. 21,846 (April 23, 2008), primarily codified at 48 C.F.R. subpart 234.2, and part 252 (sections 252.234-7001 and 7002)), amending the Defense Federal Acquisition Regulation Supplement (DFARS) to update requirements for DOD contractors to establish and maintain EVM systems. The rule also eliminated requirements for DOD contractors to submit cost-schedule status reports.

This final rule updated DFARS text addressing EVM policy for DOD contracts, supplements the final FAR rule published at 71 Fed. Reg. 38,238 on July 5, 2006, and establishes DOD-specific EVM requirements, as permitted by the FAR. The DFARS rule follows up on the policy in the memorandum the Under Secretary of Defense (Acquisition, Technology, and Logistics) issued on March 7, 2005, entitled "Revision to DOD Earned Value Management Policy."

The DFARS changes in this rule include the following: For cost or incentive contracts and subcontracts valued at $20 million or more, the rule requires an EVM system that complies with the guidelines in the American National Standards Institute/Electronic Industries Alliance Standard 748, Earned Value Management Systems (ANSI/EIA–748). For cost or incentive contracts and subcontracts valued at $50 million or more, the rule requires an EVM system that the cognizant federal agency (as defined in FAR 2.101) has determined to be in compliance with the guidelines in ANSI/EIA–748. For cost or incentive contracts and subcontracts valued at less than $20 million, the rule provides that application of EVM is optional and is a risk-based decision. For firm-fixed-price contracts and subcontracts of any dollar value, the rule discourages applying EVM. DCMA is assigned responsibility for determining EVM compliance when DOD is the cognizant federal agency. Requirements for contractor cost-schedule status reports are eliminated.

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[5] OMB, *Capital Programming Guide*: Supplement to Circular A-11, Part 7.

[6] EVM systems guidelines in American National Standards Institute (ANSI)/Electronic Industries Alliance (EIA) Standard 748 were developed and promulgated through ANSI by the National Defense Industrial Association's (NDIA) Program Management Systems Committee.

Policies

1976: OMB Circular *Major Systems Acquisitions*

OMB's 1976 Circular A-109, *Major Systems Acquisitions*, establishes policies for agencies to follow when acquiring major systems. It requires agencies to ensure that their major system acquisitions fulfill mission needs, operate effectively, and demonstrate a level of performance and reliability that justifies the use of taxpayers' funds. The policy also states that agencies need to maintain the ability to develop, review, negotiate, and monitor life-cycle costs. Moreover, agencies are expected to assess cost, schedule, and performance progress against predictions and inform agency heads of any variations at key decision points. When variations occur, the circular requires agencies to develop new assessments and use independent cost estimates, where feasible, for comparing results.

1992: OMB *Guidelines and Discount Rates for Benefit-Cost Analysis*

OMB issued Circular No. A-94 to agencies in 1992, *Guidelines and Discount Rates for Benefit-Cost Analysis of Federal Programs*, to support government decisions to initiate, review, or expand programs that would result in measurable costs or benefits extending for 3 or more years into the future. It is general guidance for conducting benefit-cost and cost-effectiveness analyses. It also gives specific guidance on discount rates for evaluating federal programs whose benefits and costs are distributed over time.

The guidance serves as a checklist for whether an agency has considered and properly dealt with all the elements of sound benefit-cost and cost-effectiveness analyses, including, among other things, identifying assumptions, analyzing alternatives, applying inflation, discounting for net present value, characterizing uncertainty, and performing sensitivity analysis.

1995: DOD's *Economic Analysis for Decisionmaking* Instruction

Economic Analysis for Decisionmaking, DOD's 1995 Instruction No. 7041.3, implements policy and updates responsibilities and procedures for conducting cost-effectiveness economic analysis. It states that economic analysis is an important tool for planning and budgeting for DOD systems, and it helps decision makers obtain insight into the economic factors of various alternatives. The instruction outlines procedures for estimating the life-cycle costs and benefits of each feasible alternative and for adjusting all costs and benefits to present value by using discount factors to account for the time value of money. These procedures provide decision makers with the information associated with each alternative's size and the timing of costs and benefits so that the best alternative can be selected. The instruction discusses the following elements of an economic analysis: a statement of the objective, assumptions, alternative ways of satisfying the objective, costs and benefits for each alternative considered, a comparison of alternatives ranked by net present value, sensitivity and uncertainty analysis, and results and recommendations. It also contains guidance on choosing alternatives and providing sensitivity analysis and proper discounting.

2003: DOD's *Defense Acquisition System Directive*

DOD's Directive No. 5000.1, *The Defense Acquisition System*, outlines the management processes DOD is to follow to provide effective, affordable, and timely systems to users. It stipulates that the Defense Acquisition System exists to manage the nation's investment in technologies, programs, and product support necessary to achieve the National Security Strategy and support the armed forces. Among other things, the policy requires every program manager to establish life-cycle cost, schedule, and performance goals that will determine the acquisition program baseline. These goals should be tracked and any deviations in program parameters and exit criteria should be reported. The directive discusses how programs should be funded to realistic estimates and states that major drivers of total ownership costs should be identified. It requires program managers to use knowledge-based acquisition for reducing risk by requiring that new technology be demonstrated before it is incorporated into a program.

DOD's Directive No. 5000.1, *The Defense Acquisition System* has been redesignated 5000.01 and certified current as of Nov. 20, 2007.

2003: DOD's *Operation of the Defense Acquisition System* Instruction

DOD's Instruction No. 5000.2, Operation of the Defense Acquisition System, establishes a framework for translating requirements into stable and affordable programs that can be managed effectively. It describes the standard framework for defense acquisition systems, which is to define the concept and analyze alternatives, develop the technology, develop the system and demonstrate that it works, produce the system and deploy it to its users, and operate and support the system throughout its useful life. The instruction also discusses in great detail the three milestones and what entrance and exit criteria must be met for each one. It explains the concept of evolutionary acquisition and how DOD prefers this strategy for acquiring technology, because it allows for the delivery of increased technical capability to users in the shortest time. The instruction identifies technology readiness assessments as a way to manage and mitigate technology risk. It discusses the different kinds of acquisition categories and their cost thresholds and decision authorities. In addition, it defines the role of the Cost Analysis Improvement Group (CAIG) in developing independent cost estimates.

DOD's Instruction No. 5000.2, *Operation of the Defense Acquisition System* has been cancelled and reissued by Instruction No. 5000.02 on Dec. 8, 2008.

2004: National Security Space Acquisition Policy 03-01

This document provides acquisition process guidance for DOD entities that are part of the National Security Space team. The Under Secretary of the Air Force is the DOD Space Milestone Decision Authority for all DOD Space Major Defense Acquisition Programs (MDAP). National Security Space is defined as the combined space activities of DOD and the National Intelligence Community. This policy describes the streamlined decision making framework for all DOD space system MDAPs.

A DOD Space MDAP is a space acquisition program that the DOD Space Milestone Decision Authority or the Defense Acquisition Executive designates as special interest or that the Space Milestone Decision Authority estimates will require an eventual total expenditure for research, development, test, and evaluation of more than $365 million in fiscal year FY 2000 constant dollars; or, for procurement, more than $2.19 billion in fiscal year 2000 constant dollars. Highly sensitive classified programs as defined by 10 U.S.C. § 2430 are not Space MDAPs.

2005: DOD's *Earned Value Management Policy*

Stating that EVM had been "an effective management control tool in the Department for the past 37 years," DOD revised its policy—with its March 7, 2005, memorandum, "Revision to DOD Earned Value Management Policy"—to streamline, improve, and increase consistency in EVM's application and implementation. The memorandum requires contracts equal to or greater than $20 million to implement

EVM systems in accordance with ANSI/EIA Standard 748. It also requires contractors with contracts equal to or greater than $50 million to have formally validated EVM systems approved by the cognizant contracting officer. The revised policy also requires contract performance reports, an integrated master schedule, and an IBR whenever EVM is required. The new policy also calls for, among other things, a common WBS structure for the CPR and IMS.

2005: OMB's Memorandum on *Improving Information Technology Project Planning and Execution*

OMB's 2005 *Improving Information Technology (IT) Project Planning and Execution* Memorandum for Chief Information Officers discusses how it expects agencies to ensure that cost, schedule, and performance goals are independently validated for reasonableness before beginning development. In addition, it requires agencies to fully implement EVM on all major capital acquisition projects. Full implementation occurs when agencies have shown that they have

1. a comprehensive agency policy for EVM;
2. included EVM system requirements in contracts or agency in-house project charters;
3. have held compliance reviews for agency and contractor EVM systems;
4. a policy of performing periodic system surveillance reviews to ensure that the EVM system continues to meet ANSI/EIA Standard 748 guidelines; and
5. a policy of conducting IBRs for making cost, schedule, and performance goals final.

The memorandum gives further guidance and explanation for each of these five key components. For example, OMB states that compliance reviews should confirm that a contractor's EVM system processes and procedures have satisfied ANSI/EIA Standard 748 guidelines and that surveillance reviews should show that agencies are using EVM to manage their programs. The memorandum stresses the importance of an IBR as a way of assessing program performance and understanding risk.

2006: OMB's Capital Programming Guide

The *Capital Programming Guide*—the part 7 supplement to OMB's Circular No. A-11—sets forth the requirements for how OMB manages and oversees agency budgets. In the budget process, agencies must develop and submit to OMB for review an exhibit 300, also known as the Capital Asset Plan and Business Case. Under OMB's circular A-11, agencies must analyze and document their decisions on proposed major investments. Exhibit 300 functions as a reporting mechanism that enables an agency to demonstrate to its own management, as well as OMB, that it has used the disciplines of good project management, developed a strong business case for investment, and met other administration priorities in defining the cost, schedule, and performance goals proposed for the investment. Exhibit 300 has eight key sections on spending, performance goals and measures, analysis of alternatives, risk inventory and assessment, acquisition strategy, planning for project investment and funding, enterprise architecture, and security and privacy. When considering investments to recommend for funding, OMB relies on the accuracy and completeness of the information reported in exhibit 300. It also cites that credible cost estimates are vital for sound management decision making and for any program or capital project to succeed. To that end, OMB states that following the guidelines in *GAO Cost Estimating and Assessment Guide* (GAO-09-3SP) will help agencies meet most cost estimating requirements.

2006: DOD's *Cost Analysis Improvement Group Directive*

DOD's Directive 5000.04 states that the CAIG is the principal advisory body on cost for milestone decision authorities. The CAIG estimates that supporting milestone decisions include costs for research and development, prime hardware and its major subcomponents, procurement, initial spares, military construction, and all operations and support—regardless of funding source or management control. The CAIG is to provide its assessments in a formal report addressed to milestone decision authorities. In addition to describing the cost estimate, the CAIG report is to include a quantitative assessment of the associated risks. The risks should include the validity of program assumptions, such as the reasonableness of program schedules and technical uncertainty and any errors associated with the cost estimating methods.

The directive describes other CAIG responsibilities, including reporting on the reasonableness of unit costs for programs breaching specific cost thresholds, the validity of costs in acquisition program baselines, and independent assessments of the Defense Acquisition Executive Summary program costs and giving guidance on preparing cost estimates, sponsoring cost research, establishing standard definitions of cost terms, and developing and implementing policy to collect, store, and exchange information on how to improve cost estimating and data.

Guidance

1992: CAIG's *Operating and Support Cost-Estimating Guide*

The 1992 Operating and Support Cost-Estimating Guide, prepared by the Cost Analysis Improvement Group in the Office of the Secretary, is intended to help DOD components prepare, document, and present operating and support cost estimates to the CAIG. It discusses the requirements for the cost estimates, provides instructions for developing them, and presents standard cost element structures and definitions for specific categories of weapon systems. Documentation and presentation requirements are provided to help prepare for CAIG reviews. The guide's primary objective is to achieve consistent, well-documented operating and support cost estimates that an independent party can replicate and verify.

1992: DOD's *Cost Analysis Guidance and Procedures*

DOD's 1992 Directive 5000.4-M, *Cost Analysis Guidance and Procedures*, is a manual for preparing the Cost Analysis Requirements Document, which the program office is to develop, describing the program in enough detail for cost estimators to develop an LCCE. The manual contains information on preparing and presenting LCCEs to the CAIG, including the scope of the estimate and the analytical methods to be used. It defines seven high-level cost terms—development cost, flyaway sailaway rollaway cost, weapons system cost, procurement cost, program acquisition cost, operating and support cost, and life cycle cost—and how they relate to WBS elements and appropriations.

2003: DOD's *Program Manager's Guide to the Integrated Baseline Review Process*

DOD developed the April 2003 *Program Manager's Guide to the Integrated Baseline Review Process* to improve the consistency of the IBR process. The intent was to ensure that the IBR would provide program managers with an understanding of the risks involved with a contractor's performance plans and corresponding EVM systems. Since DOD's acquisition policy requires IBRs on contracts with EVM requirements, the guide identifies the purpose of the IBR process and stresses the need for the process to continue even after the IBR has been conducted. Program managers are strongly encouraged to follow this guidance for training in, preparing, and conducting IBRs.

2004: *NDIA PMSC Surveillance Guide*

The *NDIA PMSC Surveillance Guide*—the short title of the 2004 edition of this document—is intended for the use of government and contractor communities in determining whether EVM systems are being used to effectively manage program cost, schedule, and technical performance. The guide gives an overview of what EVM system surveillance entails, including ensuring that company processes and procedures are followed to satisfy the ANSI/EIA 748-A Standard. It discusses the activities in proper system surveillance, including organization, planning, execution, results, management control, and corrective action. It provides a standard industry surveillance approach to ensuring a common understanding of expectations and the use of a uniform process.

2005: NDIA PMSC EVM Systems Intent Guide

The 2005 *Earned Value Management Systems Intent Guide*, issued by NDIA and its Program Management Systems Committee, is intended for the use of government analysts and contractors, wherever ANSI/EIA Standard 748 is required. The guide defines the management value and intent for each of the standard's guidelines and lists the attributes and objective evidence that can be used to verify compliance with a given guideline. The objective of compliance is to demonstrate that a contractor has thought through each guideline and can describe how its business process complies with it. A customer, independent reviewer, or auditor can use the intent, typical attributes, and objective evidence of typical outputs that the guide describes as the basis for verifying compliance. The guide's five sections are (1) organization; (2) planning, scheduling, and budgeting; (3) accounting considerations; (4) analysis and management reports; and (5) revisions and data maintenance. It recommends that

1. contract or business processes and system documentation be mapped and verified against the guideline's intent, typical attributes, and objective evidence of typical outputs described in the document by the process owner;
2. someone independent of the documenting party verify the compliance assessment;
3. the verifier be versed in ANSI/EIA 748 EVM system guidelines;
4. the customer recognize this method as being applicable and meaningful to compliance assessment verification; and
5. the customer consider past acceptance of compliance with ANSI/EIA 748 EVM system guidelines, business organization application policy, and surveillance activity in management decisions to perform a compliance assessment.[7]

2006: DOD *Earned Value Management Implementation Guide*

DCMA issued the *Department of Defense Earned Value Management Implementation Guide* in 2006 to serve as the central EVM guidance during implementation and surveillance of EVM systems in compliance with DOD guidelines. The guide has two parts. The first contains basic EVM information,

[7] *NDIA PMSC EVM Systems Intent Guide*, © 2004–2005 National Defense Industrial Association (NDIA) Program Management Systems Committee (PMSC), ANSI/EIA-748-A Standard for Earned Value Management Systems Intent Guide (January 2005 edition).

describes an EVM system's objectives, and provides guidance for interpreting EVM guidelines as they apply to government contracts. The second part describes procedures and processes government staff must follow in evaluating the implementation of EVM systems. It also provides guidance on tailoring the guidelines, analyzing EVM performance, determining the effectiveness of the baseline and its maintenance, and performing other activities that must be followed after contracts have been awarded.

2006: NDIA *System Acceptance Guide*

NDIA's Program Management Systems Committee's working draft of its EVM *System Acceptance Guide* was released for comment in November 2006. The guide defines a process in which a government or industry owner of an EVM system that has a first-time requirement to comply with the ANSI/EIA 748-A standard can

1. understand the need for and effectively design the system,
2. implement the system on the acquiring acquisition,
3. evaluate its compliance and implementation,
4. prepare and provide documentation that substantiates evaluation and implementation, and
5. receive approval and documentation that satisfies current and future requirements for the system's approval.[8]

2007: ANSI/EIA 748-B

ANSI/EIA 748-B is an update of ANSI-EIA-748A. This document provides basic guidelines for companies to use in establishing and applying an integrated EVM system. The guidelines are expressed in fundamental terms and provide flexibility for its usage. The guidelines are grouped into five major categories.

They incorporate best business practices to provide strong benefits for program or enterprise planning and control. The processes include integrating program scope, schedule, and cost objectives, establishing a baseline plan for accomplishing program objectives, and using earned value techniques for performance measurement during the execution of a program. The system provides a sound basis for identifying problems, taking corrective actions, and managing replanning as required.

The guidelines in this document are purposely high level and goal oriented, since they are intended to state the qualities and operational considerations of an integrated management system using earned value analysis methods without mandating detailed system characteristics. Different organizations must have the flexibility to establish and apply a management system that suits their management style and business environment. The system must, first and foremost, meet the organization's needs and good business practices.

2007: NDIA Systems Application Guide

NDIA's Program Management Systems Committee's working draft of its EVM *Systems Application Guide* was published in March 2007. It describes for all organizations implementing the ANSI/EIA 748-A

[8] *NDIA System Acceptance Guide*, © 2004–2005 National Defense Industrial Association (NDIA) Program Management Systems Committee (PMSC), NDIA PMSC Earned Value Management System Acceptance Guide (November 2006 Released Working Draft).

standard, EVM systems (Current Version), the importance of planning the EVM application through all phases of the acquisition life cycle. It elaborates on the performance-based management requirements in OMB's Capital Programming Guide. The *Systems Application Guide* also provides the context for the application of EVM within a federal agency's acquisition life cycle, along with government acquisition terminology.[9]

[9] *NDIA System Application Guide*, © 2007 National Defense Industrial Association (NDIA) Program Management Systems Committee (PMSC), Earned Value Management Systems Application Guide (March 2007 edition).

DATA COLLECTION INSTRUMENT

Job title____ **Job code**______________

Explain the job, identify the requester, and provide any other relevant information.

DATA REQUEST. Please provide copies of the following:

- ☐ 1. Program life-cycle cost estimates and supporting documentation, showing the basis of the estimates (methodology, data sources, risk simulation inputs and results, software cost model inputs and results, etc.)
- ☐ 2. Program management review briefings from the past year's budget documentation, including projected budget and OMB 300 reports.
- ☐ 3. The program's contract.
- ☐ 4. A short contract history, with a description of contract line item numbers, contract number and type, award date, and performance period and a summary of significant modifications (with cost and description).
- ☐ 5. Award fee determination (or incentive) letters and any presentations by the contractor regarding award fee determination (e.g., self-evaluations).
- ☐ 6. Price negotiation memos, also known as business clearance letters.
- ☐ 7. Independent cost estimate briefings and supporting documentation.
- ☐ 8. Nunn-McCurdy unit cost breach program reporting and certification documentation, if applicable.
- ☐ 9. Work breakdown structure (WBS) or cost element structure (CES), with dictionary.
- ☐ 10. The latest approved technical baseline description (TBD), also knows as cost analysis requirements description (CARD) in DOD and cost analysis data requirement CADRe at NASA.
- ☐ 11. Current acquisition program baseline.
- ☐ 12. Selected acquisition reports (SAR), if applicable.
- ☐ 13. If DOD, cost and software data reporting (CSDR) or contract critical design review (CCDR) if NASA.
- ☐ 14. Technology readiness assessments, if applicable.
- ☐ 15. Design review reports, preliminary and critical.
- ☐ 16. The acquisition decision memorandum.
- ☐ 17. EVM contract performance reports (CPR), Formats 1-5, for the past 12 months, year-end for all prior years and monthly thereafter during the audit - preferably electronic.
- ☐ 18. All integrated baseline review (IBR) reports.
- ☐ 19. EVM surveillance reports for the past 12 months and a standing request for monthly reports during the audit.
- ☐ 20. The integrated mater schedule (IMS) in its native software format (e.g. *mpp).
- ☐ 21. The integrated master plan (IMP).

CONTRACT QUESTIONS. Please answer the following questions:

1. Break down the program's budget by contract, government in-house and other costs. What percent of the program's budget do the prime contract, major subcontracts, and government costs, etc., subsume? Identify the quantities of the system to be procured, including planned options and foreign military sales, if applicable.
2. Discuss any major contract modifications and how long it took to make the changes final.
3. Discuss the award fee structure, if applicable. Does the programs use cost performance as a basis for determining award fee? Are contract performance report (CPR) data used? If not used, what is examined to determine award fees?
4. Describe any applicable teaming arrangements.

PROGRAM MANAGEMENT AND COST. Please answer the following questions:

1. Who was responsible for developing the program's life cycle cost estimate? If a support contractor prepared the estimates, what requirements and guidelines were provided to the support contractor regarding the development of the estimate? What qualifications and experience do the cost analysts have? Was the estimate prepared by a centralized cost team outside of the program office? What types of cost data are available to the cost team? Are centralized databases and experts available to the cost team to support the development of the estimate?
2. How often does the program present program management review briefings? How are decisions made and documented?
3. What are the program's current risks drivers and associated rankings-high, medium, low? Please describe the effect of each risk. Is there a risk mitigation plan? If so, please describe it.
4. Describe significant cost and schedule drivers. Are there corrective actions plans to address them?
5. Has an independent cost estimate (ICE) been performed on the program's life-cycle costs? If so, how much higher or lower was the ICE? How were the differences between the ICE and the program cost estimate reconciled? Who was briefed on the ICE?
6. Have any Monte Carlo simulations been run to determine the risk level associated with cost estimates? What were the results and how did they influence program decision regarding risk and funding?
7. How does the program procure equipment furnished by the government? Are there separate contracts for such items? If so, what is the value? How is such equipment accounted for in the program's cost estimate?
8. Who is responsible for absorbing cost overruns associated with equipment furnished by the government - the program or the program developing the item?
9. Please describe the program's software requirements. How was the effort estimated in regard to size requirements and productivity rates? Were any software cost models used? What were the associated inputs?
10. Please discuss any effects inflation has had on the program and whether inflation has played a role in cost overruns.

DATA COLLECTION INSTRUMENT: DATA REQUEST RATIONALE

The items in this appendix are keyed to the "Data Request" items in appendix VI.

1. Program life-cycle cost estimates and supporting documentation, showing the basis of the estimates (methodology, data sources, risk simulation inputs and results, software cost model inputs and results, etc.).

   Rationale: Only by assessing the estimate's underlying data and methodology can the auditor determine its quality. This information will answer important questions such as, How applicable are the data? Were the data normalized correctly? What method was used? What statistics were generated?

2. Program management review briefings from the past 2 years' budget documentation, including budget and OMB 300 reports.

   Rationale: This information tells the auditor what senior management was told and when the presentations were made—what problems were revealed, what alternative actions were discussed. Budget documentation assures the auditor that agencies are properly employing capital programming to integrate the planning, acquisition, and management of capital assets into the budget decision-making process. Agencies are required to establish cost, schedule, and measurable performance goals for all major acquisition programs and should achieve, on average, 90 percent of those goals.

3. The program's contract.

   Rationale: This tells the auditor what the contractor was required to deliver at a given time. It also provides price or cost information, including the negotiated price or cost, as well as the type of contract (such as fixed-price, cost-plus-fixed-fee, cost-plus-award, or incentive fee).

4. A short contract history, with a description of contract line item numbers, contract number and type, award date, and performance period and a summary of significant contract modifications (with cost and description).

   Rationale: This provides important context for the current contract. Only with a detailed knowledge of program history can the auditor effectively determine the program's present status and future prospects.

5. Award fee determination (or incentive) letters and any contractor presentations regarding award fee determination (e.g., self-evaluations).

   Rationale: This obviously applies only to contracts with award (or incentive) fees. For such contracts, the auditor needs to know the basis on which fees were awarded, whether it was strictly followed, and reasons for any deviations.

6. Price negotiation memos, also known as business clearance letters.

   Rationale: The price negotiation memorandum summarizes for the auditor the contract price negotiations, including documentation of fair and reasonable pricing.

7. Independent cost estimate briefings and supporting documentation.

   Rationale: This information is important because, first, it provides the auditor with the data needed to assess the quality of the LCCE and, second, it reveals what information was independently briefed to senior management about the quality of the baseline cost estimate.

8. Nunn-McCurdy unit cost breach program reporting and certification documentation, if applicable.

   Rationale: This will not apply at all to non-DOD programs and applies only to certain DOD programs. For DOD programs (major defense acquisition programs), it is important that the auditor know the nature of the breach, when it occurred, when it was reported, and what action was taken.

9. Work breakdown structure (WBS) or cost element structure (CES), with dictionary.

   Rationale: The WBS and CES and associated dictionary represent a hierarchy of product-oriented elements that provide a detailed understanding of what the contractor was required to develop and produce.

10. The latest approved technical baseline description, also known as cost analysis requirements document in DOD and CADRe at NASA.

    Rationale: The technical baseline description provides the auditor with the program's technical and program baseline. Besides defining the system, it provides complete information on testing plans, procurement schedules, acquisition strategy, and logistics plans. This is the document on which cost analysts base their estimates and is therefore essential to the auditor's understanding of the program.

11. Current acquisition program baseline.

    Rationale: The acquisition program baseline documents program goals before program initiation. The program manager derives the acquisition program baseline from the users' performance requirements, schedule requirements, and best estimates of total program cost consistent with projected funding. The baseline should contain only the parameters that, if thresholds are not met, will require the milestone decision authority to reevaluate the program and consider alternative program concepts or design approaches,

12. Selected acquisition reports (SAR), if applicable

    Rationale: For major defense acquisition programs, the SAR provides the history and current status of total program cost, schedule, and performance, as well as program unit cost and unit cost breach information. For joint programs, SARs provide information by participant. Each SAR includes a full, life-cycle cost analysis for the reporting program; an analysis of each of its evolutionary increments, as available; and analysis of its antecedent program, if applicable.

13. If DOD, cost and software data reporting, or contractor critical design review, if NASA.

    Rationale: Contractor critical design reviews provide the auditor with actual contractor development or procurement costs by WBS or CES. Especially useful is the fact that recurring and nonrecurring costs are differentiated.

14. Technology readiness assessment, if applicable.

Rationale: A technology readiness assessment provides an evaluation of a system's technological maturity by major WBS elements. It is extremely useful in countering technological overoptimism. For elements with unacceptable assessments, the auditor can then assess whether satisfactory mitigation plans have been developed to ensure that acceptable maturity will be achieved before milestone decision dates.

15. Design review reports, preliminary and critical.

    Rationale: Design review reports provide the technical information needed to ensure that the system is satisfactorily meeting its requirements. The preliminary design review ensures that the system can proceed into detailed design, while meeting its stated performance requirements within cost (program budget), schedule (program schedule), risk, and other system constraints. The critical design review ensures that the system can proceed into system fabrication, demonstration, and test, while meeting its stated performance requirements within cost, schedule, risk, and other system constraints. It also assesses the system's final design as captured in product specifications for each configuration item in the system (product baseline) and ensures that each product in the product baseline has been captured in the detailed design documentation.

16. The acquisition decision memorandum.

    Rationale: This provides the documented rationale for the milestone decision authority's (or investment review board's) approving a program to advance to the next stage of the acquisition process.

17. EVM contract performance reports, Formats 1–5, for the past 12 months, year-end for all prior years, and monthly thereafter during the audit—preferably electronic.

    Rationale: CPRs are management reports essential to an auditor's ability to develop a comprehensive analysis. They are timely, reliable summary data from which to assess current and projected contract performance. The auditor can use them to reasonably project future program performance. Format 1 provides data to measure cost and schedule performance by product-oriented WBS elements—i.e., hardware, software, and services the government is buying. Format 2 provides the same data by the contractor's organization (functional or integrated product team structure). Format 3 provides the budget baseline plan against which performance is measured. Format 4 provides staffing forecasts for correlation with the budget plan and cost estimates. Format 5 is a narrative report explaining significant cost and schedule variances and other identified contract problems and topics.

18. All integrated baseline review reports.

    Rationale: An IBR's purpose is to verify the technical content and realism of the interrelated performance budgets, resources, and schedules. It helps the auditor understand the inherent risks in offerors' or contractors' performance plans and the underlying management control systems, and it should contain a plan to handle these risks. OMB policy requires that IBRs be initiated as early as practicable.

19. EVM surveillance reports for the past 12 months and a standing request for monthly CPRs during the audit.

    Rationale: EVM surveillance reports assure the auditor that contractors are using effective internal cost and schedule control systems that provide contractor and government managers with timely and auditable data to effectively monitor programs, provide timely indications of actual and potential problems, meet requirements, and control contract performance. Surveillance ensures that a supplier's EVM implementation of processes and procedures is being maintained over time and on all applicable programs and is in compliance with the 32 EVM guidelines.

20. The integrated master schedule (IMS).

    Rationale: The IMS contains the detailed tasks or work packages necessary to ensure program execution. The auditor can use the IMS to verify the attainability of contract objectives, evaluate progress toward program objectives, and integrate the program schedule activities with the program components.

21. The integrated master plan.

    Rationale: The integrated master plan provides an event-based hierarchy of program events, with each event supported by accomplishments and each accomplishment associated with specific criteria to be satisfied for its completion. The plan is normally part of the contract and is therefore contractually binding.

SEI CHECKLIST

Checklists and Criteria contains a checklist for evaluating an organization's software and is available at .

Checklists and Criteria for Evaluating the Cost and Schedule Estimating Capabilities of Software Organizations

Robert E. Park

Approved for public release.
Distribution unlimited.

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Review and Approval

This report has been reviewed and is approved for publication.

FOR THE COMMANDER

SIGNATURE ON FILE

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EXAMPLES OF WORK BREAKDOWN STRUCTURES

DOD developed *Work Breakdown Structures for Defense Materiel Items* in 1968 to provide a framework and instructions for developing a WBS.[10] Although it now serves only as guidance, the handbook remains an excellent resource for developing a WBS for government and private industry. It outlines the contents and components that should be considered for aircraft, electronic and automated software systems, missiles, ordnance, ships, space systems, surface vehicle systems, and unmanned air vehicle systems. It gives examples and definitions, particularly in its appendixes A–I, which constitute the bulk of the document and on which tables 51, 52, and 54–59 are based. These examples of WBS were valid at the time of publication. It is advised that the source of the WBS be checked before it is used to see if any updates have been made. Table 53 presents a common WBS for software development based on NASA research conducted by the Jet Propulsion Laboratory at the California Institute of Technology. Table 60 shows the Department of Energy's Project WBS. Table 61 is an example of the General Services Administration's construction WBS, and table 62 is an Automated Information System: Enterprise Resource Planning Program Level Work Breakdown Structure. Tables 63–67 are from the Project Management Institute's *Practice Standard for Work Breakdown Structures*, second edition, published in October 2006. Table 68 is an example of a major construction renovation project. Table 69 includes IT infrastructure and IT services only. Automated information system configuration, customization, development, and maintenance are covered in chapter 8. Table 70 is an example from the CSI MasterformatTM 2004 Structure.

Table 51: Aircraft System Work Breakdown Structure

Level 2 element		Level 3 element	
1.1	Air vehicle	1.1.1	Airframe
		1.1.2	Propulsion
		1.1.3	Air vehicle applications software
		1.1.4	Air vehicle system software
		1.1.5	Communications/identification
		1.1.6	Navigation/guidance
		1.1.7	Central computer
		1.1.8	Fire control
		1.1.9	Data display and controls
		1.1.10	Survivability
		1.1.11	Reconnaissance
		1.1.12	Automatic flight control
		1.1.13	Central integrated checkout
		1.1.14	Antisubmarine warfare
		1.1.15	Armament
		1.1.16	Weapons delivery
		1.1.17	Auxiliary equipment
		1.1.18	Crew station

[10] DOD, *Department of Defense Handbook: Work Breakdown Structures for Defense Materiel Items*, MIL-HDBK-881A (Washington, D.C.: OUSD (AT&L), July 3, 2005).

Level 2 element		Level 3 element	
1.2	Systems engineering/program management		
1.3	System test and evaluation	1.3.1	Development test and evaluation
		1.3.2	Operational test and evaluation
		1.3.3	Mock-ups/system integration laboratories
		1.3.4	Test and evaluation support
		1.3.5	Test facilities
1.4	Training	1.4.1	Equipment
		1.4.2	Services
		1.4.3	Facilities
1.5	Data	1.5.1	Technical publications
		1.5.2	Engineering data
		1.5.3	Management data
		1.5.4	Support data
		1.5.5	Data depository
1.6	Peculiar support equipment	1.6.1	Test and measurement equipment
		1.6.2	Support and handling equipment
1.7	Common support equipment	1.7.1	Test and measurement equipment
		1.7.2	Support and handling equipment
1.8	Operational/site activation	1.8.1	System assembly, installation, checkout
		1.8.2	Contractor technical support
		1.8.3	Site construction
		1.8.4	Site/ship/vehicle conversion
1.9	Industrial facilities	1.9.1	Construction/conversion/expansion
		1.9.2	Equipment acquisition or modernization
		1.9.3	Maintenance (industrial facilities)
1.10	Initial spares and repair parts		

Source: DOD, *Department of Defense Handbook: Work Breakdown Structures for Defense Materiel Items*, MIL-HDBK-881A (Washington, D.C.: OUSD (AT&L), July 3, 2005), app. A.

Table 52: Electronic/Automated Software System Work Breakdown Structure

Level 2 element		Level 3 element	
1.1	Prime mission product	1.1.1	Subsystem 1...n (specify names)
		1.1.2	Prime mission product applications software
		1.1.3	Prime mission product system software
		1.1.4	Integration, assembly, test, checkout
1.2	Platform integration		
1.3	Systems engineering/program management		

Level 2 element		Level 3 element	
1.4	System test and evaluation	1.4.1	Development test and evaluation
		1.4.2	Operational test and evaluation
		1.4.3	Mock-ups/system integration labs
		1.4.4	Test and evaluation support
		1.4.5	Test facilities
1.5	Training	1.5.1	Equipment
		1.5.2	Services
		1.5.3	Facilities
1.6	Data	1.6.1	Technical publications
		1.6.2	Engineering data
		1.6.3	Management data
		1.6.4	Support data
		1.6.5	Data depository
1.7	Peculiar support equipment	1.7.1	Test and measurement equipment
		1.7.2	Support and handling equipment
1.8	Common support equipment	1.8.1	Test and measurement equipment
		1.8.2	Support and handling equipment
1.9	Operational/site activation		
1.10	System assembly, installation, checkout	1.10.1	Contractor technical support
		1.10.2	Site construction
		1.10.3	Site/ship/vehicle conversion
1.11	Industrial facilities	1.11.1	Construction/conversion/expansion
		1.11.2	Equipment acquisition/modernization
		1.11.3	Maintenance (industrial facilities)
1.12	Initial spares and repair parts		

Source: DOD, *Department of Defense Handbook: Work Breakdown Structures for Defense Materiel Items*, MIL-HDBK-881A (Washington, D.C.: OUSD (AT&L), July 3, 2005), app. B.

Table 53: Ground Software Work Breakdown Structure

Level 2 element		Level 3 element	
1.1	Software management	1.1.1	General management/control activities
		1.1.2	Software risk management
		1.1.3	Arrange and conduct reviews
		1.1.4	General documentation support
		1.1.5	Secretarial/clerical
		1.1.6	Administrative support
		1.1.7	Information technology/computer support
		1.1.8	Other expenses

Level 2 element		Level 3 element	
1.2	Software systems engineering	1.2.1	Functional design document
		1.2.2	Requirements specification
		1.2.3	Software interface documents
		1.2.4	Configuration management
		1.2.5	Procurement
		1.2.6	User manuals
		1.2.7	Ops concept
		1.2.8	Concept document
		1.2.9	Trade-off studies
		1.2.10	Review preparation
1.3	Software function i (i = 1,…,n)	1.3.1	Management and control activities
		1.3.2	High-level design
		1.3.3	Detailed design, code, and unit test
		1.3.4	Data
1.4	Software development test bed	1.4.1	Test engineering support
		1.4.2	Test bed development
		1.4.3	Simulators and test environment
		1.4.4	Test bed support software
		1.4.5	Test bed computers
1.5	Software integration and test	1.5.1	Subsystem software integration test plan
		1.5.2	Software test plans and procedures
		1.5.3	Support subsystem integration and test
		1.5.4	System integration and test
1.6	Software quality assurance	1.6.1	Software product assurance plan
		1.6.2	Software assurance activities
1.7	Delivery and transfer to operations	1.7.1	End user training

Source: NASA.

Table 54: Missile System Work Breakdown Structure

Level 2 element		Level 3 element	
1.1	Air vehicle	1.1.1	Propulsion (stages 1...n,]
		1.1.2	Payload
		1.1.3	Airframe
		1.1.4	Reentry system
		1.1.5	Post boost system
		1.1.6	Guidance and control
		1.1.7	Ordnance initiation set
		1.1.8	Airborne test equipment
		1.1.9	Airborne training equipment
		1.1.10	Auxiliary equipment
		1.1.11	Integration, assembly, test, checkout

Level 2 element		Level 3 element	
1.2	Command and launch	1.2.1	Surveillance, identification, tracking
		1.2.2	Sensors
		1.2.3	Launch and guidance control
		1.2.4	Communications
		1.2.5	Command/launch applications software
		1.2.6	Command and launch system software
		1.2.7	Launcher equipment
		1.2.8	Auxiliary equipment
		1.2.9	Booster adapter
1.3	Systems engineering/program management	1.3.1	System test and evaluation
		1.3.2	Development test and evaluation
		1.3.3	Operational test and evaluation
		1.3.4	Mock-ups/system integration laboratories
		1.3.5	Test and evaluation support
		1.3.6	Test facilities
1.4	Training	1.4.1	Equipment
		1.4.2	Services
		1.4.3	Facilities
1.5	Data	1.5.1	Technical publications
		1.5.2	Engineering data
		1.5.3	Management data
		1.5.4	Support data
		1.5.5	Data depository
1.6	Peculiar support equipment	1.6.1	Test and measurement equipment
		1.6.2	Support and handling equipment
1.7	Common support equipment	1.7.1	Test and measurement equipment
		1.7.2	Support and handling equipment
1.8	Operational/site activation		
1.9	System assembly, installation, checkout	1.9.1	Contractor technical support
		1.9.2	Site construction
		1.9.3	Site/ship/vehicle conversion
1.10	Industrial facilities	1.10.1	Construction/conversion/expansion
		1.10.2	Equipment acquisition/modernization
		1.10.3	Maintenance (industrial facilities)
1.11	Initial spares and repair parts		

Source: DOD, *Department of Defense Handbook: Work Breakdown Structures for Defense Materiel Items*, MIL-HDBK-881A (Washington, D.C.: OUSD (AT&L), July 3, 2005), app. C.

Table 55: Ordnance System Work Breakdown Structure

Level 2 element		Level 3 element	
1.1	Complete round	1.1.1	Structure
		1.1.2	Payload
		1.1.3	Guidance and control
		1.1.4	Fuze
		1.1.5	Safety/arm
		1.1.6	Propulsion
		1.1.7	Integration, assembly, test, checkout
1.2	Launch system	1.2.1	Launcher
		1.2.2	Carriage
		1.2.3	Fire control
		1.2.4	Ready magazine
		1.2.5	Adapter kits
		1.2.6	Integration, assembly, test, checkout
1.3	Systems engineering/program management		
1.4	System test and evaluation	1.4.1	Development test and evaluation
		1.4.2	Operational test and evaluation
		1.4.3	Mock-ups/system integration laboratories
		1.4.4	Test and evaluation support
		1.4.5	Test facilities
1.5	Training	1.5.1	Equipment
		1.5.2	Services
		1.5.3	Facilities
1.6	Data	1.6.1	Technical publications
		1.6.2	Engineering data
		1.6.3	Management data
		1.6.4	Support data
		1.6.5	Data depository
1.7	Peculiar support equipment	1.7.1	Test and measurement equipment
		1.7.2	Support and handling equipment
1.8	Common support equipment	1.8.1	Test and measurement equipment
		1.8.2	Support and handling equipment
1.9	Operational/site activation		
1.10	System assembly, installation, checkout	1.10.1	Contractor technical support
		1.10.2	Site construction
		1.10.3	Site/ship/vehicle conversion
1.11	Industrial facilities	1.11.1	Construction/conversion/expansion
		1.11.2	Equipment acquisition/modernization
		1.11.3	Maintenance (industrial facilities)
1.12	Initial spares and repair parts		

Source: DOD, *Department of Defense Handbook: Work Breakdown Structures for Defense Materiel Items*, MIL-HDBK-881A (Washington, D.C.: OUSD (AT&L), July 3, 2005), app. D.

Table 56: Sea System Work Breakdown Structure

Level 2 element		Level 3 element	
1.1	Ship	1.1.1	Hull structure
		1.1.2	Propulsion plant
		1.1.3	Electric plant
		1.1.4	Command/communication/surveillance
		1.1.5	Auxiliary systems
		1.1.6	Outfit and furnishings
		1.1.7	Armament
		1.1.8	Total ship integration/engineering
		1.1.9	Ship assembly and support services
1.2	Systems engineering/program management		
1.3	System test and evaluation	1.3.1	Development test and evaluation
		1.3.2	Operational test and evaluation
		1.3.3	Mock-ups/system integration laboratories
		1.3.4	Test and evaluation support
		1.3.5	Test facilities
1.4	Training	1.4.1	Equipment
		1.4.2	Services
		1.4.3	Facilities
1.5	Data	1.5.1	Technical publications
		1.5.2	Engineering data
		1.5.3	Management data
		1.5.4	Support data
		1.5.5	Data depository
1.6	Peculiar support equipment	1.6.1	Test and measurement equipment
		1.6.2	Support and handling equipment
1.7	Common support equipment	1.7.1	Test and measurement equipment
		1.7.2	Support and handling equipment
1.8	Operational/site activation	1.8.1	System assembly, installation, checkout
		1.8.2	Contractor technical support
		1.8.3	Site construction
		1.8.4	Site/ship/vehicle conversion
1.9	Industrial facilities	1.9.1	Construction/conversion/expansion
		1.9.2	Equipment acquisition/modernization
		1.9.3	Maintenance (industrial facilities)
1.10	Initial spares and repair parts		

Source: DOD, *Department of Defense Handbook: Work Breakdown Structures for Defense Materiel Items*, MIL-HDBK-881A (Washington, D.C.: OUSD (AT&L), July 3, 2005), app. E.

Table 57: Space System Work Breakdown Structure

Level 2 element		Level 3 element	
1.1	Systems engineering, integration, and test; program management; and other common elements		
1.2	Space vehicle (1…n as required)	1.2.1	Systems engineering, integration, and test; program management; and other common elements
		1.2.2	Spacecraft bus
		1.2.3	Communication/payload
		1.2.4	Booster adapter
		1.2.5	Space vehicle storage
		1.2.6	Launch systems integration
		1.2.7	Launch operations & mission support
1.3	Ground (1…n as required)	1.3.1	Systems engineering, integration, and test; program management; and other common elements
		1.3.2	Ground terminal subsystems
		1.3.3	Command and control subsystem
		1.3.4	Mission management subsystem
		1.3.5	Data archive/storage subsystem
		1.3.6	Mission data processing subsystem
		1.3.7	Mission data analysis and dissemination subsystem
		1.3.8	Mission infrastructure subsystem
		1.3.9	Collection management subsystem
1.4	Launch vehicle		

Source: DOD, *Department of Defense Handbook: Work Breakdown Structures for Defense Materiel Items*, MIL-HDBK-881A (Washington, D.C.: OUSD (AT&L), July 3, 2005), app. F.

Table 58: Surface Vehicle System Work Breakdown Structure

Level 2 element		Level 3 element	
1.1	Primary vehicle	1.1.1	Hull/frame
		1.1.2	Suspension/steering
		1.1.3	Power package/drive train
		1.1.4	Auxiliary automotive
		1.1.5	Turret assembly
		1.1.6	Fire control
		1.1.7	Armament
		1.1.8	Body/cab
		1.1.9	Automatic loading
		1.1.10	Automatic/remote piloting
		1.1.11	Nuclear, biological, chemical
		1.1.12	Special equipment
		1.1.13	Navigation
		1.1.14	Communications
		1.1.15	Primary vehicle application software
		1.1.16	Primary vehicle system software
		1.1.17	Vetronics
		1.1.18	Integration, assembly, test, checkout
1.2	Secondary vehicle	1.1.1–18	(Same as primary vehicle)
1.3	Systems engineering/program management	1.3.1	System test and evaluation
		1.3.2	Development test and evaluation
		1.3.3	Operational test and evaluation
		1.3.4	Mock-ups/system integration lab
		1.3.5	Test and evaluation support
		1.3.6	Test facilities
1.4	Training	1.4.1	Equipment
		1.4.2	Services
		1.4.3	Facilities
1.5	Data	1.5.1	Technical publications
		1.5.2	Engineering data
		1.5.3	Management data
		1.5.4	Support data
		1.5.5	Data depository
1.6	Peculiar support equipment	1.6.1	Test and measurement equipment
		1.6.2	Support and handling equipment
1.7	Common support equipment	1.7.1	Test and measurement equipment
		1.7.2	Support and handling equipment

Level 2 element		Level 3 element	
1.8	Operational/site activation	1.8.1	System assembly, installation, checkout
		1.8.2	Contractor technical support
		1.8.3	Site construction
		1.8.4	Site/ship/vehicle conversion
1.9	Industrial facilities	1.9.1	Construction/conversion/expansion
		1.9.2	Equipment acquisition / modernization
		1.9.3	Maintenance (industrial facilities)
1.10	Initial spares and repair parts		

Source: DOD, *Department of Defense Handbook: Work Breakdown Structures for Defense Materiel Items*, MIL-HDBK-881A (Washington, D.C.: OUSD (AT&L), July 3, 2005), app. G.

Table 59: Unmanned Air Vehicle System Work Breakdown Structure

Level 2 element		Level 3 element	
1.1	Air vehicle	1.1.1	Airframe
		1.1.2	Propulsion
		1.1.3	Communications/identification
		1.1.4	Navigation/guidance
		1.1.5	Central computer
		1.1.6	Auxiliary equipment
		1.1.7	Air vehicle application software
		1.1.8	Air vehicle system software
		1.1.9	Integration, assembly, test, checkout
1.2	Payload (1...n)	1.2.1	Survivability
		1.2.2	Reconnaissance
		1.2.3	Electronic warfare
		1.2.4	Armament
		1.2.5	Weapons delivery
		1.2.6	Payload application software
		1.2.7	Payload system software
		1.2.8	Integration, assembly, test, checkout
1.3	Ground segment	1.3.1	Ground control systems
		1.3.2	Command and control subsystem
		1.3.3	Launch and recovery equipment
		1.3.4	Transport vehicles
		1.3.5	Ground segment application software
		1.3.6	Ground segment system software
		1.3.7	Integration, assembly, test, checkout
1.4	System integration, assembly, test		
1.5	Systems engineering/program management		

Level 2 element		Level 3 element	
1.6	System test and evaluation	1.6.1	Development test and evaluation
		1.6.2	Operational test and evaluation
		1.6.3	Mock-ups/system integration laboratories
		1.6.4	Test and evaluation support
		1.6.5	Test facilities
1.7	Training	1.7.1	Equipment
		1.7.2	Services
		1.7.3	Facilities
1.8	Data	1.8.1	Technical publications
		1.8.2	Engineering data
		1.8.3	Management data
		1.8.4	Support data
		1.8.1	Data depository
1.9	Peculiar support equipment	1.9.1	Test and measurement equipment
		1.9.2	Support and handling equipment
1.10	Common support equipment	1.10.1	Test and measurement equipment
		1.10.2	Support and handling equipment
1.11	Operational/site activation	1.11.1	System assembly, installation, checkout
		1.11.2	Contractor technical support
		1.11.3	Site construction
		1.11.4	Site/ship/vehicle conversion
1.12	Industrial facilities	1.12.1	Construction/conversion/expansion
		1.12.2	Equipment acquisition / modernization
		1.12.3	Maintenance (industrial facilities)
1.13	Initial spares and repair parts		

Source: DOD, *Department of Defense Handbook: Work Breakdown Structures for Defense Materiel Items*, MIL-HDBK-881A (Washington, D.C.: OUSD (AT&L), July 3, 2005), app. H.

Table 60: Department of Energy Project Work Breakdown Structure

Level 2 element		Level 3 element		Level 4 element	
1.1	Fuel processing facility	1.1.1	Conceptual design	1.1.1.1	Conceptual design
				1.1.1.2	Criteria development & conceptual design reviews
		1.1.2	Design	1.1.2.1	Definitive design
				1.1.2.2	CADD consultant
				1.1.2.3	Engineering support during construction
		1.1.3	Government-furnished equipment	1.1.3.1	Construction preparation
				1.1.3.2	Building
				1.1.3.3	Process & service systems & equipment
				1.1.3.4	Quality assurance
		1.1.4	Construction	1.1.4.1	Construction preparation
				1.1.4.2	Building
				1.1.4.3	Process & service systems & equipment
				1.1.4.4	Construction inspection
				1.1.4.5	Construction management
				1.1.4.6	Construction Services
				1.1.4.7	Constructability Reviews
		1.1.5	Project administration	1.1.5.1	Project control
				1.1.5.2	Records management
				1.1.5.3	Support services
				1.1.5.4	Engineering
				1.1.5.5	Independent construction cost estimate
		1.1.6	Systems development	1.1.6.1	Process development
				1.1.6.2	Design support
				1.1.6.3	Plant liaison
				1.1.6.4	Computer/control system development
		1.1.7	Startup	1.1.7.1	SO test preparation
				1.1.7.2	SO test performance
				1.1.7.3	Manuals
				1.1.7.4	Integrated testing
				1.1.7.5	Cold run
				1.1.7.6	SO test resources
				1.1.7.7	Deleted
				1.1.7.8	Preventative maintenance
		1.1.8	Safety/ environmental	1.1.8.1	Environmental assessment
				1.1.8.2	PSD document
				1.1.8.3	Safety analysis report
				1.1.8.4	Probabilistic risk assessment
				1.1.8.5	Document coordination
				1.1.8.6	RAM study
				1.1.8.7	Hazardous waste

Level 2 element		Level 3 element		Level 4 element
1.2	Liquid effluent treatment & disposal	1.2.1	Construction	
		1.2.2	Government-furnished material	
		1.2.3	Construction inspection	
		1.2.4	Project administration	
		1.2.5	Design	

Source: Department of Energy, *Work Breakdown Structures for Defense Materiel Items* (Washington, D.C.: June 2003).

Table 61: General Services Administration Construction Work Breakdown Structure

Level 2 element		Level 3 element	
1.1	Superstructure	1.1.1	Foundations
		1.1.2	Basement construction
1.2	Exterior enclosure	1.2.1	Exterior walls
		1.2.2	Exterior glazing & doors
		1.2.3	Roofing
1.3	Interior construction	1.3.1	Partitions, doors & specialties
		1.3.2	Access/platform floors
		1.3.3	Interior finishes
1.4	Conveyance systems	1.4.1	Conveyance systems
		1.4.2	Plumbing
		1.4.3	HVAC
		1.4.4	Fire protection/alarm
		1.4.5	Electrical service distribution & emergency power
		1.4.6	Lighting and branch wiring
		1.4.7	Communications, security & other electrical systems
1.5	Equipment & furnishing	1.5.1	Equipment & furnishings
1.6	Special construction, demolition & abatement	1.6.1	Special construction
		1.6.2	Building demolition & abatement
1.7	Site work	1.7.1	Site work building related
		1.7.2	Other site work project related

Source: General Services Administration, *Project Estimating Requirement* (Washington, D.C.: January 2007).

Table 62: Automated Information System: Enterprise Resource Planning Program Level Work Breakdown Structure

Level 2 element		Level 3 element	
1.1	Configuration, customization, development	1.1.1	Site prototype design and development foundations
		1.1.2	Product application solution basement construction
		1.1.3	System integration &test
		1.1.4	Systems engineering/program management/change management
		1.1.5	System test & evaluation
		1.1.6	Training
		1.1.7	Data
		1.1.8	Reserved
		1.1.9	Reserved
		1.1.10	Reserved
		1.1.11	Industrial facilities
		1.1.12	Initial spares
1.2	Operational/site implementation	1.2.1	Site type 1
		1.2.2	Site type 2; Site type n
		1.2.3	System integration & test
		1.2.4	Systems engineering/program management/change management
		1.2.5	System test & evaluation
		1.2.6	Training
		1.2.7	Data
		1.2.8	Reserved
		1.2.9	Reserved
		1.2.10	Reserved
		1.2.11	Industrial facilities
		1.2.12	Initial spares
1.3	Sustainment	1.3.1	Management
		1.3.2	Sustaining engineering
		1.3.3	COTS software maintenance and renewal
		1.3.4	Custom software maintenance
		1.3.5	Annual operations investment
		1.3.6	Tech refresh
		1.3.7	Recurring training
		1.3.8	Hardware maintenance
		1.3.9	Help desk support
1.4	Systems engineering/ program management/change management	1.4.1	Systems engineering
		1.4.2	Program management
		1.4.3	Change management
1.5	Data		

Source: U.S. Air Force.

Table 63: Environmental Management Work Breakdown Structure

Level 2 element		Level 3 element	
1.1	System design	1.1.1	Initial design
		1.1.2	Client meeting
		1.1.3	Draft design
		1.1.4	Client and regulatory agency meeting
		1.1.5	Final design
1.2	System installation	1.2.1	Facility planning meeting
		1.2.2	Well installation
		1.2.3	Electrical power drop installation
		1.2.4	Blower and piping installation
1.3	Soil permeability test	1.3.1	System operation check
		1.3.2	Soil permeability test
		1.3.3	Test report
1.4	Initial in situ respiration test	1.4.1	In situ respiration test
		1.4.2	Test report
1.5	Long-term bioventing test	1.5.1	Ambient air monitoring
		1.5.2	Operation, maintenance, and monitoring
		1.5.3	Three-month in situ respiration test
		1.5.4	Test report
		1.5.5	Six-month in situ respiration test
		1.5.6	Test report
1.6	Confirmation sampling	1.6.1	Soil boring and sampling
		1.6.2	Data validation
1.7	Report preparation	1.7.1	Predraft report
		1.7.2	Client meeting
		1.7.3	Draft report
		1.7.4	Client and regulatory agency meeting
		1.7.5	Final report
1.8	Project management		

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Table 64: Pharmaceutical Work Breakdown Structure

Level 2 element		Level 3 element	
1.1	Project initiation	1.1.1	Decision to develop business case
		1.1.2	Business case
		1.1.3	Project initiation decision
1.2	Marketing/sales support	1.2.1	Market research program
		1.2.2	Branding program
		1.2.3	Pricing program
		1.2.4	Sales development program
		1.2.5	Other marketing/sales support

Level 2 element		Level 3 element	
1.3	Regulatory support	1.3.1	IND submission
		1.3.2	End of Phase 2 meeting
		1.3.3	BLA/NDA submission
		1.3.4	Postapproval regulatory support program
1.4	Lead identification program	1.4.1	Hypothesis generation
		1.4.2	Assay screening
		1.4.3	Lead optimization
		1.4.4	Other discovery support
1.5	Clinical pharmacology support	1.5.1	Pharmacokinetic studies
		1.5.2	Drug interaction studies
		1.5.3	Renal effect studies
		1.5.4	Hepatic effect studies
		1.5.5	Bioequivalency studies
		1.5.6	Other clinical pharmacology studies
1.6	Preclinical program	1.6.1	Tox/ADME support
		1.6.2	Clinical pharmacology support
1.7	Phase I clinical study program	1.7.1	Pharmacokinetic/pharmacodynamic studies
		1.7.2	Dose ranging studies
		1.7.3	Multiple dose safety studies
1.8	Phase II clinical study program	1.8.1	Multiple dose efficacy studies
		1.8.2	Other clinical studies
1.9	Phase III clinical study program	1.9.1	Pivotal registration studies
		1.9.2	Other clinical studies
1.10	Submission/launch phase	1.10.1	Prelaunch preparation
		1.10.2	Launch
		1.10.3	Post-Launch Support
1.11	Phase/commercialization clinical study program	1.11.1	Investigator-sponsored studies
		1.11.2	Registry studies
1.12	Legal support	1.12.1	Publications
		1.12.2	Patents/intellectual property
		1.12.3	Trademarks
		1.12.4	Other legal support
1.13	Program management support	1.13.1	Program-level project management
		1.13.2	Preclinical project management
		1.13.3	Clinical project management
		1.13.4	CM&C project management
		1.13.5	Other project management support

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Table 65: Process Plant Construction Work Breakdown Structure

Level 2 element		Level 3 element	
1.1	Plant system design	1.1.1	Business requirements
		1.1.2	Process models
1.2	Construction	1.2.1	Site development
		1.2.2	Civil structure
		1.2.3	Thermal systems
		1.2.4	Flow systems
		1.2.5	Storage systems
		1.2.6	Electrical systems
		1.2.7	Mechanical systems
		1.2.8	Instrument and control systems
		1.2.9	Environmental systems
		1.2.10	Temporary structure
		1.2.11	Auxiliary systems
		1.2.12	Safety systems
1.3	Legal and regulatory	1.3.1	Licensing (nongovernment)/permitting (government)
		1.3.2	Environmental impact
		1.3.3	Labor agreements
		1.3.4	Land acquisition
1.4	Testing	1.4.1	System test
		1.4.2	Acceptance test
1.5	Startup		
1.6	Project management		

Source: Project Management Institute: *Practice Standards for Work Breakdown Structures,* Project Management Institute, Inc., (2006).

Table 66: Telecon Work Breakdown Structure

Level 2 element		Level 3 element	
1.1	Concept/feasibility	1.1.1	Concept
		1.1.2	Marketing analysis
		1.1.3	Market plan
		1.1.4	Technical analysis
		1.1.5	Product scope definition
		1.1.6	Prototype
1.2	Requirements	1.2.1	End-user requirements
		1.2.2	Application requirements
		1.2.3	Infrastructure (systems) requirements
		1.2.4	Operations/maintenance requirements
		1.2.5	Service requirements

Level 2 element		Level 3 element	
1.3	Go/no go decision	1.3.1	Prototype review
		1.3.2	Financial review
		1.3.3	Schedule review
		1.3.4	Technical capabilities review
		1.3.5	Financial commitment review
		1.3.6	Go/no-go decision
1.4	Development	1.4.1	End-user systems
		1.4.2	Application
		1.4.3	Infrastructure Systems
		1.4.4	Network
		1.4.5	Operations/maintenance systems
		1.4.6	Service plan
1.5	Testing	1.5.1	Test plans
		1.5.2	Tests
		1.5.3	Results
		1.5.4	Corrective actions
		1.5.5	Retests
		1.5.6	Retest results
1.6	Deployment	1.6.1	Trial in a nonpenalty environment
		1.6.2	First action site
		1.6.3	Deployment
1.7	Life-cycle support	1.7.1	Customer training & education
		1.7.2	Turnover to customer
		1.7.3	Customer acceptance
		1.7.4	Support & maintenance
1.8	Project management		

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Table 67: Software Implementation Project Work Breakdown Structure

Level 2 element		Level 3 element	
1.1	Project management		
1.2	Product requirements	1.2.1	Software requirements
		1.2.2	User documentation
		1.2.3	Training program materials
		1.2.4	Hardware
		1.2.5	Implementation & future support
1.3	Detail software design	1.3.1	Initial software design
		1.3.2	Final software design
		1.3.3	Software design approval

Level 2 element		Level 3 element	
1.4	System construction	1.4.1	Configured software
		1.4.2	Customized user documentation
		1.4.3	Customized training program materials
		1.4.4	Installed hardware
		1.4.5	Implementation & future support
1.5	Test	1.5.1	System test plan
		1.5.2	System test cases
		1.5.3	System test results
		1.5.4	Acceptance test plan
		1.5.5	Acceptance test cases
		1.5.6	Acceptance test results
		1.5.7	Approved user documentation
1.6	Go live		
1.7	Support	1.7.1	Training
		1.7.2	End user support
		1.7.3	Product support

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Table 68: Major Renovation Project Work Breakdown Structure

Level 2 element		Level 3 element	
1.1	Requirements	1.1.1	Requirements
		1.1.2	Planning
		1.1.3	Design
1.2	Construction	1.2.1	Move out
		1.2.2	Entrances
		1.2.3	Preconstruction
		1.2.4	Core and shell
1.3	Tenant fit out	1.3.1	Tenant fit out construction
		1.3.2	Security
		1.3.3	Furniture, fixture, equipment
		1.3.4	Move-in
		1.3.5	Commissioning
1.4	Information management and telecomms	1.4.1	Design and engineering
		1.4.2	Temporary and transitional communication
		1.4.3	Backbone basic
		1.4.4	Tenant specific
		1.4.5	Systems

Source: DOD, Pentagon Renovation Program

Table 69: Sample IT Infrastructure and Service Work Breakdown Structure

This sample WBS includes IT infrastructure and IT services only. Automated information system configuration, customization, development, and maintenance are covered in chapter 8 in this guide.

Level 1 element	Level 2 element	Level 3 element
1. IT project investment (nonrecurring)	1.1. Facility Type 1 – n (e.g., buildings, flooring, cooling)	1.1.1 Infrastructure site construction
		1.1.2 Operational site construction
		1.1.3 Integration/test facility construction
	1.2 Purchased software licenses (e.g., application software, system software, database)	
	1.3. Infrastructure purchased hardware (e.g., UNIX servers, Windows servers, WAN/LAN equipment)	
	1.4 End user purchased hardware (e.g., switches, PC, printers, copiers)	
	1.5. Operational/site implementation (aka deployment) (e.g., system architecture, training, hardware & software setup)	1.5.1 IT systems architecture/design
		1.5.2 Software/database services (e.g., deploying & supporting enterprise applications, databases, data migration, middleware and software services)
		1.5.3 Infrastructure hardware & software installation, activation, & checkout (e.g., setup, deploy, test, checkout infrastructure systems such as servers, storage systems, & networks)
		1.5.4 End user hardware & software installation, activation, & checkout: (e.g., labor to setup & deploy end user systems such as PC's, notebooks, PDAs, communication devices, and other mobile devices)
		1.5.5 Data (e.g., user documentation preparation labor)
		1.5.6 Training development (e.g., course development)
		1.5.7 Initial training (e.g., personnel training)
		1.5.7 Data migration
		1.5.8 Operational test & evaluation (e.g., labor and material to test and certify the overall IT project)
	1.6 Management	1.6.1 Government program office
		1.6.2 Contractor program management

Level 1 element	Level 2 element	Level 3 element
2.0 Operations & support (recurring)	2.1 IT facility operations Type 1	2.1 .1 IT Facilities maintenance & support
		2.1.2 Power
	2.2 Facility operations type 2	
	2.3 Facility operations type n	
	2.4. Purchased software maintenance (e.g., ongoing licensing)	2.4.1 Application software
		2.4.2 System software
		2.4.3 Database
	2.5 Purchased hardware maintenance	2.5.1 Infrastructure
		2.5.2 End user
	2.6 Change architecture/ design	
	2.7 Purchased software and hardware refresh (e.g., new hardware, new software, spares)	
	2.8 IT project operations & monitoring	2.8.1 System administration
		2.8.2 Database administration
		2.8.3 Help desk support (Tier I, II, III)
		2.8.4 Security
		2.8.5 Other IT operations & monitoring (e.g., hardware maintenance, computer operations, etc.)
		2.8.6 Data maintenance (e.g., documentation review & update labor)
		2.8.7 Recurring training (e.g., end users, developers, IT operations personnel)
		2.8.8 Data migration update
		2.8.9 Management

Source: GAO, DOD, and industry expert collaboration.

The MasterFormat™ and OmniClass™ Work Classification System

Many standard project construction breakdown structures have been created over the years for use in construction management. The most common, in existence since the 1960s, are the CSI (Construction Specifications Institute) format in North America and the SMM7 (Standard Method of Measurement) format in Great Britain.[11] They originated as breakdowns for commercial building construction but have evolved to include other forms of construction.

CSI introduced an expanded version, the MasterFormat™, in 2004, that includes 50 divisions of work covering civil site and infrastructure work as well as process equipment—a significant increase from the previous 16 divisions covering building construction that had been in use for years. This expansion reflects the growing complexity of the construction industry, as well as the need to incorporate facility life cycle

[11] More information is available on CSI'S Web site, www.csinet.org/s_csi/index.asp. The Construction Specifications Institute "maintains and advances the standardization of construction language as it pertains to building specifications." It also provides structured guidelines for specification writing in its *Project Resource Manual: CSI Manual of Practice*, 5th ed. (New York: McGraw-Hill, 2004).

and maintenance information into the building knowledge base. Another level of standardized numbers was added to the publication. One goal was to eventually facilitate building information modeling to contain project specifications.

The MasterFormat standard serves as the organizational structure for construction industry publications such as the Sweets catalog, with a wide range of building products, MasterSpec, and other popular master guide specification applications, and RS Means and other cost information applications. MasterFormat helps architects, engineers, owners, contractors, and manufacturers classify the typical use of various products to achieve technical solutions on the job site, known as "work results." Work results are permanent or temporary aspects of construction projects achieved in the production stage or by subsequent alteration, maintenance, or demolition processes, through the application of a particular skill or trade to construction resources.

The OmniClass™ Construction Classification System, a new North American classification system, is useful for many additional applications, from organizing library materials, product literature, and project information to providing a classification structure for electronic databases.[12] It incorporates other systems in use as the basis of many of its tables, including MasterFormat for work results and UniFormat™ for elements.

OmniClass follows the international framework set out in International Organization for Standardization (ISO) Technical Report 14177—Classification of Information in the Construction Industry, July 1994. This document has been established as a standard in ISO 12006-2: Organization of Information about Construction Works—Part 2: Framework for Classification of Information.

It is also worth noting that CSI is involved in developing a corresponding system for terminology based on a related ISO standard, ISO 12006-3 Organization of Information about Construction Works—Part 3: Framework for Object-Oriented Information. The system known as the International Framework for Dictionaries (IFD) Library is a standard for terminology libraries or ontologies. It is part of the international standards for building information modeling being developed and promoted by buildingSMART International (bSI). CSI sees the IFD Library being used in conjunction with OmniClass to establish a controlled vocabulary for the North American building industry, thereby improving interoperability. Both OmniClass and IFD Library are included in the development work of the buildingSmart alliance (the North American chapter of bSI) and its National Building Information Modeling Standard (NBIMS).

OmniClass consists of 15 tables, each representing a different facet of construction information. Each table can be used independently to classify a particular type of information, or entries on it can be combined with entries on other tables to classify more complex subjects. The tables are not numbered sequentially and there are gaps in the progression. The first is Table 11, Construction Entities by Function, and the last of the 15 is Table 49, Properties.

The OmniClass structures start to approach the DOD WBS template model at the system level regarding construction classifications. In its table 21 under "Utilities and Infrastructure" is included breakdowns

[12] More information is available from the OmniClass Web site at www.omniclass.org. The OmniClass™ material included here is used with permission. Copyright © 2006 the Secretariat for the OCCS Development Committee. All Rights Reserved. www.omniclass.org, Edition 1.0, 2006-03-28 Release.

for roadways, railways, airports, space travel, utilities, and water-related construction. This is not unlike a concept in aircraft systems, electronic systems, missile systems, and ship systems from the DOD Mil Handbook template.

OmniClass table 22 is based almost entirely on the CSI MasterFormat tables, although it is noted in OmniClass that "some content of MasterFormat 2004 Edition is not included in table 22."[13]

None of the current construction breakdowns, including CSI, fully cover the complete civil infrastructure project life cycle, including development, engineering, construction, operations, maintenance, and risk mitigation. The current CSI MasterFormat 2004 edition comes closest to covering all the scope of work found in the construction of building facilities and site work. It falls short in addressing the unique requirements of program managers, estimators, schedulers, and cost engineers and in identifying all phases of work included in major infrastructure work such as Build Own and Transfer programs.

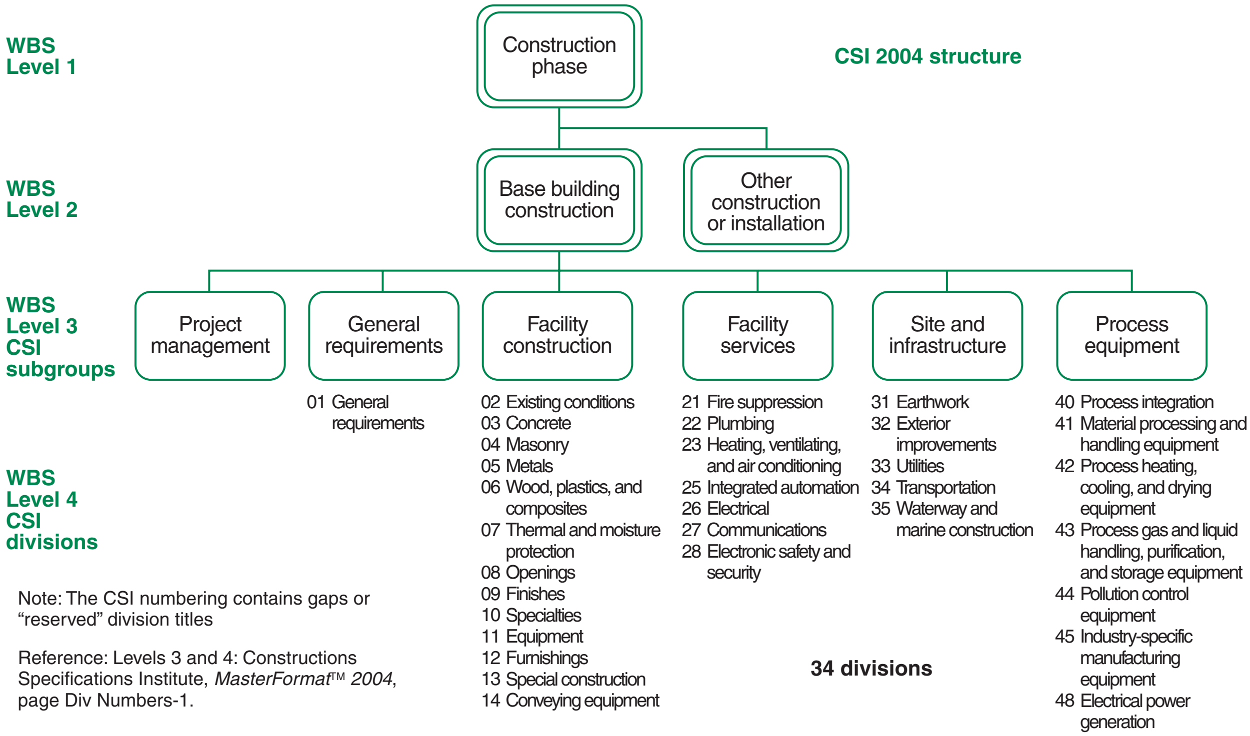
These structures, MasterFormat, and OmniClass are not program work breakdown structures, although some subsections have the appearance of a WBS. However, at all levels the elements in the structures are candidates for WBS element descriptors, including work packages, and they meet the common definitions of WBS elements, being all nouns or nouns and adjectives. The MasterFormat tables include the equivalent of a WBS dictionary for the lowest levels.

Many listings available in MasterFormat would enable an organization to pick and choose to provide ready-to-go WBS elements for virtually any work on any construction project, including related equipment and furnishings. It must be noted, however, that the summary headings are not truly WBS elements, since the breakdown or listings under the headings are further listings of categories within a heading and do not meet the WBS 100 percent rule.

Figure 43 illustrates the relationship of the CSI MasterFormat structure to a WBS based on the CSI structure. (A true WBS would be based on the actual product structure.) The summary CSI elements are listed as the 34 divisions. Each division contains one or more sections that would be selected from the complete MasterFormat set to relate to the specific needs of the project. Also, although not shown, the specific physical breakdown of the building needs to be overlaid. For example, it would be normal for the individual floors to be identified and the appropriate work packages for each floor selected from the appropriate MasterFormat sections. Note, also, that there is no further breakdown of the project management element as would be the case in a true WBS.

[13] OmniClass™ Edition 1.0 May 2, 2006 page 22-ii.

Figure 43: MasterFormat™ Work Breakdown Structure



Source: CSI and CSC MasterFormat™ 2004 (c) 2006.

Building Information Modeling/Management (BIM) Applications

OmniClass, MasterFormat, and UniFormat are used to index, organize and retrieve a variety of different information types throughout a project’s life cycle. The consistent use of standard classifications from any of these, applied to objects, will enhance users’ ability to sort data, roll up or drill down through data based on the hierarchy that all these classifications are built on. A standard implementation of any of these classifications within a BIM model will allow for this same information sorting and retrieval across multiple platforms and by all users at any stage in a facility’s life cycle.

In conjunction with the IFD Library, the structure of the classification systems can be explicitly applied to the information used in model-based design, analysis, and management systems. A more consistent naming system for objects captured in a BIM has the potential to support the goals of the buildingSMART organization to improve interoperability of systems and processes. In North America, these systems are used by the buildingSmart alliance (the North American chapter of buildingSMART International) in pilot projects and in the development of the U.S. National Building Information Modeling Standard (NBIMS).

Table 70: CSI MasterFormatTM 2004 Structure Example: Construction Phase

Level 2 element		Level 3 CSI subgroup	Level 4 CSI division
1.1	Base construction	Project management	
		General requirements	General requirements
		Facility construction	Existing conditions
			Concrete
			Masonry
			Metals
			Wood, plastics, composites
			Thermal and moisture protection
			Openings
			Finishes
			Specialties
			Equipment
			Furnishings
			Special construction
			Conveying equipment
		Facility services	Fire suppression
			Plumbing
			Heating, ventilating, air conditioning
			Integrated automation
			Electrical
			Communications
			Electronic safety and security
		Site and infrastructure	Earthwork
			Exterior Improvements
			Utilities
			Transportation
			Waterway and marine construction
		Process equipment	Process integration
			Material processing and handling equipment
			Process heating, cooling & drying equipment
			Process gas and liquid handling, purification and storage equipment
			Pollution control equipment
			Industry specific manufacturing equipment
			Electrical power generation
1.2	Other construction or installation		

Source: CSI MasterFormatTM 2004 " © 2006

Note: The numbers and titles used in this publication are from *MasterFormat*™ 2004, published by The Construction Specifications Institute (CSI) and Construction Specifications Canada (CSC), and are used with permission from CSI. For those interested in a more in-depth explanation of *MasterFormat*™ 2004 and its use in the construction industry visit or contact: The Construction Specifications Institute (CSI), 99 Canal Center Plaza, Suite 300, Alexandria, VA 22314. 800-689-2900; 703-684-0300, .

SCHEDULE RISK ANALYSIS

A schedule risk analysis uses statistical techniques to predict a level of confidence in meeting a program's completion date. This analysis focuses on critical path activities and on near-critical and other activities, since any activity may potentially affect the program's completion date. Like a cost estimate risk and uncertainty analysis, a schedule risk analysis requires the collection of program risk data such as

- risks that may jeopardize schedule success, usually found in the risk register prepared before the risk analysis is conducted;
- probability distributions, usually specified by a point estimate of activity durations;
- probability of a risk register risk's occurring and its probability distribution of impact if it were to occur;
- probability that a branch of activities might occur (for example, a test failure could lead to several recovery tasks); and
- correlations between activity durations.

Schedule risk analysis relies on Monte Carlo simulation to randomly vary the following:

- activity durations according to their probability distributions or
- risks according to their probability of occurring and the distribution of their impact on affected activity if they were to occur and
- existence of a risk's or a probabilistic branch's occurring.

The objective of the simulation is to develop a probability distribution of possible completion dates that reflect the program and its quantified risks. From the cumulative probability distribution, the organization can match a date to its degree of risk tolerance. For instance, an organization might want to adopt a program completion date that provides a 70 percent probability that it will finish on or before that date, leaving a 30 percent probability that it will overrun, given the schedule and the risks. The organization can thus adopt a plan consistent with its desired level of confidence in the overall integrated schedule. This analysis can give valuable insight into what-if drills and quantify the impact of program changes.

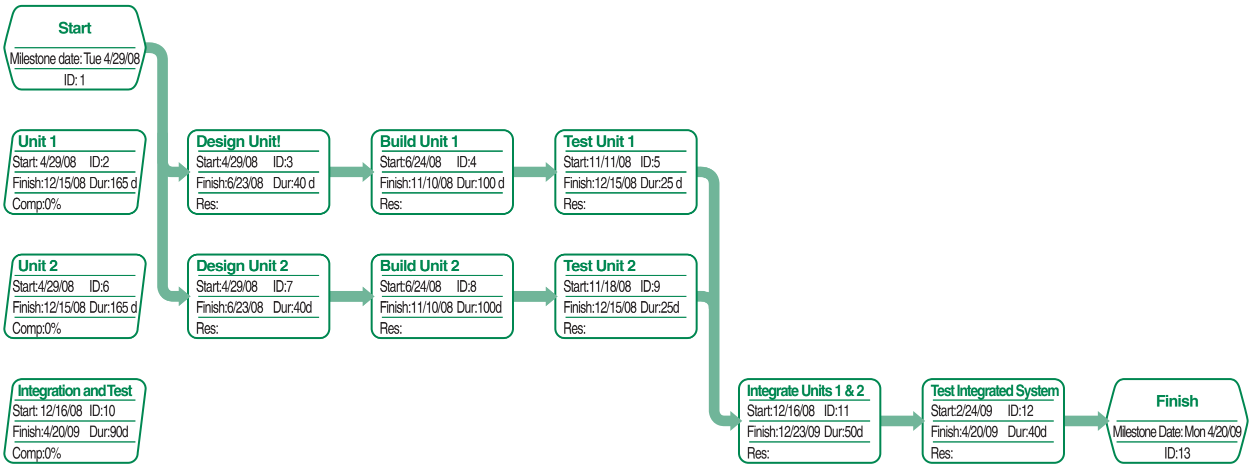
In developing a schedule risk analysis, probability distributions for each activity's duration have to be established. Further, risk in all activities must be evaluated and included in the analysis. Some people focus only on the critical path, but because we cannot know the durations of the activities with certainty, we cannot know the true critical path. Consequently, it would be a mistake to focus only on the deterministic critical path when some off-critical path activity might become critical if a risk were to occur. Typically, three-point estimates—that is, best, most likely, and worst case estimates—are used to develop the probability distributions for the duration of workflow activities. After the distributions are developed, the Monte Carlo simulation is run and the resulting cumulative distribution curve, the S curve, displays the probability associated with the range of program completion dates.

If the analysis is to be credible, the program must have a good schedule network that clearly identifies the critical path and that is based on a minimum number of date constraints. The risk analysis should also identify the tasks during the simulation that most often ended up on the critical path, so that near-critical path activities can also be closely monitored. It is important to represent all work in the schedule, since any activity can become critical under some circumstances. Complete schedule logic that addresses the logical relationships between predecessor and successor activities is also important. The analyst needs to be confident that the schedule will automatically calculate the correct dates and critical paths when the activity durations change, as they do thousands of times during a simulation. Because of debugging, and because the collection of schedule risk data can take time and resources, it is often a good idea to work with a summary schedule rather than the most detailed schedule.

One of the most important reasons for performing a schedule risk analysis is that the overall program schedule duration may well be greater than the sum of the path durations for lower-level activities. This is in part because of

- schedule uncertainty, which can cause activities to shorten (an opportunity) or lengthen (a threat). For instance, if a conservative assumption about labor productivity was used in calculating the duration of an activity, and during the simulation a better labor productivity is chosen, then the activity will shorten. However, most program schedule risk phenomena exhibit more probability of overrunning (threats) than underrunning (opportunities), which can cause activities to lengthen.
- schedule structure. A schedule's structure has many parallel paths joined at a merge or join point, which can cause the schedule to lengthen. Merge points include program reviews (preliminary design review, critical design review, etc.) or the beginning of an integration and test phase. The timing of these merge points is determined by the latest merging path. Thus, if a late required element is delayed, the merge event will also be delayed. Since any merging path can be risky, any merging path can determine the timing of the merge event. This added risk at merge points is called the "merge bias." Figure 44 gives an example of the schedule structure that illustrates the network or pure-logic diagram of a simple schedule with a merge point at integration and test.

Figure 44: Network Diagram of a Simple Schedule



Source: Copyright 2007 Hulett and Associates, LLC.

Since each activity has an uncertain duration, it stands to reason that the entire duration of the overall program schedule will also be uncertain. Therefore, unless a statistical simulation is run, calculating the completion date based on schedule logic and the most likely duration distributions will tend to underestimate the overall program critical path duration.

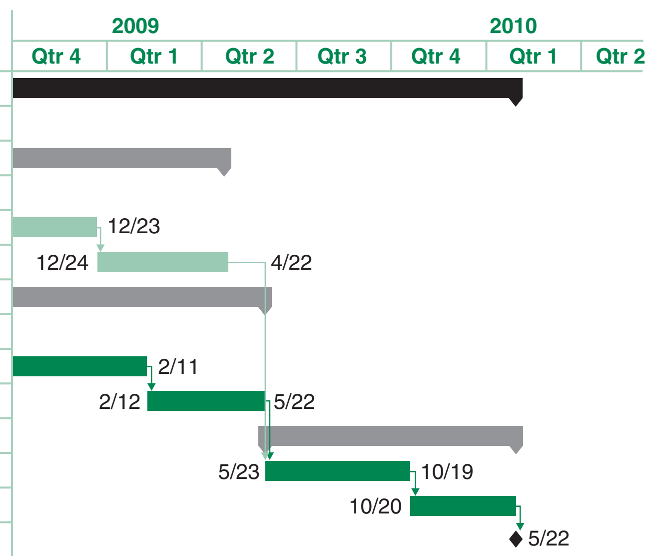
Schedule underestimation is more pronounced when the schedule durations or logic have optimistic bias—for instance when the customer or management has specified an unreasonably short duration or early completion date. The schedule can be configured and assumptions made about activity durations to make a schedule match these imposed constraint durations. When this is the case, durations are often "best case" scenarios or based on unreasonable assumptions about the resources availability or productivity. Further, the schedule may overlap activities or phases (for example, detailed engineering, fabrication, and testing) that would otherwise be more prudently scheduled in a series to compress the time. In addition, external contributions may be assumed with optimistic bias when there is little confidence that their suppliers will be able to comply. As a result, fitting the schedule to predetermined dates is dangerous.

The preferred approach to scheduling is to build the schedule by starting with the WBS to define the detailed activities using program objectives to guide major events. When determining the durations for the activities, resource availability and productivity need to be reasonably assumed, external factors need to be realistically considered, and organizational risk associated with other programs and the priority of this program need to be considered. Once all these aspects have been modeled in the schedule, the scheduling system software can calculate the completion date. Following these best practice approaches to developing a schedule will provide a reasonable first step in determining the schedule duration. If the duration is too long, or the dates are too late, then more resources or less scope may be required. Unless more resources are provided it is inappropriate to shorten the schedule to fit a preconceived date, given the original scope of work.

Accordingly, because activity durations are uncertain, the probability distribution of the program's total duration must be determined statistically, by combining the individual probability distributions of all paths according to their risks and the logical structure of the schedule. Schedule activity duration uncertainty can be represented several ways. The example schedule in figure 45 illustrates.

Figure 45: Example Project Schedule

ID	Task name	Duration	Start	Finish
0	**Three path project GAO**	**750 d**	**1/9/08**	**1/27/10**
1	Start	0 d	1/9/08	1/9/08
2	**Software**	**470 d**	**1/9/08**	**4/22/09**
3	Software design	100 d	1/9/08	4/17/08
4	Software coding	250 d	4/18/08	12/23/08
5	Software testing	120 d	12/24/08	4/22/09
6	**Hardware**	**500 d**	**1/9/08**	**5/22/09**
7	Hardware design	100 d	1/9/08	4/17/08
8	Hardware fabrication	300 d	4/18/08	2/11/09
9	Hardware test	100 d	2/12/09	5/22/09
10	**Integration H/W and S/W**	**250 d**	**5/23/09**	**1/27/10**
11	Integration	150 d	5/23/09	10/19/09
12	Integrated test	100 d	10/20/09	1/27/10
13	Finish	0 d	1/27/10	1/27/10



Source: Copyright 2007 Hulett and Associates, LLC.

In this example schedule, the project begins on January 9, 2008, and is expected to be completed about 2 years later, on January 27, 2010. Three major efforts involve software, hardware, and integration.

According to the schedule logic and durations, hardware fabrication, testing, and the integration of hardware and software drive the critical path.

The first way to capture schedule activity duration uncertainty is to collect various estimates from individuals and, perhaps, from a review of actual past program performance. Estimates derived from interviews or in workshops should be formulated by a consensus of knowledgeable technical experts and coordinated with the same people who manage the program's risk mitigation watch list. Figure 46 shows a traditional approach with the three-point estimate applied directly to the activity durations.

Figure 46: Estimated Durations for Remaining WBS Areas in the Schedule

ID	Task name	Rept ID	Mn Rdur	ML Rdur	Max Rdur	Rept ID
0	**Three path GAO project**	**2**	**0 d**	**0 d**	**0 d**	**0**
1	Start	0	0 d	0 d	0 d	0
2	**Software**	**0**	**0 d**	**0 d**	**0 d**	**0**
3	Software design	0	85 d	100 d	150 d	2
4	Software coding	0	212.5 d	250 d	375 d	2
5	Software testing	0	90 d	120 d	240 d	2
6	**Hardware**	**0**	**0 d**	**0 d**	**0 d**	**0**
7	Hardware design	0	85 d	100 d	130 d	2
8	Hardware fabrication	0	255 d	300 d	390 d	2
9	Hardware test	0	75 d	100 d	200 d	2
10	**Integration H/W and S/W**	**0**	**0 d**	**0 d**	**0 d**	**0**
11	Integration	0	120 d	150 d	210 d	2
12	Integrated test	0	75 d	100 d	200 d	2
13	Finish	0	0 d	x d	0 d	0

Source: Copyright 2007 Hulett and Associates, LLC.

Note: Rept ID = Report Identification; Rdur = Remaining Duration, Mn = Minimum, ML = Most Likely, Max = Maximum; H/W = hardware; S/W = software.

The example shows three-point estimates of remaining durations. In a real program schedule risk analysis, these would be developed from in-depth interviews of people who are expert in each of the WBS areas of the program. To model the risks in the simulation, the risks are represented as triangular distributions specified by the three-point estimates of the activity durations. These probability distributions combine the effects of all risks that affect the activities.

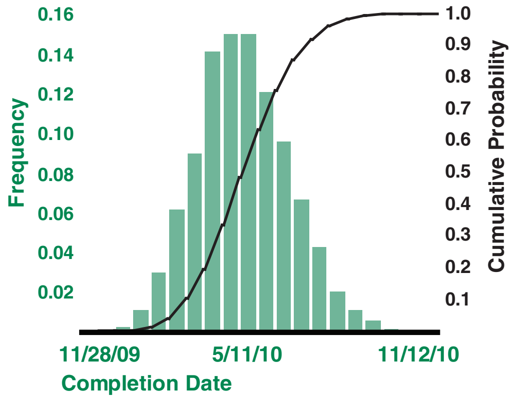
Once the distributions have been established, the Monte Carlo simulation uses random numbers to select specific durations from each activity probability distribution and calculates a new critical path and dates, including major milestone and program completion. The Monte Carlo simulation continues this random selection thousands of times, creating a new program duration estimate and critical path each time. The resulting frequency distribution displays the range of program completion dates along with the probabilities that these dates will occur.

Figure 47 shows that the most likely completion date is about May 11, 2010, not January 27, 2010, which is the date the deterministic schedule computed. The cumulative distribution also shows that a January 27, 2010 completion is less than 5 percent likely, given the schedule and the risk ranges used for the durations. An organization that wants to cover 80 percent of its known unknowns would have to add a time reserve of about 5 months to June 24, 2010. While it would be prudent to establish a 5-month reserve for this project, each organization should determine its tolerance level for schedule risk.

Figure 47: Cumulative Distribution of Project Schedule, Including Risk

Date: 12/7/2007 5:35:45 PM
Samples: 5000
Unique ID: 0
Name: Three Path Project GAO

Completion Std Deviation: 51.79 d
95% Confidence Interval: 1.44 d
Each bar represents 20 d



Completion Probability Table

Prob	Date	Prob	Date
0.05	2/19/10	0.55	5/15/10
0.10	3/6/10	0.60	5/22/10
0.15	3/18/10	0.65	5/29/10
0.20	3/29/10	0.70	6/6/10
0.25	4/5/10	0.75	6/15/10
0.30	4/12/10	0.80	6/24/10
0.35	4/19/10	0.85	7/5/10
0.40	4/25/10	0.90	7/20/10
0.45	5/2/10	0.95	8/8/10
0.50	5/9/10	1.00	11/12/10

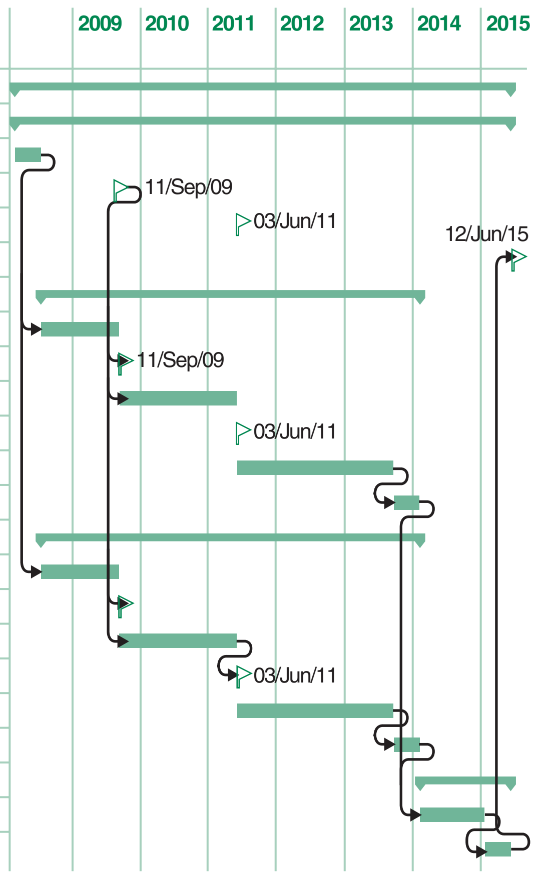
GAO

Source: Copyright 2007 Hulett and Associates, LLC.

Schedule activity duration uncertainty can be determined by analyzing the probability of risks from the risk register. Using a probability distribution of the risk impact on the duration, risks are assigned to specific activities. This approach focuses on how risks affect time. Figure 48 shows how this approach can be used.

Figure 48: Identified Risks on a Spacecraft Schedule: An Example

ID	Description	Rem duration	Start	Finish
SUMMA	**Project summary**	**1900**	**03/Mar/08**	**12/Jun/15**
00001	**Spacecraft project milestones**	**1900**	**03/Mar/08**	**12/Jun/15**
00002	**Requirements definition spacecraft**	**100**	**03/Mar/08**	**18/Jul/08**
00003	PDR spacecraft	0		11/Sep/09
00004	CDR spacecraft	0		03/Jun/11
00005	Ship to launch site	0		12/Jun/15
00006	**First stage**	**1450**	**21/Jul/08**	**07/Feb/14**
00007	**FS preliminary design**	**300**	**21/Jul/08**	**11/Sep/09**
00008	FS PDR	0		11/Sep/09
00009	**FS final design**	**450**	**14/Sep/09**	**03/Jun/11**
00010	FS CDR	0		03/Jun/11
00011	**FS fabrication**	**600**	**06/Jun/11**	**20/Sep/13**
00012	**Test FS engine**	**100**	**23/Sep/13**	**07/Feb/14**
00020	**Upper stage**	**1450**	**21/Jul/08**	**07/Feb/14**
00021	**US preliminary design**	**300**	**21/Jul/08**	**11/Sep/09**
00022	US PDR	0		11/Sep/09
00023	**US Final design**	**450**	**14/Sep/09**	**03/Jun/11**
00024	US CDR	0		03/Jun/11
00025	**US fabrication**	**600**	**06/Jun/11**	**20/Sep/13**
00026	**US test**	**100**	**23/Sep/13**	**07/Feb/14**
00027	**Integration**	**350**	**10/Feb/14**	**12/Jun/15**
00028	**Integration**	**250**	**10/Feb/14**	**23/Jan/15**
00029	**Integration testing**	**100**	**26/Jan/15**	**12/Jun/15**



Source: Copyright 2007 Hulett and Associates, LLC.

In this example of a spacecraft schedule, the work begins on March 3, 2008, and is expected to finish more than 7 years later, on June 12, 2015. Because of the long time and the risk associated with developing the spacecraft technology, the risk driver method can be used to examine how various risks from the risk register may affect this schedule.

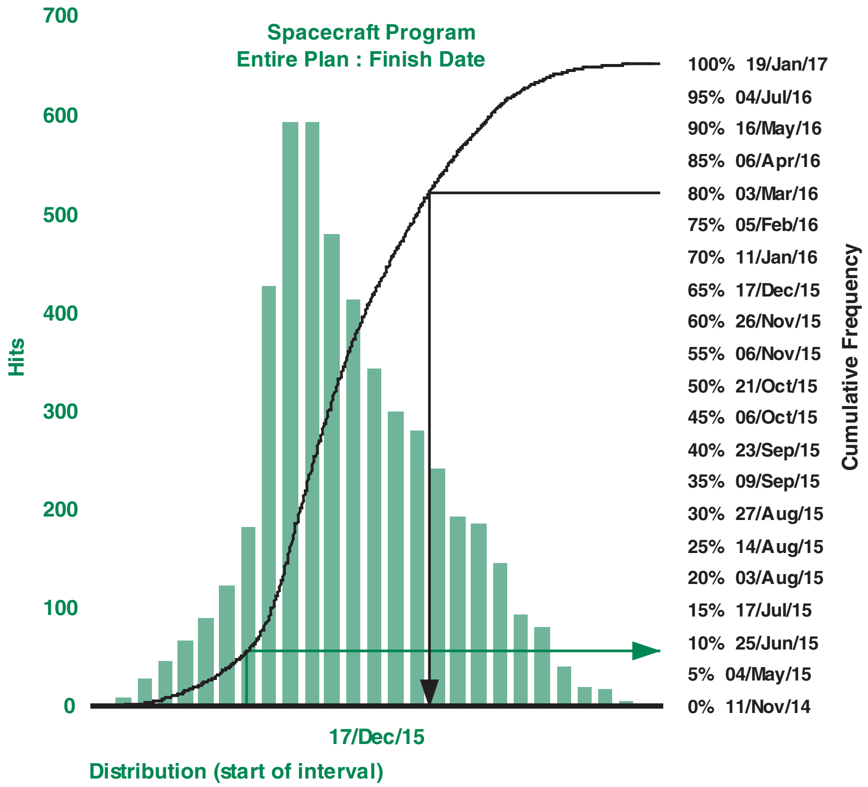
Figure 49: A Risk Register for a Spacecraft Schedule

	Description	Optimistic	Most likely	Pessimistic	Likelihood
1	Requirements have not been decided	95.00%	105.00%	120.00%	30.00%
2	Several alternative designs considered	95.00%	100.00%	115.00%	60.00%
3	New designs not yet proven	96.00%	103.00%	112.00%	40.00%
4	Fabrication requires new materials	96.00%	105.00%	115.00%	50.00%
5	Lost know-how since last full spacecraft	95.00%	100.00%	105.00%	30.00%
6	Funding from congress is problematic	90.00%	105.00%	115.00%	70.00%
7	Schedule for testing is aggressive	100.00%	120.00%	130.00%	100.00%

Source: Copyright 2007 Hulett and Associates, LLC.

In figure 49, one can quickly determine that the biggest risk affecting the spacecraft schedule has to do with testing, because the schedule is very aggressive. Moreover, lack of requirements, funding delays, alternative designs, and the fact that some of the designs are unproven are also highly likely to affect the schedule. With the risk driver method, these risks are shown as factors that will be used to multiply the durations of the activities they are assigned to, if they occur in the iteration. Once the risks are assigned to the activities, a simulation is run. The results may be similar to those in figure 50.

Figure 50: Spacecraft Schedule Results from a Monte Carlo Simulation



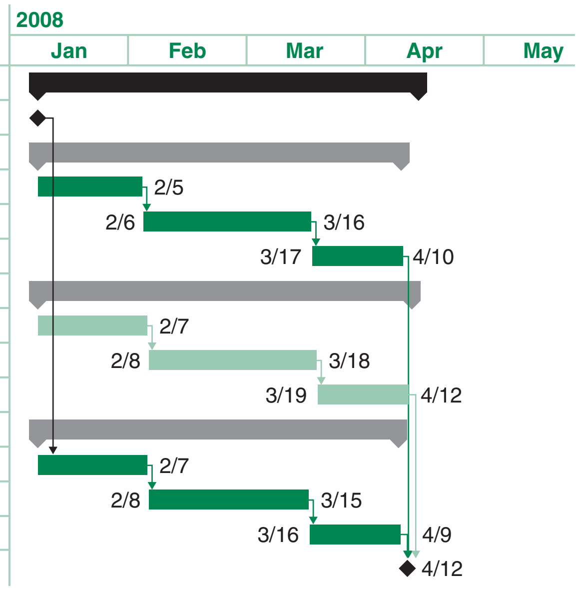
Source: Copyright 2007 Hulett and Associates, LLC.

In this example, the schedule date of June 12, 2015, is estimated to be 9 percent likely, based on the current plan. If the organization chooses the 80th percentile, the date would be March 3, 2016, representing a 9-month time contingency. Notice that the risks have caused a 14-month spread, a respectable range of uncertainty, between the 5 percent and 95 percent confidence dates.

Regardless of which method is used to examine schedule activity duration uncertainty, it is important to identify the risks that contribute most to the program schedule risk. In figure 51 is one approach to identifying activities that need close examination for effective risk mitigation. It compares a schedule with a well-managed critical path (unit 2) and two other paths that have risk but positive total float. The noncritical path efforts (units 1 and 3) therefore did not attract the program manager's risk management attention.

Figure 51: A Schedule Showing Critical Path through Unit 2

Task name	Rept ID	Mn Rdur	Mn Rdur	Max Rdur	Curve
Risk criticality project	**2**	**0 d**	**0 d**	**0 d**	**0**
Start	0	0 d	0 d	0 d	0
Unit 1	**0**	**0 d**	**0 d**	**0 d**	**0**
Design unit 1	0	18 d	28 d	43 d	2
Build unit 1	0	35 d	40 d	50 d	2
Test unit 1	0	20 d	25 d	50 d	2
Unit 2	**0**	**0 d**	**0 d**	**0 d**	**0**
Design unit 2	0	25 d	30 d	38 d	2
Build unit 2	0	37 d	40 d	45 d	2
Test unit 2	0	22 d	25 d	35 d	2
Unit 3	**0**	**0 d**	**0 d**	**0 d**	**0**
Design unit 3	0	20 d	30 d	45 d	2
Build unit 3	0	32 d	37 d	47 d	2
Test unit 3	0	20 d	25 d	50 d	2
Finish	0	0 d	0 d	0 d	0



Source: Copyright 2007 Hulett and Associates, LLC.

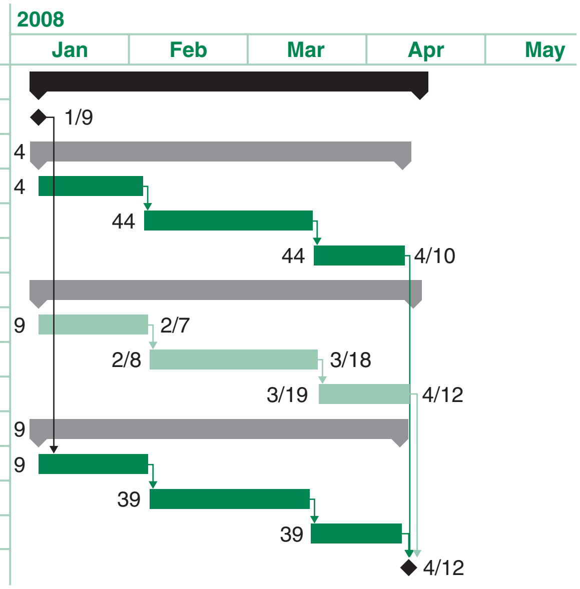
Note: Rept ID = Report Identification; Rdur = Remaining Duration, Mn = Minimum, ML = Most Likely, Max = Maximum; H/W = hardware; S/W = software.

The measure of merit, the risk criticality, shows that the risky noncritical paths are more likely to delay the project than the so-called critical path. After running the simulation, which takes into account the minimum, most likely, and maximum durations, one can see that although unit 2 is on the schedule's deterministic critical path, unit 1 is 44 percent likely to ultimately delay the project and unit 3 is 39 percent likely to do the same. In other words, the critical path method "critical path" is the least likely path to delay the project, in this simple case.

Figure 52 shows the results of each unit's probability of landing on the critical path, based on the Monte Carlo simulation.

Figure 52: Results of a Monte Carlo Simulation for a Schedule Showing Critical Path through Unit 2

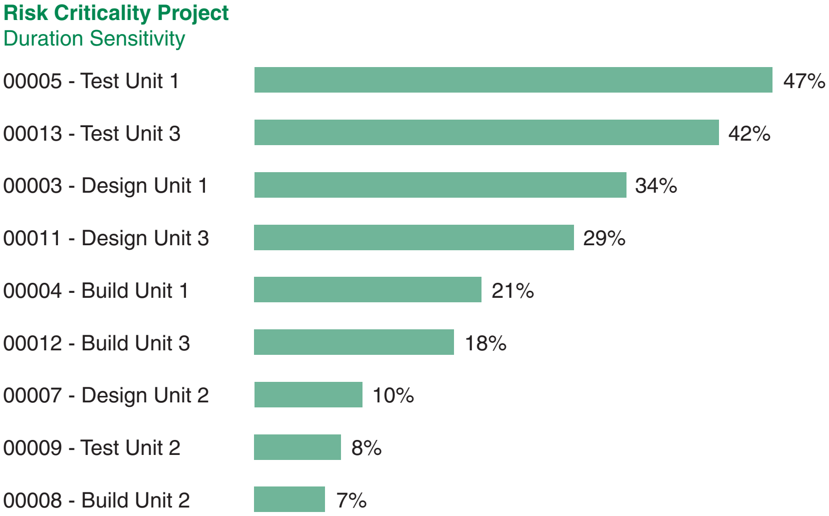
ID	Task name	Total slack	Critical	% Critical	Risk Critical
0	**Risk criticality project**	**0 d**	**Yes**	**0**	**No**
1	Start	0 d	Yes	100	No
2	**Unit 1**	**2 d**	**No**	**44**	**Yes**
3	Design unit 1	2 d	No	44	Yes
4	Build unit 1	2 d	No	44	Yes
5	Test unit 1	2 d	No	44	Yes
6	**Unit 2**	**0 d**	**Yes**	**17**	**No**
7	Design unit 2	0 d	Yes	17	No
8	Build unit 2	0 d	Yes	17	No
9	Test unit 2	0 d	Yes	17	No
10	**Unit 3**	**3 d**	**No**	**39**	**Yes**
11	Design unit 3	3 d	No	39	Yes
12	Build unit 3	3 d	No	39	Yes
13	Test unit 3	3 d	No	39	Yes
14	Finish	0 d	Yes	100	No



Source: Copyright 2007 Hulett and Associates, LLC.

Other measures of risk importance can be reviewed. For instance, sensitivity measures reflecting the correlation of the activities or the risks with the final schedule duration can be produced by most schedule risk software. Figure 53 is a standard schedule sensitivity index for the spacecraft project discussed earlier.

Figure 53: Sensitivity Index for Spacecraft Schedule

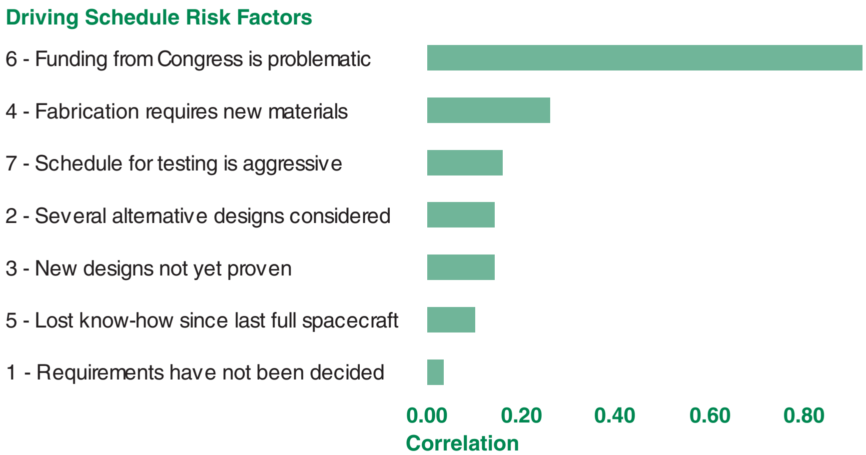


Source: Copyright 2007 Hulett and Associates, LLC.

In this example, the testing and design of units 1 and 3 affect the schedule duration more than the design, testing, and building of unit 2, even though unit 2 represents the critical path in the deterministic schedule. Therefore, without taking into account the risk associated with each unit's duration, the program manager would not know that keeping a strong eye on units 1 and 3 would be imperative for keeping the program on schedule.

Figure 54 is a different view of final duration sensitivity resulting from the risk register risks themselves, using the risk driver approach discussed earlier. In this case, when a risk is assigned to several activities, its sensitivity measure reflects the entire correlation, not just the correlation of one activity to the project duration.

Figure 54: Evaluation of Correlation in Spacecraft Schedule



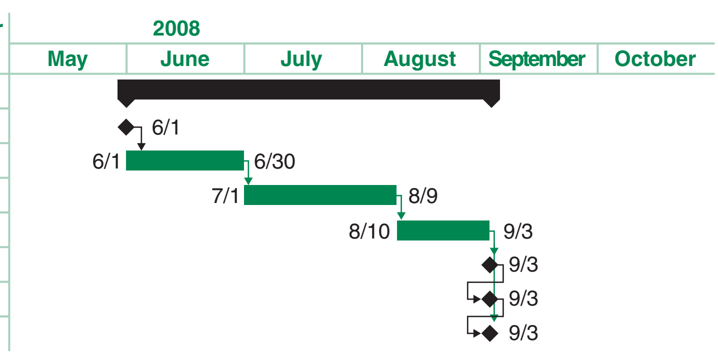
Source: Copyright 2007 Hulett and Associates, LLC.

In the example in figure 54, funding from the Congress is the biggest risk driver in the program schedule, followed by new materials that may be needed for fabrication. While not much can be done about the congressional funding issue since this is an external risk, contingency plans can be made for several scenarios in which funding may not come through as planned.

In addition to standard schedule risk and sensitivity analysis, events that typically occur in government programs require some new activities. This is called "probabilistic branching." One such event that commonly occurs is the completion of a test of an integrated product (software program, satellite, etc.). The schedule often assumes that tests are successful, whereas experience indicates that tests may fail and only their failure will require the activities of root cause analysis, plan for recovery, execution of recovery, and retest. This is a branch that only happens with some probability. An example is shown in figure 55.

Figure 55: An Example of Probabilistic Branching Contained in the Schedule

ID	Task name	Duration	Start	Finish	Predecessor
1	**Project**	**95 d**	**6/1**	**9/3**	
2	Start	0 d	6/1	6/1	
3	Design Unit	30 d	6/1	6/30	2
4	Build Unit	40 d	7/1	8/9	3
5	Test Unit	25 d	8/10	9/3	4
6	FIXIT	0 d	9/3	9/3	5
7	Retest	0 d	9/3	9/3	6
8	Finish	0 d	9/3	9/3	7,5



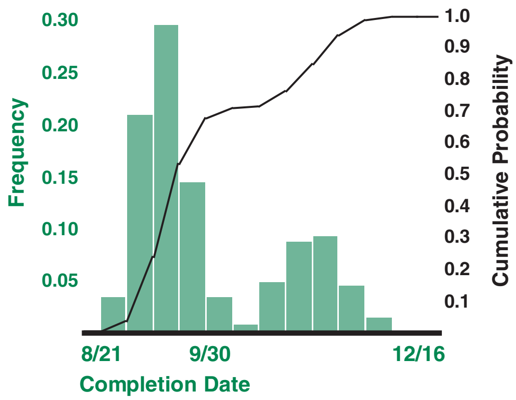
Source: Copyright 2007 Hulett and Associates, LLC.

If the test unit activity fails, FIXIT and retest occur; otherwise, their duration is 0 days. This is a discontinuous event that leads to the two new activities. If the test is estimated to fail with some probability such as 30 percent, the resulting probability distribution of dates for the entire project can be depicted as in figure 56.

Figure 56: Probability Distribution Results for Probabilistic Branching in Test Unit

Date: 1/9/2006 8:03:50 PM
Samples: 3000
Unique ID: 0
Name: Probabilistic Branch

Completion Std Deviation: 27.45 d
95% Confidence Interval: 0.98 d
Each bar represents 10 d



Completion Probability Table

Prob	Date	Prob	Date
0.05	9/1	0.55	9/20
0.10	9/4	0.60	9/23
0.15	9/6	0.65	9/26
0.20	9/8	0.70	10/4
0.25	9/10	0.75	10/28
0.30	9/11	0.80	11/3
0.35	9/13	0.85	11/9
0.40	9/14	0.90	11/13
0.45	9/16	0.95	11/20
0.50	9/18	1.00	12/16

Source: Copyright 2007 Hulett and Associates, LLC.

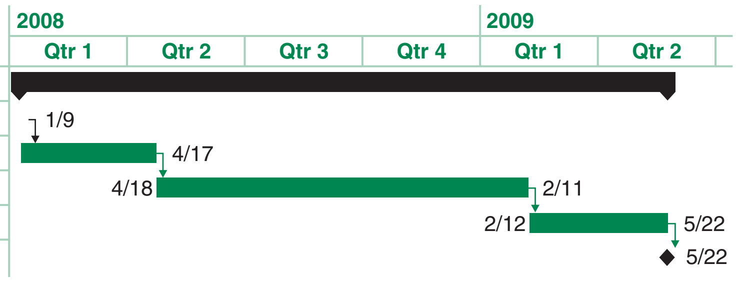
Notice the bimodal distribution with the test success iterations on the left of figure 56 and the test failure iterations on the right. If the organization demands an 80th percentile schedule, it would be November 3, although if it is satisfied by anything under the 70th percentile, the possibility of failure would not be important.

Other capabilities are possible once the schedule is viewed as a probabilistic statement of how the program might unfold. One that is notable is the correlation between activity durations. Correlation is when two activity durations are both influenced by the same external force and can be expected to vary in the same direction within their own probability distributions in any consistent scenario. While durations might vary in opposite directions if they are negatively correlated, this is less common than positive correlation in program management. Correlation might be positive and fairly strong if, for instance, the same assumption about the maturity of a technology is made to estimate the duration of design, fabrication, and testing activities. If the technology maturity is not know with certainty, it would be consistent to assume that design, fabrication, and testing activities would all be longer, or shorter, than scheduled together. It is the "together" part of the consistent scenario that represents correlation.

Without specifying correlation between these activity durations in simulation, some iterations or scenarios would have some activities long and others short in their respective ranges. This would be inconsistent with the idea that they all react to the maturity of the same technology. Specifying correlations between design, fabrication, and testing ensures that each iteration represents a scenario in which their durations are consistently long or short in their ranges. Because schedules tend to add durations (given their logical structure), if the durations are long together or short together there is a chance for very long or very short projects. How much longer or shorter depends, but without correlation, the risk analysis may underestimate the final effect. Figure 57 demonstrates this issue with a simple single-path hardware development fabrication test program.

Figure 57: A Project Schedule Highlighting Correlation Effects

ID	Task name	Duration	Start	Finish
0	**Correlation Project GAO**	**500 d**	**1/9/08**	**5/22/09**
1	Start	0 d	1/9/08	1/9/08
2	Hardware Design	100 d	1/9/08	4/17/08
3	Hardware Fabrication	300 d	4/18/08	2/11/09
4	Hardware Test	100 d	2/12/09	5/22/09
5	Finish	0 d	5/22/09	5/22/09



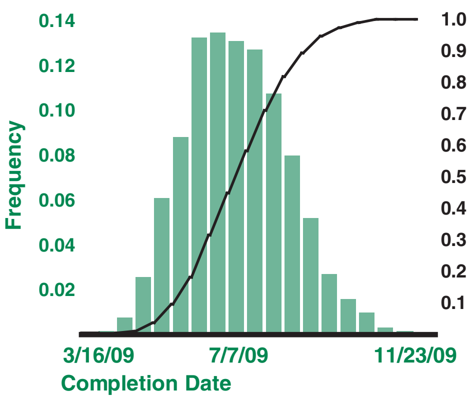
Source: Copyright 2007 Hulett and Associates, LLC.

Assuming no correlation between the activities' durations, the result would be as shown in figure 58. In this uncorrelated case, the 80 percent probability date is August 10, 2009, and the standard deviation of completion date, a measure of dispersion, is 40.47 days.

Figure 58: Risk Results Assuming No Correlation between Activity Durations

Date: 12/7/2007 8:59:10 PM
Samples: 5000
Unique ID: 0
Name: Correlation Project GAO

Completion Std Deviation: 40.47 d
95% Confidence Interval: 1.12 d
Each bar represents 15 d



Completion Probability Table

Prob	Date	Prob	Date
0.05	5/6/09	0.55	7/10/09
0.10	5/15/09	0.60	7/16/09
0.15	5/25/09	0.65	7/22/09
0.20	6/1/09	0.70	7/27/09
0.25	6/7/09	0.75	8/3/09
0.30	6/12/09	0.80	8/10/09
0.35	6/18/09	0.85	8/18/09
0.40	6/23/09	0.90	8/29/08
0.45	6/29/09	0.95	9/14/09
0.50	7/4/09	1.00	11/23/09

GAO No Correlations

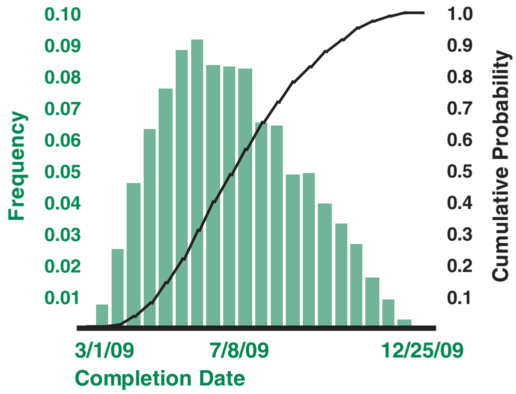
Source: Copyright 2007 Hulett and Associates, LLC.

However, if the influence of the technology maturity is strong and the program team believes that there is a 90 percent correlation between design, fabrication, and test of the hardware system, the simulation results will be affected dramatically. While the 90 percent correlation is high (correlation is measured between –1.0 and +1.0), there are often no actual data on correlation, so expert judgment is often used to set the correlation coefficients in many cases. Assuming this degree of correlation, we get the result in figure 59.

Figure 59: Risk Results Assuming 90 Percent Correlation between Activity Durations

Date: 12/7/2007 9:05:20 PM
Samples: 5000
Unique ID: 0
Name: Correlation Project GAO

Completion Std Deviation: 62.59 d
95% Confidence Interval: 1.73 d
Each bar represents 15 d



Completion Probability Table

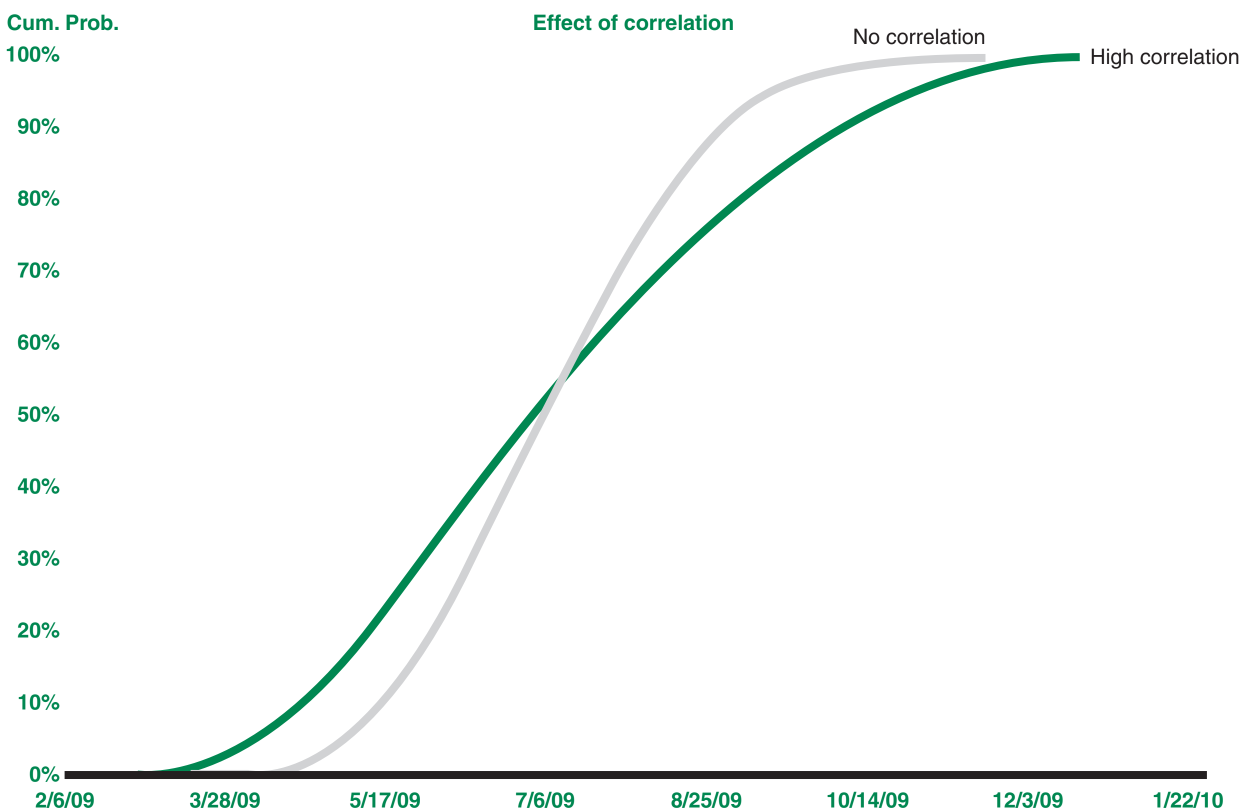
Prob	Date	Prob	Date
0.05	4/6/09	0.55	7/10/09
0.10	4/21/09	0.60	7/19/09
0.15	5/2/09	0.65	7/29/09
0.20	5/11/09	0.70	8/9/09
0.25	5/20/09	0.75	8/21/09
0.30	5/28/09	0.80	9/4/09
0.35	6/6/09	0.85	9/19/09
0.40	6/14/09	0.90	10/7/09
0.45	6/22/09	0.95	10/28/09
0.50	7/1/09	1.00	12/25/09

GAO Correlation = 0.9

Source: Copyright 2007 Hulett and Associates, LLC.

In this case the 80 percent probability date is September 4, 2009, nearly a month longer, and the standard deviation is 55 percent larger than when the activities were assumed independent. While the expected July 8, 2009, date varied little from the uncorrelated risk analysis, the deterministic May 22, 2009, date increased in probability to more than 25 percent by correlating the risks. The two results, are compared in figure 60.

Figure 60: Schedule Analysis Results with and without Correlation



Source: Copyright 2007 Hulett and Associates, LLC.

Other rules of thumb that can mitigate schedule risk include

- break down longer activities to show critical handoffs—for example, if a task is 4 months long but a critical handoff is expected halfway through, the task should be broken down into separate 2-month tasks that logically link the handoff between tasks. Otherwise, long lags must be used, which are rigid and tend to skew the risk results.
- detailed program schedules should contain a predominance of finish-to-start logical relationships but summary schedules, typically used in risk analysis, may have more start-to-start and finish-to-finish relationships between phases. This practice requires care in completing the logic with the following rule:

  > Each activity needs a finish-to-start or start-to-start predecessor that drives it as well as a finish-to-start or finish-to-finish successor that it drives—in other words, dangling activities must be avoided. In this way, risks in predecessors and successors will be transmitted correctly down the paths to the later program milestones.

- work packages in detailed program schedules should be no longer than 2 months so that work can be planned within two reporting periods, but for schedule risk a more summary schedule with basic activities representing phases is often used.
- lags should represent only the passing of time on detailed program schedules and should never be used to replace a task, whereas in summary schedules used for schedule risk, the lags may have to be longer.
- resources should be scheduled to reflect their scarcity, such as availability of staff or equipment.
- constraints should be minimized, because they impose a movement restriction on tasks and can cause false dates in a schedule.
- total float that is more than 5 percent of the total program schedule may indicate that the network schedule is not yet mature.

The Schedule Risk Analysis aims to answer 11 fundamental questions:

1. Does the schedule reflect all work to be completed?
2. Are the program critical dates used to plan the schedule?
3. Are the activities sequenced logically?
4. Are activity interdependencies identified and logical?
5. If there are constraints, lags, and lead times, are they required, and is documentation available to justify the amounts?
    - Constraints and lags should be used sparingly. There may be legitimate reasons for using constraints, but each constraint should be investigated. For instance, start-not-earlier-than constraints might reflect the availability of funding or a weather limitation and may be logical.
    - Finish-not-later-than constraints are usually artificial and reflect some policy rather than a program reality. If the program does not meet these dates, imposing this kind of constraint in a

computer model of the program schedule might make the schedule look good in the computer while the program is in trouble in the field.

- Constraints that push the program activities beyond the dates that predecessors require in order to add float or flexibility are arbitrary and not recommended. The schedule risk analysis should determine the amount of time contingency needed.

6. How realistic are the schedule activity duration estimates?
7. How were resource estimates developed for each activity and will the resources be available when needed?
8. How accurate is the critical path and was it developed with scheduling software?
9. How reasonable are float estimates? Activities' floats should be realistic. High total float values often indicate that logic is incorrect or missing and that there are dangling activities.
10. Can the schedule determine current status and provide reasonable completion date forecasts?
11. What level of confidence is associated with the program schedule completion date? Does it reflect a schedule risk analysis and the organization's or stakeholders' risk tolerance?

LEARNING CURVE ANALYSIS

In this appendix, we describe the two ways to develop learning curves—unit formulation and cumulative average formulation—and discuss associated issues.

Unit Formulation

Unit formulation (or unit theory) states that as the quantity of units doubles, unit cost decreases by a constant percentage. It is represented by the formula

$Y = AX^b$, where

Y = the cost of the Xth unit,

A = the first unit (T1) cost,

X = the unit number, and

b = the slope coefficient (defined as the Ln (slope) / Ln (2)).

What causes the cost to decrease as the quantity doubles is the rate of learning, depicted by b in the equation. Stated more simply, if the slope were 80 percent, then the value of unit 2 would be 80 percent of the value of the 1st unit, the 4th unit would be 80 percent of the value of the 2nd unit, and so on. As the quantity doubles, the cost reduces by the learning curve slope.

Cumulative Average Formulation

Cumulative average formulation is commonly associated with T. P. Wright, who initiated an important discussion of this method in 1936.[14] The theory is that as the total quantity of units produced doubles, the cumulative average cost decreases by a constant percentage. This approach uses the same functional form as unit formulation, but it is interpreted differently:

$Y = AX^b$, where

Y = the average cost of X units,

A = the first unit (T1) cost,

X = the cumulative number of units, and

b = the slope coefficient (defined as above).

In cumulative average theory, if the average cost of the first 10 units were $100 and the slope were 90 percent, the average cost of the first 20 units would be $90, the average cost of the first 40 units would be $81, and so on.

The difference between unit formulation and cumulative average theory is in where the curve affects the overall cost. For the first few units, using cumulative average will yield higher cost savings than using

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[14] T. P. Wright, "Factors Affecting the Cost of Airplanes," *Journal of Aeronautical Science* 3:4 (1936): 122–28; reprinted in *International Library of Critical Writings in Economics* 128:3 (2001): 75–81.

a unit curve with the same slope. As the number of units increases, the difference between the results decreases.

Choosing between Unit Formulation and Cumulative Average

Choosing a formulation is not so much a science as an art. No firm rules would cause a cost estimator to select one approach over the other, but analyzing some factors can help decide which might best model the actual production environment. Some factors to consider when determining which approach to use are

1. analogous systems,
2. industry standards,
3. historic experience, and
4. expected production environment.

Analogous Systems

Systems that are similar in form, function, development, or production process may help justify choosing one method over the other. For example, if an agency is looking to buy a modified version of a commercial aircraft and unit curve were used to model the production cost for a previous version of a modified commercial jet, the estimator should choose unit formulation.

Industry Standards

Certain industries sometimes tend to prefer one method over the other. For example, some space systems have a better fit using cumulative average formulation. If an analyst were estimating one of these space systems, cumulative average formulation should be used, since it is an industry standard.

Historic Experience

Some contractors have a history of using one method over another because it models their production process better. The cost estimator should use the same method as the contractor, if the contractor's method is known.

Expected Production Environment

Certain production environments favor one method over another. For example, cumulative average formulation best models production environments in which the contractor is just starting production with prototype tooling, has an inadequate supplier base, expects early design changes, or is subject to short lead times. In such situations, there is a risk of concurrency between the development and production phases. Cumulative averaging helps smooth out the initial cost variations and provides overall a better fit to the data. In contrast, unit formulation is a better fit for production environments where the contractor is well prepared to begin production in terms of tooling, suppliers, lead times, and so on. As a result, there is less need for the data to be smoothed out by averaging the results.

There are no firm rules for choosing one method over the other. Choosing between unit formulation and cumulative average formulation should be based on the cost estimator's ability to determine which one best models the system's costs.

Production Rate Effects and Breaks in Production

Not only do costs decrease as more units are produced but also costs usually decrease as the production rate increases. This effect can be modeled by adding a rate variable to the unit learning formulation. The equation then becomes

$Y = AXbQr$, where

> Y, A, X, and b are as defined earlier,
>
> Q = production rate (quantity per time period or lot), and
>
> r = rate coefficient (Ln (slope) / Ln (2)).

This rate equation directly models cost reductions achieved by economies of scale. The rate at which items can be produced can also be affected by the continuity of production. Production breaks may occur because of program delays (budget or technical), time lapses between initial and follow-on orders, or labor disputes. Examining a production break can be divided into two questions:

- How much learning has been lost (or forgotten) because of the break in production?
- How will the learning loss affect the costs of future production items?

An analyst can answer the first question by using the Anderlohr method for estimating the loss of learning. The analyst can then determine the effect of the loss by using the retrograde method.

Anderlohr Method

When assessing the effect of a production break on costs, it is necessary first to quantify how much learning was achieved before the break and then to quantify how much of it was lost by the break. The Anderlohr method divides learning into five categories: personnel learning, supervisory learning, continuity of production, methods, and special tooling. Personnel learning loss occurs because of layoffs or removal of staff from the production line. Supervisory learning loss occurs when the number of supervisors is reduced because personnel have been reduced, so that supervisors who may no longer be familiar with the job are no longer able to provide optimal guidance.

Learning can also be lost when production continuity changes because the physical configuration of the production line has moved or optimization for new workers is lacking. Methods are usually affected least by production breaks, as long as they are documented. However, revisions to the methods may be required if the tooling has to change once the production line restarts. Finally, tools may break during the production halt or may not be replaced when they are worn, causing productivity loss.

Each category must have a weight assigned to capture its effect on learning. The weights can vary by production situation but must always total 100 percent. To find the percentage of lost learning—known as the learning lost factor—the estimator must determine the learning lost factor in each category and then calculate the weighted average (see table 71).

Table 71: The Anderlohr Method for the Learning Lost Factor

Category	Weight	Learning lost	Weighted loss
Personnel learning	30%	51%	0.1530
Supervisory learning	20	19	0.0380
Production continuity	20	50	0.1000
Tooling	15	5	0.0075
Methods	15	7	0.0105
Total learning lost	100%		0.3090 or 30.9%

Source: DOD.

In the table, if the production break were 6 months, the effect on learning would be almost a 31 percent reduction in efficiency, since the production line shut down.

Retrograde Method

Assume that 10 units had been produced before the production break. The true cost of the first unit produced after the production break would then equal the cost of the 11th unit—assuming no production break—plus the 30.9 percent penalty from the lost learning. The retrograde method simply goes back up the learning curve to the unit (X) where that cost occurred. The number of units back up the curve is then the number of retrograde or lost units of learning. Production restarts at unit X rather than at unit 11.

As illustrated by the Anderlohr and retrograde methods, costs increase as a result of production breaks. Cost estimators and auditors should question how the costs were estimated to account for learning that is lost, taking into account all factors that can be affected by learning.

Step-Down Functions

A step-down function is a method of estimating first unit production costs from prototype (or development) cost data. The first step is to account for the number of equivalent prototype units, based on both partial and complete units. This allows the cost estimator to capture the effects of units that are not entirely whole on the improvement curve. For example, if the development program includes a static article that represents 85 percent of a full aircraft, a fatigue article that represents 50 percent of a full aircraft, and three full aircraft, the development program would have 4.35 equivalent units. If the program is being credited with learning in development, the first production unit would then be unit 5.35.

After equivalent units have been calculated, the analyst must determine if the cost improvement achieved during development on these prototype units applies to the production phase. The following factors should be considered when analyzing the amount of credit to take in production for cost improvement incurred in development:

- the break between the last prototype unit and the start of production units,
- how similar the prototype units are to the production units,
- the production rate, and
- the extent to which the same facilities, processes, and people are being used in production as in development.

By addressing these factors, the analyst can determine proper placement on the curve for the first production unit. For example, analysis might indicate that cost improvement is continuous and, therefore, the first production unit is really the number of equivalent development units plus one. If it is further determined that the development slope should be the same as the production slope, the production estimate can be calculated by continuing down the curve for the desired quantity. This is referred to as the continuous approach.

Analysis of the four factors often leads the analyst to conclude that totally continuous improvement is not appropriate and that some adjustment is required. This could be because prototype manufacture was accomplished in a development laboratory rather than in a normal production environment or that engineering personnel were used rather than production personnel. Numerous reasons are possible for less than totally continuous cost improvement. Since all programs are unique, the analyst must thoroughly evaluate their particularities.

Two Theories Associated with Less Than Continuous Improvement

Two theories, sequential and disjoint, address the issue of less than continuous improvement. Both theories maintain that the improvement slope is the same in production and development but that a step down in value occurs between the cost of the first prototype unit and the cost of the first production unit.

In sequential theory, cost improvement continues where the first production unit equals the last production unit plus one, but a displacement on the curve appears at that point. In disjoint theory, the curve is displaced, but improvement starts over at unit one rather than at the last production unit plus one. These displacements are typically quantified as factors. Because disjoint theory restarts learning, it usually results in significantly lower production estimates.

The continuous cost improvement concept and sequential and disjoint displacement theories assume the same improvement slope in production as in development. Plots of actual cost data, however, sometimes indicate that production slopes are either steeper or flatter than development slopes. In cases in which the historic data strongly support a change in slope, the analyst should consider both a step down and a shift. For example, changing from an engineering environment to a heavily automated production line might both displace the improvement curve downward and flatten it.

End-of-Production Adjustments

As production ends, programs typically incur greater costs for both recurring and nonrecurring efforts. The recurring cost of end-of-production units is often higher than would have been projected from a program's historic cost improvement curve. This is referred to as toe-up. The main reasons for toe-up are

- the transfer of more experienced and productive employees to other programs, resulting in a loss of learning on the production line;
- reduced size of the final lot, resulting in rate adjustment penalties;
- a decrease in worker productivity from the psychological effect of the imminent shutdown of the production line;

- a shift of management attention to more important or financially viable programs, resulting in delayed identification and resolution of production problems;
- tooling inefficiency, resulting from tear-down of the tooling facility while the last production lot is still in process;
- production process modifications, resulting from management's attempts to accommodate such factors as reductions in personnel and production floor space; and
- similar problems with subcontractors.

No techniques for projecting recurring toe-up costs are generally accepted. In truth, such costs are often ignored. If, however, the analyst has access to relevant historic cost data, especially contractor-specific data, it is recommended that a factor be developed and applied.

Typically far more extensive than recurring toe-up costs are the nonrecurring close-out costs that account for the numerous nonrecurring activities at the end of a program. Examples of close-out costs are

- the completion of all design or "as built" drawings and files to match the actual "as built" system; often during a production run, change orders that modify a system need to be reflected in the final data package that is produced;
- the completion of all testing instructions to match "as built" production; and
- dismantling the production tooling or facility at the end of the production run and, sometimes, the storage of that production tooling.

TECHNOLOGY READINESS LEVELS

Readiness level	Definition
1. Basic principles observed and reported	Lowest level of technology readiness. Translation of scientific research into applied research and development begins—examples might include paper studies of a technology's basic properties
2. Technology concept or application formulated	Invention begins, application is speculative, and no proof or detailed analysis supports assumptions. Examples are limited to paper studies
3. Analytical and experimental critical function or characteristic proof of concept	Active research and development begins, including analytical and laboratory studies to physically validate analytical predictions of technology's separate elements. Examples include components not yet integrated or representative
4. Component or breadboard validation in a laboratory	Basic technological components are integrated to establish that the pieces will work together. This is relatively low fidelity compared to the eventual system. Example is integration of ad hoc hardware in a laboratory
5. Component or breadboard validation in relevant environment	Fidelity of breadboard technology increases significantly. The basic technological components are integrated with reasonably realistic supporting elements so that the technology can be tested in a simulated environment. Example is high-fidelity laboratory integration of components
6. System or subsystem model or prototype demonstration in a relevant environment	Representative model or prototype system, well beyond level 5, is tested in a relevant environment, representing a major step up in a technology's demonstrated readiness. Examples include testing a prototype in a high-fidelity laboratory environment or in simulated operational environment
7. System prototype demonstration in an operational environment	Prototype near or at planned operational system, representing a major step up from level 6, requiring the demonstration of an actual system prototype in an operational environment, such as in an aircraft, in a vehicle, or in space. Example is testing the prototype in a test bed aircraft
8. System completed and flight qualified through test and demonstration	Technology has been proven to work in its final form and under expected conditions; in almost all cases, represents the end of true system development. Example is developmental test and evaluation of the system in its intended weapon system to determine if it meets design specifications
9. System flight proven through successful mission operations	Actual application of the technology in its final form and under mission conditions, such as those encountered in operational test and evaluation. In almost all cases, this is the end of the last bug fixing aspects of true system development. Example is using the system under operational mission conditions

Source: GAO.

EVM-RELATED AWARD FEE CRITERIA

Criterion	Rating	Rationale
EVM is integrated and used for program management	Unsatisfactory	Contractor fails to meet criteria for satisfactory performancea
	Satisfactory	Contractor team uses earned value performance data to make program decisions, as appropriate
	Good	Meets all satisfactory criteria, and earned value performance is effectively integrated into program management reviews and is a primary tool for program control and decisionmaking
	Very good	Meets all good criteria and the contractor team develops and sustains continual and effective communication of performance status with the government
	Excellent	Meets all very good criteria, and the entire contractor team proactively and innovatively uses EVM and plans and implements continual EVM process improvement
Contractor manages major subcontractors	Unsatisfactory	Fails to meet criteria for satisfactory performance
	Satisfactory	Routinely reviews the subcontractors' performance measurement baseline
	Good	Meets all satisfactory criteria and the management system is structured for oversight of subcontractor performance
	Very good	Meets all good criteria and actively reviews and manages subcontractor progress so that it provides clear and accurate status reporting to government
	Excellent	Meets all very good criteria, the effective and timely communication of subcontractor cost and schedule status are reported to government, and issues are proactively managed
Cost, expenditure, and schedule forecasts are realistic and current	Unsatisfactory	Contractor fails to meet criteria for satisfactory performance.
	Satisfactory	Contractor provides procedures for delivering realistic and up-to-date cost and schedule forecasts as presented in the CPR, EACs, contract funds status report, IMS, etc. Forecasts are complete and consistent with program requirements and reasonably documented
	Good	Meets all satisfactory criteria, and all requirements for additional funding and schedule changes are thoroughly documented and justified. Expenditure forecasts are consistent, logical, and based on program requirements. The contractor acknowledges any cost growth in the current reporting period and provides well-documented forecasts
	Very good	Meets all good criteria, and expenditure forecasts reflect constant scrutiny to ensure accuracy and currency. The contractor prepares and develops program cost and schedule data that allow government a clear view into current and forecast program costs and schedule. Schedule milestone tracking and projections are very accurate and reflect true program status. The contractor keeps close and timely communications with the government
	Excellent	Meets all very good criteria, and the contractor consistently submits a realistic, high-quality EAC; reported expenditure profiles are accurate. Contractor develops comprehensive and clear schedule data with excellent correlation to technical performance measures and CPRs that permit early identification of problem areas. Schedule milestone tracking and projections are accurate and recognize potential program effect

Criterion	Rating	Rationale
Contractor's cost proposals are adequate during award fee evaluation period	Unsatisfactory	Fails to meet criteria for satisfactory performance
	Satisfactory	Proposal data, including subcontractor data, are logically organized and give government a view adequate to support cost analysis and technical review. A basis of estimate is documented for each element, and when insufficiently detailed. the contractor provides it to the government on request. The proposal is submitted on time
	Good	Meets all satisfactory criteria and provides detailed analysis for subcontractor and material costs
	Very good	Meets all good criteria. Proposal data are traceable and give the government a view for supporting a detailed technical review and thorough cost analysis; only minor clarification is required by government. Potential cost savings are considered in the proposal
	Excellent	Meets all very good criteria; change proposals stand alone and require no iteration for government understanding. The contractor stays in communication during proposal preparation and resolves issues effectively before submission
Costs are controlled	Unsatisfactory	Contractor fails to meet criteria for satisfactory performance
	Satisfactory	Contractor and subcontractor control cost to meet program objectives
	Good	Meets all satisfactory criteria; contractor stays within target cost and provides good control during contract performance
	Very good	Meets all good criteria, and the contractor stays within cost and continues to provide good control during contract performance
	Excellent	Meets all very good requirements; contractor provides suggestions and, when appropriate, proposals to the program office for initiatives that can reduce costs. The contractor implements cost reduction ideas across the program and at the subcontract level and identifies (and when appropriate implements) new technologies, commercial components, and manufacturing processes that can reduce costs
Contractor conducts variance analysis	Unsatisfactory	Fails to meet criteria for satisfactory performance
	Satisfactory	Variance analysis is sufficient and usually keeps the government informed of problem areas and their causes and corrective action. When detail is insufficient, the contractor provides it to the government promptly on request
	Good	Meets all satisfactory criteria and routinely keeps government informed of problem areas and their causes and corrective action. Updates explanations monthly and analyzes potential risks for cost and schedule impacts
	Very good	Meets all good criteria and always keeps government informed of problem areas and their causes and corrective action. Variance analysis is thorough and used for internal management to control cost and schedule. Detailed explanations and insight are provided for schedule slips or technical performance that could result in cost growth. The government rarely requires further clarification
	Excellent	Meets all very good criteria; variance analysis is extremely thorough. Contractor proactively keeps the government informed of all problem areas and their causes, emerging variances, impacts, and corrective actions. Keeps government informed of progress implementing the corrective action plans and fully integrates analysis with risk management plans and processes

Criterion	Rating	Rationale
Billing and cumulative performance data are accurate, timely, and consistent and subcontractor data are integrated	Unsatisfactory	Contractor fails to meet criteria for satisfactory performance
	Satisfactory	Billings to the government may have slight delays or minor errors and the CPR, contract funds status report, and IMS reports are complete and consistent, with only minor errors. Data can be traced to the WBS with minimum effort, and subcontractor cost and schedule data are integrated into the appropriate reports with some clarification required. Reports may be submitted late, but electronic data are correct
	Good	Meets all satisfactory criteria, and billing to government is accurate, although with slight delays. Data are complete, accurate, and consistent and can be traced to the WBS, with some clarification required. Subcontractor performance data are fully integrated into the appropriate on-time reports, with no clarification required
	Very good	Meets all good criteria, and data are complete, accurate, and consistent
	Excellent	Meets all very good criteria, and billing is submitted to government on time. Data are complete, accurate, and consistent and can be traced clearly to the WBS. CPR and contract funds status report data elements are fully reconcilable. Subcontractor schedule performance is vertically and horizontally integrated with the contractor schedule
Baseline is disciplined and system is in compliance	Unsatisfactory	Contractor fails to meet criteria for satisfactory performance
	Satisfactory	Contractor develops a reliable performance measurement baseline that includes work scope, schedule, and cost. The contractor or government may discover system deficiencies or baseline planning errors through either routine surveillance or data inaccuracies in the CPRs. Contract changes and undistributed budget are normally incorporated into the baseline in a timely manner. Management reserve is properly tracked, and eliminating performance variances is limited to correcting errors
	Good	Meets all satisfactory criteria. Contractor develops a reliable performance measurement baseline that includes work scope, schedule, and cost. The contractor or government may discover system deficiencies or baseline planning errors through either routine surveillance or data inaccuracies in the CPRs. Contract changes and undistributed budget are normally incorporated into the baseline in a timely manner. Management reserve is tracked and used properly, and elimination of performance variances is limited to correction of errors
	Very good	Meets all good criteria and the contractor builds a proper and realistic baseline in a timely way. The contractor ensures that work packages are detailed and consistent with scope of contract and planned consistent with schedule. The contractor conducts routine surveillance that reveals minor system deficiencies or minor baseline planning errors that are quickly assessed and corrected, resulting in little or no impact to data accuracy. Contractor's EVM system is effectively integrated
	Excellent	Meets all very good criteria and the contractor proactively manages the baseline and maintains timely detailed planning as far in advance as practical and implements proper baseline controls. The contractor controls and minimizes changes to the baseline, particularly in the near term, and system deficiencies or planning errors are few and infrequent. The contractor streamlines internal processes and maintains a high level of EVM system competency and training

Source: GAO and DCMA.

[a]Program managers need to determine what satisfactory performance criteria will be used since each program is unique.

INTEGRATED BASELINE REVIEW CASE STUDY AND OTHER SUPPLEMENTAL TOOLS

As described in the Cost Guide, the objectives of the integrated baseline review (IBR) are to gain insight into cost and schedule risk areas associated with the subject program (or contract) and to develop confidence in the program's operating plans. The focus of this review should be primarily to assessing the adequacy of the baseline plan to execute the approved program (or contract). In chapter 19, we discuss the key practices for planning and executing an effective IBR. In this appendix, we provide supplemental information on the IBR to help organizations in implementing or improving their IBR capabilities, as well as provide our auditors with further guidance on the planned effort to perform a quality IBR. This information is based on the process the Naval Air Systems Command (NAVAIR) uses, an organization considered a leader in IBR process and in maximizing the value gained from these reviews.[15]

NAVAIR IBR Preparation

IBR Team Roles and Responsibilities

The typical IBR team is made up of the government program manager, technical experts, an EVM analyst, and DCMA, as well as other personnel who may help during the review. The duties of all team members include attending IBR training before the start of the IBR, reviewing contract documentation before baseline discussions with the control account manager (CAM), conducting CAM and senior manager discussions, helping to complete applicable documentation, providing a risk assessment based on the prescribed risk evaluation criteria, and helping to prepare the IBR out-brief. Table 72 describes the specific responsibilities of the key team leaders.

Table 72: IBR Leadership Roles and Responsibilities

Key leader	Role	Responsibility
Program manager	Acts as or assigns the team leader for the IBR; jointly responsible for the IBR process	Plan and perform the IBR Monitor progress on required actions until issues are resolved Provide an adequate number of qualified personnel as IBR team members Specify evaluation criteria for risk areas Document risk issues identified during an IBR Present the IBR out-brief
Performance measurement deputy team leader	This lead role is filled by the NAVAIR [AIR-4.2.3] EVM analyst	Provide overall facilitation for the IBR Provide IBR training before the start of the IBR Review contract documentation before baseline discussions with the control account manager Conduct control account manager and senior manager discussions Provide policy and interpretation of EVM system guidance Provide technical direction and leadership emphasizing the importance of thorough cost, schedule, and technical integration of contract work Ensure that all action item reports are tracked in the EVM risk database Provide an assessment of risk based on the prescribed risk evaluation criteria and all program risk based on the defined risk evaluation criteria Help complete all IBR documentation Help prepare the IBR out-brief

Source: NAVAIR.

[15] The IBR approach is scalable—e.g., the NAVAIR case study is of a major system acquisition, but IBRs on small programs that do not involve a major acquisition may not require the time and number of people cited in this case study to achieve IBR objectives.

Based on experience, NAVAIR officials have told us that the data review with the IBR team before the event is really the key to a successful IBR. Being prepared goes a long way to being able to dig deep in the data to determine whether there are issues and risks in the plan.

IBR Team Training

In the weeks leading up to the IBR event, the IBR team typically participates in a day of training tailored to the subject program that includes the

- basic IBR fundamentals and review of the methodology to be followed on subject program;
- detailed roles and responsibilities of team members;
- guidance on baseline discussions with control account managers and the key documents that should be referenced (and sample data traces across these documents) to see how work is defined, baselined, measured, and scheduled;
- results from recent schedule risk assessments, management system assessments, and major subcontractor IBRs (elements of the IBR NAVAIR performed before the IBR event to better understand the current risks in the baseline and focus on the program areas that align with these risks during the IBR);
- IBR out-brief contents; and
- evaluation criteria, tools, and forms expected to be used during execution (see exhibits B–D at the end of this appendix for select NAVAIR discussion forms and sample questions).

IBR Execution

The duration of the IBR is based on program and contract scope, complexity, and risk; typically, it lasts over several days. Exhibit A at the end of this appendix, for example, is the agenda of activities for an actual 4-day IBR for Program X; it had just implemented an overtarget baseline on its prime contract. (Specific references to the actual program and contractor have been removed.)

This IBR was kicked off with the contractor's overview briefing on its internal management process—risk management, baseline establishment and maintenance, scheduling, EVM methods and tools, work authorization, and standing management meetings with control account managers and subcontractors. The process overview briefing was followed by the team's discussion with the contractor program manager. At the conclusion of this discussion, team members wrote up their observations and findings in their individual assessments. Once the individual assessments were completed (see exhibit B), the team came together to complete a consensus assessment (exhibit B). It is during these consensus meetings that action item reports are typically assigned to individual members for drafting, where applicable (see exhibit C). This same methodology is applied to the control account manager discussions, as well.

Formal Out-brief of IBR Results

Figure 61 shows the team's summary assessment of the risks in Program X, based on the amount of remaining work, level of severity of the risks (many of which affected tasks found on the integrated master schedule's critical path), and the government risk evaluation criteria that was applied. The most critical risks identified were related to the prime contractor's management of its major subcontractors. During the out-brief presentation, the government program manager noted concerns about the prime contractor's current practices in overseeing selected subcontractors because of ongoing poor quality and late receipt of key deliverables—some of which affected the program's critical path. The other critical risks were associated with the specific earned value metrics applied to measure progress in software development.

Figure 61: IBR Team's Program Summary Assessment Results for Program X

Program level rollup of risk

1. Based on remaining work
2. Level of severity (risk level and schedule critical path taken into account)
3. Also considered government risk evaluation criteria

Management processes	Resources	Cost	Schedule	Technical
High	**Medium**	**Medium**	**Medium**	**Medium**
Subcontractor management processes and lack of valuable software earned value performance measures	Have key vacancies in staffing at this time Didn't staff to plan in software area Low confidence in personnel turnover plans and risk of losing expertise	Cost impact of subcontractor (prime using management reserve to mitigate poor performing contractor); software continues to be a risk, but expect to be less than 10% of program at this time	Activities pushing out from original baselines dates, however, appear to be overcoming difficulties with critical path driver subcontractor Will continue to stress importance of near-term schedule	Hardware and software Integration plan was not in place Few identified opportunities (budget and schedule) available to mitigate potential risk areas

Source: NAVAIR.

Figure 62 shows a summary of the detailed assessment results at the major system development areas under evaluation during the IBR.

Figure 62: Program X IBR Team's Assessment Results by Program Area

CAM/Area	BCWS remaining June 2007	Critical path June 2007	Management processes	Resources	Cost	Schedule	Technical
Subcontractor	$49K	SIL TRR	High	High	High	High	High
Subcontractor	$14,626K	SDD	High	Low	Medium	High	Low
Prime contract/Control account manager		SIL	Low	Medium	Low	Medium	Low
Prime contract/Control account manager		&	Low	Medium	Low	Low	Low
Prime contract/Control account manager	$7,299K	SDD	Low	High	Medium	Medium	Medium
Subcontractor/software	$1,344K	NO	Medium	Medium	High	High	High
Subcontractor	$3,629K	NO	High	Low	Low	Low	Low
Prime contractor/logistics	$2,658K	NO	Low	Low	Low	Low	Low
Prime contractor/PM	$2,906K	SIL TRR & SDD	Low	Medium	Low	Low	Low

Source: NAVAIR.

Figure 63 is an example from the detailed findings of a particular program area. This final assessment represents the team's consensus of overall risk ratings by IBR risk category, based on the agreed-on observations and findings from the control account manager discussions. Each corrective action corresponds to a specific action item report.

Figure 63: Program X IBR Team's Detailed Assessment Results for an Individual Program Area

Overall assessment

- Lack of integration of the subcontractor schedule with the program IMS is a big concern
- Communication processes between subcontractor and prime contractor must improve
- Timeliness of EV and technical information transfer is inadequate

Assessment area	Management process	Resources	Cost	Schedule	Technical
Score	H	L	M	H	L

Dialogue highlights

Strengths

- Work allocated to subcontractor is well defined and understood

Risks and issues

- Few identified opportunities remain to mitigate potential technical or cost risk, no management reserve
- Special management attention/monitoring of subcontractor critical path items. Touch points between prime contractor and subcontractor/gov need to be coordinated to reduce any potential schedule risk
- Unable to assess total cost risk due to lack of subcontractor schedule with the program IMS
- Management process issues:
  - Subcontractor PM management reserve decisions
  - Prime subcontractor mgmt processes have yet to be validated
  - Timing of subcontractor IMS submissions
  - Lack of a management process to use management reserve
  - Lack of cost and schedule integration

Risks and issues continued

- Communications between team members and the data sharing across the contract and subcontract especially during A/C installation and test

Corrective actions

- Develop and integrate an IMS with subcontractor (CAR#4)
- Although resources are assessed as low risk, identification of subcontractor scheduler is a high priority
- Prime contractor formally documents emerging processes (EAC, schedule inputs, program management, finalize restructure, and prime contractor evaluation of EVM data) 15 Oct goal to revisit (CAR#6)
- Request a subcontractor org chart with contact information (data request #5)
- Continue A/C induction discussion…to be continued as an action out of IBR (CAR#8)
- Concern that prime contractor is not using subcontractor EVM data to manage subcontractor effort, recommend more detailed analysis of subcontractor CPR prior to submitting to gov (CAR#6)

Source: NAVAIR.

Post IBR Activities

After IBR event activities, the IBR team is responsible for developing the final action item reports, which are then formally submitted to the contractor, who is given about a month to respond back to the team. The team reviews the contractor's responses; sometimes these require further negotiation on the closure of the action item reports. NAVAIR determines whether the contractor has responded sufficiently and the original risk has been addressed. NAVAIR closes the action item, requests further information or clarification, or decides to introduce the risk into the risk management plan. A decision to include the program's risk in the NAVAIR risk database is based on several factors, including the contractor's inability to address the item fully, the lack of a clear action to take at the time, or the realization that it is a risk that the program has to manage. In some cases, IBR reports can remain open for a significant amount of time.

From their experience, NAVAIR officials have told us that they often find that the most difficult parts of the IBR are coming to closure on outstanding action item reports and keeping the program team focused on the issues long after actual events have occurred. Overcoming the perceptions that the IBR is just an event is definitely a challenge.

In consultation with our experts, they noted that the critical factor in closing IBR actions is ensuring that these items receive ongoing attention from the program manager (both government and contractor) based on lessons learned. The most effective way to do this is to incorporate these action items into the business rhythm (usually monthly, including the monthly program management review). Any and all IBR action items captured in the out-brief and supporting documentation should go directly into the contractor's internal action item database for disposition and closure with the appropriate government approvals. The monthly program management review should be used to track the status of the IBR actions. Our experts noted that having a separate list of things to do outside the contractor's business rhythm (and some of the issues are hard to tackle), simply will not get done. Also, waiting long enough could mean that the action items could even be overtaken by events.

In summary, the experts highlighted several key points to this lesson learned:

- use the contractor's action item tracking database;
- load the actions properly into it, assign appropriate responsibilities, receive status updates monthly, and obtain appropriate government reviews and approval to close them; and
- hold the contractor accountable with the award fee process, as applicable.

EXHIBIT A

PROGRAM X: SUBJECT CONTRACTOR

Integrated Baseline Review
August 20–23, 2007

Monday, August 20, 2007
Conference Room A

1400–1430	Opening Comments
1430–1600	Program X Overview Management Systems
1600–1700	Contractor Program Management, Program X, Program Management Discussion
1700–1800	Contractor Program Management Process Write-Up

Tuesday, August 21, 2007
Conference Room B

0800–0830	Government IBR Team Only
0830–1000	Test Team, Control Account Managers 1 and 2
1000–1030	Test Team Write-Up
1030–1045	Break
1045–1200	Major Subcontractor A, Control Account Managers 3 and 4
1200–1300	Lunch
1300–1330	Major Subcontractor A Write-Up
1330–1500	Logistics and Technical Data, Control Account Manager 5
1500–1530	Logistics and Technical Publication Write-Up
1600–1630	Informal Out-brief (to Contractor)
1630–1730	Complete Formal Out-brief for Days 1 and 2, Control Account Managers

Wednesday, August 22, 2007
Conference Room B

0800–0830	Government IBR Team Only
0830–1030	Systems Engineering and SIL Support, Control Account Managers 6 and 7
1030–1130	Systems Engineering and SIL Support Write-Up
1130–1230	Lunch
1230–1400	Major Subcontractor B, Control Account Managers 3 and 8
1400–1430	Major Subcontractor B Write-Up
1430–1500	Break
1500–1630	Major Subcontractor C, Control Account Managers 3 and 8
1630–1700	Major Subcontractor C Write-Up
1700–1730	Informal Out-brief (to Contractor)

Thursday, August 23, 2007
Conference Room B

0800–1130	Government IBR Team: Documentation Wrap-Up & Preparation of Formal Out-brief
1130–1230	Lunch
1230–1330	IBR Schedule Reserve
1400	Deliver Formal Out-brief to Contractor

EXHIBIT B

IBR DISCUSSION ASSESSMENT FORMS

In using assessment forms to frame discussions with control account managers, evaluators should keep in mind three fundamental objectives: (1) to achieve the technical plan, (2) to complete the schedule, and (3) to ensure the sufficiency and adequacy of resources and their time-phasing. These objectives make up the core of the IBR.

Individuals with experience conducting IBRs should be present for each discussion. Without complete understanding of the baseline plan, the results of an IBR are negligible. Our experts discouraged overreliance on checklists or questionnaires, since these may result in "failure to see the forest for the trees." With these three objectives in mind, the forms presented here can be useful for focusing discussions.

IBR Discussion Assessment Form from NAVAIR

Log No. _______________ Team ________ Date________________

1. Manager ___________________ Area of responsibility ___________________

2. Technical scope (statement of work)
   - ______ Complete identification, definition, and flow down
   - ______ Consistency with contract requirements
   - ______ Assignment of responsibility, authority, and accountability

3. Schedules Period of performance________________________
   - ______ Realistic planned durations
   - ______ Logical sequence of work planned
   - ______ Consistency with intermediate/master schedule and contract milestones
   - ______ Significant interdependencies, interfaces, and constraints

4. Cost and resource risk
   - ______ Basis of estimate[16]
   - ______ Budget adequacy and reasonableness (time phasing, levels, mix, type)
   - ______ Resource availability
   - ______ Provisions for scrap, rework, retest, or repair

5. Management process risk
   - ______ Integrated cost, schedule, and technical planning
   - ______ Status of EVM system acceptance. If not accepted, EVM specialists should assess the adequacy of key EVM concepts:
     - ______ Baseline change control
     - ______ Reliability and timeliness of management and performance data
     - ______ EAC determination and maintenance process
     - ______ Subcontract management
     - ______ Objectively planned earned value methods correlated with technical progress
   - ______ Objective determination of progress?
   - ______ Methods correlate with technical achievement?

6. Brief summary of discussion

7. Action item report prepared?

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[16] "Sound basis of estimate" should be understood in the context of the estimate (or contract target value) that resulted after the proposal and negotiation process was completed—the contract value is the new "basis of estimate."

An Alternative Discussion Form

Date: ____________________ Time: ____________________

Program: ____

Control account Managers: ____

WBS (or CLIN): ____

Attendees: ____

____

____

____

Documents reviewed:

Statement of work	WBS and WBS dictionary
Organizational breakdown structure	Responsibility Assignment Matrix
Work authorization document	Control account plans
Integrated master schedule	Critical path analyses
Entrance and exit criteria	Assumptions
Resource planning	Other ____________________

Brief summary of subjects discussed:

Identification of risks:

Were any action item forms prepared? Yes No

If yes, brief description of actions:

Brief statement of strengths, weaknesses, conclusions:

5 = Achievable — risks adequately identified

4 = Probably achievable — risk mitigation effort required in one or more minor areas

3 = Potentially achievable — additional risk mitigation effort required in a number of areas

2 = Risk mitigation borderline — significant risk mitigation effort required; may not be achievable

1 = Not achievable — not achievable as currently planned; risks significantly affect achieving objectives

Plan's achievability:	1	2	3	4	5
• Technical:	1	2	3	4	5
• Schedule:	1	2	3	4	5
• Cost:	1	2	3	4	5

Planned follow-up:

Signatures:

____________________ Government discussion lead

____________________ Contractor discussion participant

EXHIBIT C

IBR ACTION ITEM FORMS

NAVAIR IBR Action Item Report

WBS / Control account: ________________ Log no.: _____________ Date: ____________________

Submitted by: ________________________

Subject of issue or observation:

Discussion of root problem and cause. (Provide impact assessment. Quantify problem and impacts where possible. Provide recommended actions and exit criteria for resolution. Attach exhibits if applicable. Provide reference to control account or work package number).

Contractor's response. (Address root cause of the problem, impact, corrective and preventive action plan; identify dates and POC. Identify exit criteria for corrective action).

Subteam leader signature: __________________

Team leader signature: ______________________

An Alternative Action Item Form

Date: ______________________ Time: ______________________

Program: ____

Control account Manager: ____

WBS (or CLIN): ____

Issue:

Actions required:

Criteria for success:

Estimated completion date: ____

Point of contact: ____

Signatures:

______________________________ ______________________________

Government program manager Control account manager or Functional lead

EXHIBIT D

SAMPLE IBR DISCUSSION QUESTIONS

The following questions were used in the NAVAIR IBR training. They are intended only as a reference guide. NAVAIR expects its IBR teams to select and tailor questions to a program's condition (that is, new program versus overtarget baseline), issues, and risks.

Organization

To introduce the IBR team, identify (graphically if possible) the location of the integrated process team (IPT) in the program (that is, its organizational breakdown structure) relative to other IPTs. Similarly, identify the control and schedule accounts assigned to the IPT and which ones the IPT will discuss in answering the remaining questions. Include your areas of responsibility in the program, whom you report to, your responsibilities toward this person, and how you keep this person informed of status and progress.

What is the manager's scope of effort?

The manager should be able to refer to a statement of work paragraph, a contract WBS narrative, or a work authorization document.

- How many people work for you and what do they do?
- How do they report to you (how do you know the performance status of their work)?

Is all the work planned into control accounts?

The statement of work defines the effort. The contract WBS provides specifics, such as work definition. The work authorization and change documentation should show information such as dollars and hours, period of performance, and the scope of work and any changes.

Are all elements of the scope planned?

The manager should be able to show the scope of work broken down into work packages and the budgets and estimates to complete (ETC) associated with each work package and planning package. The sum of the work packages and planning packages should equal the control account budget. The actual costs plus the estimates to complete should equal the estimate at completion.

What are the manager's resources for assigned work?

Baseline resources should be identified in the work authorization document, and changes in scope, cost, or schedule requirements should be reflected in change request documentation.

Are the resources required to accomplish the current plan consistent with the original plan?

Review the basis of estimate for reasonableness. Does the manager believe that the budget (or ETC if different from BAC) is sufficient to perform the work?

Elicit a range of possibilities (low and high) that represents as clearly as possible the complete judgment of the control account manager, as follows:

- The adequacy of the planned and approved baseline to achieve the approved scope.

- Risks and opportunities included or not included in the baseline. What are the major risks or challenges remaining to accomplish the control account manager's or subcontractor's responsibilities?
  - Ask the control account manager to describe why it is a risk or opportunity.
  - Exchange ideas about risks and opportunities.
  - Establish the likelihood of the risk or opportunity event.
- Ask the control account manager to explain the risk mitigation plan emphasizing risk mitigation milestones and associated risk performance measurement.
- Determine the impact (cost and schedule) for medium and high risks.
- Ask the control account manager to consider extreme values for his effort (optimistic or pessimistic).
- Document results on the risk assessment form.

Authorization

What is the status of work authorization?

Give an example of work authorization documentation.

Ask the control account manager to show his work authorization documents, which define the work to be accomplished. Ask the control account manager to relate these requirements to the work remaining within his team or WBS element when the cost to complete was analyzed or developed.

Budget

Discuss how the control account manager's budget was derived.

How did you arrive at your budget figures? Do you have the backup or worksheets you derived your estimates from?

Was there a negotiation process for your budgets after contract award? Is your budget adequate?

How were you advised of budget? Of tasks? Of schedule? Of changes?

Control Account

How many control accounts are you responsible for and what is their total dollar? May we see a control account plan?

How are your budgets time-phased, and is this reflected in your control account plan?

How do you status your accounts? How does the performance status of your accounts get into the system?

Do you have any LOE accounts? Please describe their tasks.

Do you have any control accounts that contain a mixture of LOE and discrete effort? What is the highest percentage of LOE within an account that also contains discrete effort?

How do you open and close a control account?

What does your computer run show when a control account is opened or closed?

What reports do you receive that give you cost and schedule progress of your control accounts?

Work Package

Assess whether work is measured objectively and whether LOE is appropriate for the nature of the work.

How do your work package activities relate to the master program schedule or underlying intermediate supporting schedules? Support your answer with examples.

How was the budget time-phased for each work package—i.e., what was the basis for the spread? Is the time-phased budget related to planned activities of the work package?

For the example control account, what is your total (IPT) budget amount? Of this total budget amount, how much is distributed to work packages and how much is retained in planning packages? Do you have an undistributed budget and management reserve account?

Do you use interim milestones on any of your work packages to measure BCWP?

How do you define a work package? How many work packages do you have responsibility for?

What options does your EVM system provide for taking BCWP?

Do your control account plans indicate the method used in taking BCWP?

How do you open and close work packages?

Who prepares the budgets for your work packages?

Demonstrate how you earn BCWP in the same way that BCWS was planned.

Can you provide examples of how you measure BCWP or earned value for work-in-process?

Planning Package

What is the procedure and time period for discretely developing work packages from the planning packages?

Are your planning packages time-phased?

Schedule

What are your schedule responsibilities?

What schedule milestones did the manager use in planning the cost accounts? Ask the manager to show the team the schedule milestones used in planning the cost accounts. How does the current schedule compare with the baseline schedule?

The manager should discuss

- relationships of work packages to milestones,
- schedule interfaces and constraints,
- staffing levels to support schedule milestones,
- relationships to other organizations or IPTs,

- schedule impacts related to other work or organizations, and
- level-of-effort tasks that support the schedule.

How did the manager time-phase the work to achieve the schedule? All work should be logically planned in compliance with the SOW and schedule.

Has the manager considered risks in developing the plan?

Has the manager adequately planned and time-phased resources to meet the plan?

Do you directly support any major master or intermediate schedule milestones?

Do you have detailed schedules below the work package? How do detailed schedules below the work package support the work package schedules?

How are you informed by other organizations or IPTs of changes in their output that may affect your control accounts schedules (horizontal trace)?

Demonstrate that the progress reflected on the master program schedule or underlying intermediate schedules correlates to the relative progress reflected in the EVM system.

Change Control

Has the budget baseline had changes or replanning efforts?

Have you had any changes to your accounts? (Give example of how these are handled.)

Have you had any management reserve or undistributed budget activity?

Do you have any work originally planned for in-house that was off-loaded? How was this accomplished?

Earned Value

What methods and tools does the manager use in administering the plan?

Examples are weekly or monthly earned value reports; master, intermediate, and detail schedules; periodic meetings; and independent assessments of technical progress. Determine how changes are incorporated. Evaluate the effect of changes on performance measurement information. Assess whether changes accord with the EVM system description.

What formal training have you had in EVM?

Estimate at Completion and Cost-to-Complete Subcontractor

Are you responsible for any subcontracts? How do you monitor their performance? How do you take BCWP?

How are subcontracts managed? Ask the subcontracts manager to describe the process for managing subcontractor earned value.

- What subcontracts are your responsibility? What types of subcontracts exist or are planned for negotiation (e.g., fixed price vs. cost reimbursement)?

- What are the major challenges or risks to the subcontractor in accomplishing program responsibilities?
- Are these items tracked by the program management office or functional manager in a risk register or plan?
- What subcontractor technical, schedule, and cost reports must be submitted to you or your team?
- What is your total budget (for each subcontract and the corresponding control accounts)? How is profit or fee included in your budget?
- How was the budget established? Does it reflect an achievable value for the resources to fully accomplish the control account scope of effort?
- What rationale was used to time phase the budget resources into monthly or weekly planning packages, tasks, work packages, or summary activities?
- Are the time-phased budget resources consistent with your program master schedule? Show the trace from your control account to intermediate or master schedules.
- When are you required to plan planning packages or summary activities in detail? What schedule document or system is used to develop detail planning for your control account?
- How do you know that the work within your control accounts to be performed by subcontractor has been properly planned?
- How do you check the status and performance of work on your control account by a subcontractor?
- How are actual costs recorded against your cost account?
- What techniques are available for determining earned value? Explain the techniques you are using for this control account.
- How and when is the risk assessment or risk management plan updated for technical,/ schedule, and cost risk items affecting your control account?
- How and when is the actual and forecast schedule update provided for your control account effort?
- Are variance analysis thresholds or requirements established for reporting technical, schedule, or cost variances to planned goals established for your control accounts? Do you informally or formally report the cause of variance, impact, or corrective action for these variances?
- What document authorizes you to begin work on a subcontract?
- For these selected work packages, what specific outputs, products, or objectives are to be accomplished?
- What specifically do you need from other control account managers to generate subcontractor outputs or products? How do you monitor progress?
- Who specifically needs the subcontractor outputs or products to perform their program functions? How do you status others on the progress of your outputs to them?

- Specifically, what technical items are produce the greatest risk to achieving technical, schedule, or cost goals? Are these items reviewed as part of a risk assessment, management plan, or other reporting tool to your boss or the program management office?
- How do you determine whether the reported cost variance stems from subcontractor effort or company overhead rate?

Have material budgets been planned?

Is material tracked before delivery?

How do you track material when deliveries are late?

When is BCWP or earned value taken on material?

Analysis

Do you have any variance thresholds for your control accounts?

What are the variance thresholds for your control accounts?

How do you know when you have exceeded a threshold?

Do you have samples of any variance analysis reports? Do they show a statement of the problem, the variance, cause, impact, and proposed corrective action?

Who receives your variance reports? What action is taken on the reports?

Which reports do you use most frequently? Why?

Not Categorized

How are you reporting labor, material, and other direct costs?

Has your IPT effort been affected by any directed contractual change? When did you receive authorization to proceed with the change and how did your IPT incorporate the change in its planning (schedule and budget time phasing)?

Demonstrate that the current planning for your IPTs product delivery and services provided supports program IPTs and contract delivery commitments.

What changes have been made to the control account planning (technical definition of scope, schedule, budget resources, ETCs)?

- What documents are involved in a change to the control accounts' scope of work, schedule, budget, or ETC?
- Did the control account manager rephase or replan work? In process work? Completed work? Unopened work packages? Make current period or retroactive changes?
- Did the control account manager transfer budget between control accounts?
- How have contract changes or other changes been incorporated into the control account?

COMMON RISKS TO CONSIDER IN SOFTWARE COST ESTIMATING

This appendix lists common risks in software acquisition and offers some possible risk containment actions to mitigate certain effects. It is organized by key area of software acquisition: (1) requirements, (2) design, (3) test and evaluation, (4) technology, (5) developer, (6) cost or funding, (7) monitoring, (8) schedule, (9) personnel resources, (10) security and privacy, (11) project implementation strategy and plans, (12) specific commercial off-the-shelf risks, (13) business risk, and (14) management.

		Potential effect on										
Area and risk	**Potential effect**	**Design**	**Code**	**Test**	**Acceptance testing**	**Operations and maintenance**	**Program operations**	**User acceptance**	**Training**	**Upgrades**	**Documentation**	**Possible risk containment action**
Requirements												
Does not reflect user needs	System rejection; program operations adversely affected; cost increases; rework	x	x	x	x	x	x	x	x			Those affected manage requirements, with review and approval
Too many or too restrictive design and implementation constraints	Infeasibility; increased cost to meet requirements, poor design	x	x	x	x	x	x	x		x		Rewrite and review requirements to address functions embedded in the constraints; perform cost-benefit analysis of constraints and remove unnecessary or costly constraints
Uncertain requirements	Rework; unsuitable product, cost, and schedule increases; inaccurate cost estimates; possibly infeasible end product	x	x	x	x	x	x	x	x	x	x	Define requirements before proceeding to next stage; prototype; hedge cost and schedule for risk; divide end-product in segments and prioritize for implementation

		Potential effect on										
Area and risk	**Potential effect**	**Design**	**Code**	**Test**	**Acceptance testing**	**Operations and maintenance**	**Program operations**	**User acceptance**	**Training**	**Upgrades**	**Documentation**	**Possible risk containment action**
Unstable	Rework; unsuitable product; cost and schedule increases	x	x	x	x	x	x	x	x	x	x	Limit size of implementation segments; prototype
Untraceable	Design does not meet requirements; rework; cost and schedule increases; unreliable testing		x	x	x	x	x	x	x	x	x	Establish and maintain traceability to products and tests
2. Design												
Does not achieve performance objectives	Increased program operation costs				x	x	x	x				Review design for alternatives; establish performance objectives for acceptance; simulations
Does not meet requirements	System rejection; rework		x	x	x	x	x	x	x			Establish traceability to requirements
Infeasibility	Product does not work		x	x	x	x	x	x	x	x		Review design, including feasibility analysis
Not cost effective	Increased maintenance costs				x	x	x			x		Analyze design for effectiveness and other design alternatives before coding
More training needed	Increased program operating cost						x	x	x		x	Review design for alternatives
3.Test and evaluation												
Does not address operating environment	Poor system performance; increased operating and maintenance costs		x		x	x	x	x			x	Perform operational capability testing

		Potential effect on										
Area and risk	**Potential effect**	**Design**	**Code**	**Test**	**Acceptance testing**	**Operations and maintenance**	**Program operations**	**User acceptance**	**Training**	**Upgrades**	**Documentation**	**Possible risk containment action**
Inadequate acceptance testing	Premature acceptance; increased operating and maintenance costs				x	x	x	x	x	x	x	Plan and allow time for acceptance testing; establish traceability to design and requirements
Insufficient time to fix	More acceptance testing needed		x	x	x	x	x	x	x	x	x	Increase schedule
Insufficient time to test thoroughly	More acceptance testing needed		x	x	x	x	x				x	Require test plans, reports, and compliance matrixes as deliverables; increase schedule to allow for adequate testing
Test planning not begun during initial development	Increased costs; inadequate testing; rework		x	x	x	x	x	x			x	Begin acceptance test planning immediately after requirements are baselined; establish traceability to requirements
Test procedures do not address all major performance and reliability requirements	Poor system performance; poor product quality; more acceptance testing needed; negative effect on program operations; rework		x	x	x	x	x	x	x		x	Establish traceability to all requirements; include performance and reliability requirements as acceptance criteria; require test plans, reports, and compliance matrixes as deliverables

		Potential effect on										
Area and risk	**Potential effect**	**Design**	**Code**	**Test**	**Acceptance testing**	**Operations and maintenance**	**Program operations**	**User acceptance**	**Training**	**Upgrades**	**Documentation**	**Possible risk containment action**
Various levels of testing are not performed (system, integration, unit)	Poor system performance; more acceptance testing needed; poor product quality		x		x	x	x	x			x	Establish traceability to all requirements; include testing requirements in contract; require test plans, reports, and compliance matrixes as deliverables
4. Technology												
Availability	Needed functionality delayed; increased program operation costs; business disruption					x	x	x	x	x		Devise alternate business processes; consider other technology
Potential advances result in less- than-optimal cost-effective system	Increased program operating and operations and maintenance costs					x	x	x				Consider replacing; change business process
Potential changes make other components obsolete	Increased operations and maintenance costs; program disruption	a	x	x	x	x	x	x		x	x	Periodic review of architecture and of changes in technology field; regular cycle upgrade

Area and risk	Potential effect	Potential effect on: Design	Code	Test	Acceptance testing	Operations and maintenance	Program operations	User acceptance	Training	Upgrades	Documentation	Possible risk containment action
Relies on complex design	Increased program operations costs (additional training); reduced cost-benefit; increased operations and maintenance costs				x	x	x		x	x	x	Simplify and review design; conduct and compare parallel design activities; prototyping
Technology becomes obsolete or is abandoned	Program disruption; needed functionality unavailable; new acquisition required	a				x	x	x		x	x	Scheduled upgrades; periodic review of changes in technology field
Unproven or unreliable	Program disruption Increased operations and maintenance costs				x	x	x	x	x	x	x	Operational capability demonstrations and testing; delay acquisition; use other technology
5. Developer												
Ability to produce item; poor track record for costs and schedule; key personnel turnover	Needed functionality unavailable or delayed; increased financial risk to acquirer; increased cost, reduced quality, delays	x	x	x	x	x	x	x	x	x	x	Terminate contract; performance-based contract; limited task orders; EVM or similar system
6. Cost or funding												
Funding type does not match acquisition strategy	Uncertain financing; changes in project direction	b	b	b	b	b	b	b	b	b	b	Plan new acquisition strategy to map to funding type

Area and risk	Potential effect	Potential effect on: Design	Code	Test	Acceptance testing	Operations and maintenance	Program operations	User acceptance	Training	Upgrades	Documentation	Possible risk containment action
Marginal performance capabilities incorporated at excessive costs (cost-benefit tradeoffs not performed)	Increased program operation costs and operations and maintenance costs for little benefit					x	x	x				Maintain updated business case analysis return on investment; re-scope; risk-adjusted cost benefit analysis of alternatives
Realistic cost objectives not established early	Greater financial risk; potential delays	x	x	x	x	x	x	x	x	x	x	Scheduled estimate updates and reviews
Schedule not considered in choosing alternative implementation strategies	Unrealistic schedule; increased costs; reduced quality; infeasibility; changes in project direction	x	x	x	x	x	x	x	x	x	x	Re-examine business case and update for better information
Unstable funding	Increased costs and schedule and reduced quality due to stop and start; loss of project momentum	b	b	b	b	b	b	b	b	b	b	Incremental, modular implementation segments that can be funded
7. Monitoring												
Insufficient monitoring	Transfer of risk to acquirer; inability to recover from schedule slippage for lack of timely information	x	x	x	x	x	x	x	x		x	Increase monitoring in riskiest areas
8. Schedule												
Dependence on other projects	Delays; increased costs	x	x	x	x	x	x	x	x	x	x	Reduce dependencies; coordinate with another project
Insufficient resources to meet schedule	Delays; poor quality	x	x	x	x	x	x	x	x	x	x	Increase resource or schedule; reduce scope

		Potential effect on										
Area and risk	**Potential effect**	**Design**	**Code**	**Test**	**Acceptance testing**	**Operations and maintenance**	**Program operations**	**User acceptance**	**Training**	**Upgrades**	**Documentation**	**Possible risk containment action**
Schedule may be delayed waiting for external approvals	Inability to meet due date; increased cost; reduced scope; product failure	x	x	x	x	x	x	x	x	x	x	Reduce scope; increase resources where reasonable, allowing for greater coordination complexity; extend due date
Tasks allocated poorly	Poor quality; inefficiency	x	x	x	x	x	x	x	x	x	x	Reallocate or restructure tasks
Unrealistic	Poor quality from shortening vital tasks; cost increases; infeasibility	x	x	x	x	x	x	x	x	x	x	Increase schedule; reduce scope
9. Personnel resources												
Inadequate skills or staffing; inadequate mix of staff and skills	Poor quality; delays; increased costs	x	x	x	x	x	x	x	x	x	x	Training; hire more staff; reassign tasks or staff outside the project
10. Security and privacy												
Inadequate	Failure to certify system; system breaches; data corruption	x	x	x	x	x	x	x	x	x	x	Address security in requirements, design, and testing; test periodically or as changes are made to ensure continued security and privacy
11. Project implementation strategy and plans												
Architectural dependencies	Architectural components	x	x	x	x	x				x		Adhere to enterprise architecture

		Potential effect on										
Area and risk	**Potential effect**	**Design**	**Code**	**Test**	**Acceptance testing**	**Operations and maintenance**	**Program operations**	**User acceptance**	**Training**	**Upgrades**	**Documentation**	**Possible risk containment action**
Dependence on other projects or systems	Schedule delay;cost increases; uncontrolled changes; service disruption	x	x	x	x	x	x	x	x	x	x	Memorandum of understanding with other project or system owner; regular coordination meetings; reduce dependencies and predecessors
Inadequate link to mission need	Unnecessary system components; increased costs or schedule	x				x	x	x				Check back to system goals in each system phase
Nonmodular development and implementation approach	Funding risks; schedule; cost; quality; requirements instability	x	x	x	x	x	x	x	x	x	x	Incremental or modular implementation segments
Overall implementation strategy does not properly address key development phases and technology considerations	Troubled project; product defects	x	x	x	x				x	x	x	Follow industry standards in development and tailor to nature of technology being implemented
Risks not acted on	Troubled project; product defects; cost and schedule increases	x	x	x	x	x	x	x	x	x	x	Manage risks
Significant custom development required, with additional requirements	Product problems; increased operations and maintenance	x	x	x	x	x	x		x	x	x	Consider other technology or alternatives; reengineer or simplify business process

		Potential effect on										
Area and risk	**Potential effect**	**Design**	**Code**	**Test**	**Acceptance testing**	**Operations and maintenance**	**Program operations**	**User acceptance**	**Training**	**Upgrades**	**Documentation**	**Possible risk containment action**
Subordinate strategies and plans not developed in a timely manner	Delays; inefficiency	x	x	x	x				x			Create strategies and plans in a timely manner
Subordinate strategies and plans not linked to overall strategy	Delays inefficiency	x	x	x	x				x			Create links to higher- level plans
Wide scope of work	Increased complexity, cost, or schedule	x	x	x	x	x	x	x	x	x	x	Prioritize requirements
12. Commercial off-the-shelf												
Long-term maintenance and support not considered	Inability to perform maintenance; lack of skills or resources					x	x			x	x	Transition plan; training; link to business and human resources goals
Planned life of more than 5 years per version or vendor	Obsolescence; lack of vendor support if business is sold or turns down					x	x			x		Planned upgrades or replacement
Significant number of complex interfaces to other systems	Data quality and timeliness; increased maintenance; additional requirements	x	x	x	x	x	x			x	x	Simplify or reduce interfaces
Total life cycle costs not considered	System goals not reached; uncertain operations and maintenance costs					x	x	x				Initial business case analysis with cost-adjusted risk analysis of alternatives; return on investment

		Potential effect on										
Area and risk	**Potential effect**	**Design**	**Code**	**Test**	**Acceptance testing**	**Operations and maintenance**	**Program operations**	**User acceptance**	**Training**	**Upgrades**	**Documentation**	**Possible risk containment action**
13. Business												
Inappropriate development approach or methodology	Cost and schedule overruns; failure; lost opportunity	x	x	x	x	x	x	x			x	Use appropriate development model (spiral, incremental, waterfall)
Downtime affects service or business	Loss of opportunity; customer dissatisfaction and complaints; inability to perform business function					x	x					Monitor system performance; periodic upgrades or enhancements; backup and redundancy
Technology is built on old business processes	Inefficiency or redundancy; operational failure; increased personnel costs					x	x		x			Benchmark and reengineer or streamline processes
14.Management												
Demand for service is higher than resources can handle	Staff burnout; reduced service quality; loss of customer satisfaction	x	x	x	x	x	x	x	x	x	x	Prioritize service to ensure quality remains high
Inability to manage the complexity or scope of system, project, or operations	Failure; system or implemented processes degrade from original implementation; project goes over schedule or over budget	x	x	x	x	x	x	x	x	x	x	Training; use project sponsor to ensure ongoing coordination across groups; decrease scope; break effort into segments

		Potential effect on										
Area and risk	**Potential effect**	**Design**	**Code**	**Test**	**Acceptance testing**	**Operations and maintenance**	**Program operations**	**User acceptance**	**Training**	**Upgrades**	**Documentation**	**Possible risk containment action**
Outside pressures to produce something shortens the requirements period	Cost and schedule increase; disputes with customer about end-product; contract disputes; substandard product	x	x	x	x	x	x	x	x	x	x	Resist pressure to bypass requirements; use prototypes or storyboards to produce something and refine requirements; select a different development approach
Progress is affected by unstable or unstated business processes	Failure or rejection; increased schedule and cost to implement; additional changes to system; user confusion; business process inefficiency or ineffectiveness	x	x	x	x	x	x	x	x	x	x	Design processes before committing to system design
Users or organizations resist change	Failure or rejection; increased schedule and cost to implement; additional changes to system	x	x	x	x	x	x	x	x	x	x	Involve parties in requirements and design, communication, organizational change management plan; bring project sponsor to upper management; training and support

Source: GAO.

[a]Architecture.

[b]Impact area depends on financing and timing.

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