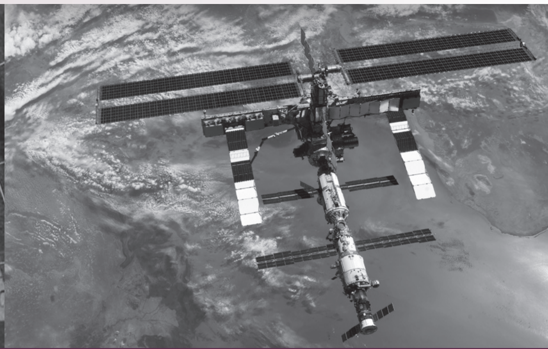
GAO BEST PRACTICES

COST ESTIMATING AND ASSESSMENT GUIDE

Best Practices for Developing and Managing Program Costs



GAO-20-195G

March 2020

GAO
U.S. GOVERNMENT ACCOUNTABILITY OFFICE

Contents

Tables

Figures

Acronyms and Abbreviations

AAV	Assault Amphibious Vehicle
ABL	Airborne Laser
AC	actual cost
ACWP	actual cost of work performed
ALIS	Autonomic Logistics Information System
ANSI	American National Standards Institute
AOA	analysis of alternatives
BAC	budget at complete
BCWP	budgeted cost of work performed
BCWS	budgeted cost of work scheduled
CAM	control account manager
CAPE	Cost Assessment and Program Evaluation
CARD	Cost Analysis Requirements Description
CBB	contract budget base
CBO	Congressional Budget Office
CER	cost estimating relationship
CER	compliance evaluation review
CPI	cost performance index
CPR	contract performance reports
DCMA	Defense Contract Management Agency
DHS	Department of Homeland Security
DOD	Department of Defense
DOE	Department of Energy
EAC	estimate-at-complete
EIA	Electronic Industries Alliance
ERP	enterprise resource planning
EV	earned Value
EVM	earned value management
FFP	firm fixed price
GR&A	ground rules and assumptions
GSA	General Services Administration
HUD	Housing and Urban Development
IBR	integrated baseline review
ICA	independent cost assessment
ICE	independent cost estimate
ICEAA	International Cost Estimating and Analysis Association
IGCE	Independent Government Cost Estimates
IMS	integrated master schedule

IS	information system
IT	information technology
JIAC	Joint Intelligence Analysis Complex
JSF	Joint Strike Fighter
JWST	James Webb Space Telescope
LCCE	life cycle cost estimates
MOX	Mixed Oxide
MR	management reserve
NASA	National Aeronautics and Space Administration
NDIA	National Defense Industrial Association
NNSA	National Nuclear Security Administration
OBS	organizational breakdown structure
OMB	Office of Management and Budget
OSM	objectives, scope, and methodology
PMB	performance measurement baseline
PMI	Project Management Institute
POE	program office estimate
PV	planned value
PWS	performance work statement
ROM	rough order of magnitude
SAR	Selected Acquisition Reports
SLOC	source lines of code
SLS	Space Launch System
SME	subject matter expert
SOO	statement of objective
SOW	statement of work
SPI	schedule performance index
TCPI	to complete performance index
TRA	technology readiness assessment
TRL	technology readiness level
USCG	United States Coast Guard
USMC	United States Marine Corps
VAC	variance at completion
WBS	work breakdown structure

U.S. GOVERNMENT ACCOUNTABILITY OFFICE
441 G St. N.W.
Washington, DC 20548

Preface

To use public funds effectively, the government must employ 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 program costs are. The U. S. Government Accountability Office (GAO) has shown that in order to conduct oversight of the federal government, including agencies' stewardship of public funds, reliable cost information is required. We developed this Guide to establish a consistent methodology based on best practices that can be used across the federal government for developing, managing, and evaluating program cost estimates. The *Cost Estimating and Assessment Guide* presents the best practices associated with developing a reliable, high-quality cost estimate and the best practices associated with effective management of program costs using earned value management (EVM).[1] Use of these best practices should enable government programs to better estimate and manage their costs to improve program management and execution.

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. The management of a cost estimate involves updating the estimate with actual data as they become available, revising the estimate to reflect program changes, and analyzing differences between estimated and actual costs—for example, by using data from a reliable EVM system.

The methodology outlined in this Guide is a compilation of best practices that federal cost estimating organizations, the public sector, and industry use to develop and maintain reliable cost estimates throughout the life of a government program. The ability to generate reliable cost estimates is a critical function for federal agencies and is necessary to support the Office of Management and Budget's (OMB) capital programming

[1]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 actual cost of the work accomplished and the value of the work planned in that period. Differences are measured in both cost and schedule variances. The Office of Management and Budget (OMB) requires agencies to use EVM for major acquisitions with development effort.

process.[2] Without this ability, agencies are at risk of experiencing cost overruns, missed deadlines, and performance shortfalls—all recurring problems that GAO program assessments too often reveal. Furthermore, cost overruns may cause the government to reduce funding for other programs, which affects their results or timely execution.

GAO, the Congressional Budget Office (CBO), and other organizations have developed projections that show the nation's fiscal path is unsustainable, primarily because of health care programs and net interest on the debt. New resource 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. When resources are scarce, competition for those resources increases. It is imperative, therefore, that government programs deliver their promised results, not only because of their value to the public, but also because every dollar spent on one program is one less dollar available to fund other efforts.

We intend to update the *Cost Estimating and Assessment Guide* to keep it current. Comments and suggestions from experienced users, as well as recommendations from experts in the cost estimating, scheduling, and program acquisition disciplines, are always welcome. If you have any questions concerning this Guide, you may contact me at (202) 512-6888 or personst@gao.gov. Contact points for our Office of Congressional Relations and Office of Public Affairs may be found on the last page of this Guide. Major contributors to this project are listed in appendix III.

T.M. Persons

Timothy M. Persons, Ph.D.
Chief Scientist and Managing Director
Science, Technology Assessment, and Analytics Team

[2] Office of Management and Budget, Executive Office of the President, *Preparation, Submission, and Execution of the Budget*, Circular No. A-11 (Washington, D.C.: December 2019); Office of Management and Budget, Executive Office of the President, *Managing Federal Information as a Strategic Resource*, Circular No. A-130 (Washington, D.C.: July 28, 2016); and Office of Management and Budget, Executive Office of the President, *Capital Programming Guide, Supplement to Circular A-11, Part 7, Preparation, Submission, and Execution of the Budget* (Washington, D.C.: December 2019).

Introduction

Developing reliable cost estimates is crucial for realistic program planning, budgeting and management. While some agency guidelines on cost estimating are thorough, other agency guidance is limited regarding processes, procedures, and practices for ensuring reliable cost estimates. The *Cost Guide* is intended to address that gap. Its purpose is twofold—to address generally accepted best practices for ensuring reliable cost estimates (applicable across government and industry) and to provide a detailed link between cost estimating and earned value management (EVM). Providing that link is especially critical, because it demonstrates how both elements are necessary for setting realistic baselines and managing risk. As a result, government managers and auditors can use the best practices in the *Cost Guide* to assist them as they assess (1) the reliability of a program's cost estimate for budget and decision-making purposes, and (2) the program's status using EVM.

The *Cost Guide* outlines key steps in the cost estimating process: the purpose, scope, and schedule of a cost estimate; a technical baseline description[3]; a work breakdown structure (WBS); ground rules and assumptions; data collection; estimating methodologies; sensitivity and risk analysis; documenting and presenting results; and updating estimates with actual costs. The Guide also includes information on EVM; the composition of a competent cost estimating team; software cost estimating; and best practices for an analysis of alternatives. Additionally, the Guide addresses auditing and validating cost estimates. The Guide discusses pitfalls associated with cost estimating and EVM that can lead government agencies to accept unrealistic budget requests—such as when risks are unaccounted for in an otherwise logical approach to estimating costs.

Developing the Guide

Our approach to developing this Guide was to revise and update best practices and standard criteria originally published in GAO's *Cost Guide*. To update the criteria for cost estimating standards, we consulted with a committee of cost estimating, scheduling, and earned value analysis specialists from across government, private industry, and academia. We sought input and feedback from all who expressed interest in revising the *Cost Guide* for three months. We describe our scope and methodology in detail in appendix I.

[3]A technical baseline description is a document or set of documents that describe the program's or project's purpose, system, performance characteristics, and system configuration.

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

The *Cost Guide* in Relation to Established Standards

Appendix XII provides information on how cost estimating standards relate to an entity's internal control system. 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 International Cost Estimating and Analysis Association (ICEAA) and AACEI, which provide standards for cost estimating, and the Project Management Institute (PMI), which provides EVM standards.

The Guide's Readers

The federal audit community is the primary audience for this Guide. Besides GAO, auditing agencies include Inspectors General and agency audit services. Additionally, agencies that do not have a formal policy for conducting or reviewing cost estimates will benefit from the Guide because it will inform them of the criteria GAO uses in assessing a cost estimate's reliability. The National Science Foundation, Federal Railroad Administration, and Missile Defense Agency are examples of agencies that have aligned their cost estimating guidance to GAO's cost estimating best practices.

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. Appendix II gives some background information for each program used in the case studies. Some case studies in this Guide are reprinted from GAO reports that are several years old. These case studies are reflective of agency practices at that time and are provided for illustration purpose only.

Applicability of the Guide

Throughout this Guide, we refer primarily to cost estimates that encompass major system acquisitions, although the best practices in the Guide are equally applicable to capital and non-capital program cost estimates. Since its publication in 2009, we have applied the cost estimating best practices as auditing criteria to a myriad of capital and non-capital programs. These criteria are not limited to large-scale, non-real estate programs such as weapons systems, spacecraft, aircraft carriers, and software systems. We have applied the cost estimation practices in past work involving communications networks, the decennial census, high speed rail projects, and federal construction and maintenance projects. The practices are also applicable to government in-house development efforts for which a cost estimate must be developed to support a budget request. Wherever possible, the Guide uses generalized cost estimating terminology for practices and related documentation. However, in certain cases we use Department of Defense terminology because DOD is considered by many experts to be a leading agency in cost estimating techniques.

In this Guide, we use the term “program,” but some agencies may make distinctions between programs, projects, activities, functions, policies, or products. For the purposes of this Guide, these terms can be used interchangeably to accommodate an agency’s particular application. The processes and best practices developed in this Guide are intended for use in any acquisition, program, project, activity, function, policy, or product that benefits from the use of cost estimating and earned value management.

Finally, while we briefly discuss economic analyses in an overview of cost analysis in chapter 2, this Guide does not pertain to economic analyses.

The New *Cost Guide*

Chapters 1–16 of the *Cost Guide* discuss the importance of cost estimating and best practices associated with creating reliable cost estimates. They describe how cost estimates are used to predict, analyze, and evaluate a program’s cost and schedule and serve as a critical program control planning tool. The first two chapters discuss government’s need for cost estimating and a general overview of types of cost estimates and related analyses. Chapter 3 introduces the 12 steps in developing a reliable cost estimate, the associated best practices, and how the steps and best practices relate to the four characteristics of a reliable estimate. Chapters 4 through 15 address each of the 12 cost estimating steps. Chapter 16 is a new chapter focused on the auditor, and recaps steps, best practices, and characteristics and the process for auditing and validating an estimate.

Chapters 17-20 discuss cost management and the use of earned value management for measuring program performance against an approved baseline plan. Those chapters address best practices in implementing and integrating cost estimating, system development oversight, and risk management and their use to manage costs throughout the life of a program.

Changes from the 2009 *Cost Guide*

We have revised the initial version of the *Cost Guide* for the following reasons:

- To better describe the alignment of best practices, cost estimate characteristics, and cost estimating steps
- To clarify some of the best practices and their related criteria
- To provide additional content in technical appendixes and revise or delete others
- To update case studies and references to legislation and rules
- To modernize the Guide's format and graphics

We developed one new chapter and significantly revised a second one to better describe the alignment of best practices to the characteristics of a reliable cost estimate and the process for creating reliable estimates. Chapter 3 introduces the four characteristics: comprehensive, well documented, accurate, and credible. It also introduces the 18 best practices and shows how the best practices align to the four characteristics. Additionally, it introduces the 12 steps of the cost estimating process that produce reliable estimates, and shows how the best practices align with the 12 steps. Chapter 16 reviews the characteristics and best practices in the context of auditing and validating the cost estimate. It describes each characteristic, its associated best practices, and includes effects that may occur if the best practices are not met. Chapter 16 also explains to the auditor how to assess a cost estimate, determine the reliability of a cost estimate, and how to evaluate an organization's cost estimating guidance.

We added a survey of each cost estimating step at the end of its associated chapter. The survey describes the cost estimate process tasks and associated best practices. It also includes likely effects if the associated criteria are not fully met.

We have clarified some of the best practices. For example, the original Guide states that it is a best practice to present the estimate to management in a briefing. We recognize that organizations may use other methods to inform management about cost estimates and have updated the best practice by generalizing the requirement. In the updated Guide, any form of presentation to management is a valid means of meeting the best practice. Additionally, we previously described the technical baseline as a single document that includes detailed technical, program, and schedule information about a system. We have found that some programs describe this system information in a collection of documents. Thus, we have generalized our description of the technical baseline to be a single document or several documents stored in one location.

We have added two new appendixes, one that discusses best practices for analysis of alternatives (AOAs) and the second describing the relationship of internal controls to the cost estimating process. We have removed three appendixes. The appendix covering federal cost estimating and earned value legislation has been streamlined and is now included as a table in chapter 16. Because schedule risk analysis is covered in depth in GAO's Schedule Assessment Guide, we have removed that appendix from the Guide. Additionally, we moved the software chapter to the appendix and deleted the previous appendix on software cost estimating risks. Finally, some material related to award fee criteria and progress payments was removed from chapter 18.

The original *Cost Guide* includes case studies from 1998-2007. Where possible, we have used GAO reports published since then to include more recent case studies within the Guide. Additionally, we have updated references in this Guide.

The original *Cost Guide* was published in 2009. Since then, GAO has updated and modernized the style and appearance of its best practice guides. This Guide has been revised to align with its companion guides, the *Schedule Assessment Guide* and the Technology Readiness Assessment Guide.

Acknowledgments

The *Cost Guide* team thanks the many members of the cost community who helped to develop and improve the Guide. After we discussed our plans for performing an update to the original Guide with members of the cost community, several experts expressed interest in working with us. Their contributions are invaluable.

Together with these experts, GAO has developed a Guide that clearly outlines its criteria for assessing cost estimates and EVM data during audits 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.

Chapter 1: 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.

Developing reliable cost estimates has been difficult for agencies across the federal government for many years. 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 capability shortfalls.

OMB's *Capital Programming Guide* requires agencies to have a disciplined capital programming process that sets priorities between new and existing assets.[4] 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 cost, schedule, and performance goals. 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

[4]OMB first issued the *Capital Programming Guide* as a Supplement to the 1997 version of Circular A-11, Part 3. We refer to the 2019 version.

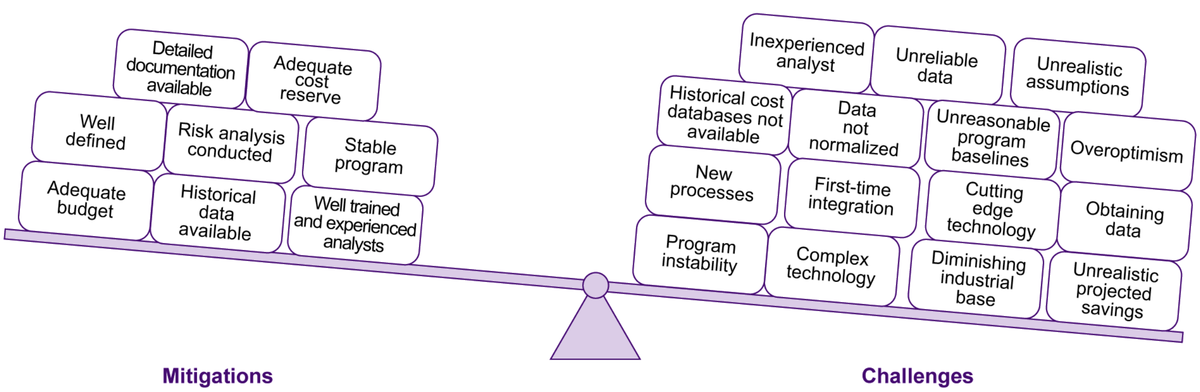
and necessary to establish realistic baselines from which to measure future progress.

Cost Estimating Challenges

Reliable cost estimates are important for program approval and for continued funding. However, cost estimating is challenging. Limited time and resources often prevent the development of the perfect cost estimate; it is proper and prudent to complete the estimate with the best available information at the time while also documenting the estimate's shortcomings. 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. These challenges increase the possibility that programs will fall short of cost, schedule, and performance goals. Recognizing and planning for these challenges early in the process can mitigate the risks.

Even in the best of circumstances, cost estimating can be difficult. The cost estimator typically faces many challenges. These challenges often lead to unreliable estimates—for example, 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, or adhere to no defined process for generating the estimate. Figure 1 illustrates some of the challenges a cost estimator faces and some of the ways to mitigate them.

Figure 1: Cost Estimating Challenges and Mitigations



Source: GAO. | GAO-20-195G

Some cost estimating challenges are common. For example, deriving high-quality cost estimates depends on the quality of historical databases.

It is often not possible for the cost analyst to collect the kinds of data needed to develop cost estimating relationships (CER) and other estimating methods. In most cases, better data enables the estimator to create a better estimate. Because much of a cost analyst's time is spent collecting and normalizing data, experienced and well-trained cost analysts are necessary. Too often, individuals without these specialized skills are tasked with performing a cost analysis to meet a pressing need.

In addition, limited program funding and available time often hinder 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.

Many cost estimating challenges can be traced to over-optimism. Cost analysts typically develop their estimates from technical baselines provided by program offices. Recognizing the uncertainty in a program's technical baseline can help form a better understanding of where problems will occur in the execution phase. For example, if a software 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 lines of code from a legacy system but can eventually reuse only 10,000, the cost will be underestimated.

Similarly, program proponents often postulate the availability of a new technology, only to discover that it is not ready when needed, which then increases program costs. Proponents also often make unrealistic assumptions about the complexity or difficulty of new processes, such as first-time integration efforts. In both instances, the additional time and effort leads directly to greater costs, as case study 1 demonstrates.

Case Study 1: 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 one of 14 critical technologies was mature at program initiation, and it was found that one 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.: November 17, 2006).

Program stability presents another serious challenge to cost analysts. 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 procured will typically decrease, causing average unit procurement costs to increase. Projected savings from initiatives such as multiyear procurement—contracting for purchase of supplies or services for more than one program year—may not be realized. Case study 2 shows how cost overruns happen due to program instability.

Case Study 2: Program Stability Issues, from Federal Real Property, GAO-14-648

As of 2014, DHS and GSA were managing an estimated $4.5 billion construction project at the St. Elizabeth's Campus in Washington, D.C. The project is designed to consolidate DHS's executive leadership, operational management, and other personnel at one secure location rather than at multiple locations throughout the Washington, D.C. metropolitan area. GAO was asked to examine DHS and GSA management of the headquarters consolidation, including the development of the St. Elizabeth's campus.

In 2007, DHS and GSA estimated that the total cost of construction at St. Elizabeth's was $3.26 billion, with construction to be completed in 2015, and with potential savings of $1 billion attributable to moving from leased to owned space. However, according to DHS and GSA officials, the lack of consistent funding had affected cost estimates, estimated completion dates, and savings. For example, in 2006, DHS and GSA projected that USCG would move to St. Elizabeth's in 2011, but the move was delayed because sufficient funding for Phase 1 of the project was not available until fiscal year 2009. In 2009, DHS and GSA updated the projected completion date to the summer of 2013. The majority of funding for the St. Elizabeth's consolidation project through fiscal year 2013 had been allocated to the construction of a new consolidated headquarters for the U.S. Coast Guard (USCG) on the campus.

According to DHS and GSA officials, the funding gap between what was requested and what was received from fiscal years 2009 through 2014, was over $1.6 billion. According to these officials, this gap had escalated estimated costs by over $1 billion—from $3.3 billion to $4.5 billion—and delayed scheduled completion by over 10 years, from an original completion date of 2015 to the then current estimate of 2026. However, GAO found that DHS and GSA had not conducted a comprehensive assessment of current needs, identified capability gaps, or evaluated and prioritized alternatives to help them adapt consolidation plans to changing conditions and address funding issues as reflected in leading practices. DHS and GSA reported that they had begun to work together to consider changes to their plans, but as of August 2014, they had not announced when new plans will be issued and whether they would fully conform to leading capital decision-making practices to help plan project implementation.

GAO, *Federal Real Property: DHS and GSA Need to Strengthen the Management of DHS Headquarters Consolidation*, GAO-14-648 (Washington, D.C.: September 19, 2014).

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.

Significantly accelerating a development schedule also presents risk. In such cases, technology tends to be incorporated before it is ready, tests are reduced or eliminated, or logistics support is not in place. 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.

In developing cost estimates, analysts often fail to adequately address risk, especially risks that are outside the estimator's control or that were not expected. This can result in point estimates that give decision-makers no information about their likelihood of success, or give them misleading estimate confidence levels. A risk and uncertainty 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 levels because the analysts did not understand the underlying mathematics or tools.

A risk analysis should be used to determine a program's contingency funding.[5] All development programs should have contingency funding because it is unreasonable to expect a program not to encounter problems. Program managers need ready access to funding in order to resolve problems without adversely affecting programs (for example, by stretching the schedule). Unfortunately, budget cuts often target contingency funding, and in some cases such funding is not allowed by

[5]For our purposes in this *Cost Guide*, contingency 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, 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.

policy. Decision-makers and budget analysts should understand that eliminating contingency funding limits program managers' ability to respond to program risks.

Too often, organizations encourage goals that are unattainable because of over-optimism. A 2012 report by NASA's Office of Inspector General found that a culture of optimism helps when developing and procuring state-of-the-art and cutting edge technological products, but it can also lead management to overestimate their ability to deliver such products within their cost and schedule baselines. It can also result in an underestimation of risks, which can lead to the development of unrealistic cost and schedule estimates. While program managers believe they build risk into their plan, they often do not sufficiently account for risk.[6]

Optimistic program managers believe in the original estimates for the plan without adequately allowing for changes in scope, schedule delays, or other elements of risk. In addition, in a competitive environment, contractor program managers may overestimate what their company can do compared to their competition.

To properly mitigate this optimism, it is important to have an independent view of the program. 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 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 to respond to risks.

Earned Value Management Challenges

OMB requires that major acquisition programs manage risk by applying earned value management (EVM), among other ways. Reliable EVM data usually indicate 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. EVM systems represent a best practice if implemented correctly, but an unreliable EVM system will produce unreliable results. (See case study 3.)

[6]"NASA's Challenges to Meeting Cost, Schedule, and Performance Goals," NASA Office of Inspector General, September 27, 2012, Report IG-12-021, Washington DC.

Case Study 3: Applying EVM, from Nuclear Waste Cleanup, GAO-19-223

The Department of Energy's (DOE) Office of Environmental Management (EM) manages most of its cleanup of nuclear waste (77 percent of its fiscal year 2019 budget) under a category that EM refers to as operations activities, using less stringent requirements than are used for its capital asset projects. EM's mission is to complete the cleanup of nuclear waste at 16 DOE sites and to work to reduce risks and costs within its established regulatory framework. In December 2018, DOE reported that it faced an estimated $494 billion in future environmental cleanup costs.

Our analysis of EM contractors' EVM systems for operations activities found that EM has not followed best practices for a reliable EVM system. The EVM data for contracts covering operations activities contained numerous, unexplained anomalies in all the reports GAO reviewed, including missing or negative values for some of the completed work to date. Negative values should occur rarely, if ever, in EVM reporting because they imply the undoing of previously scheduled or performed work. In addition, GAO found problems with the estimate at completion in all 20 contractors' EVM systems. More specifically, GAO found (1) many instances where the actual costs exceeded the estimates at completion even though there was still a significant amount of work remaining; (2) several occasions where the estimates at completion were less than half of the original budget at the beginning of the project; and (3) several contractors reported estimates at completion of zero dollars when their original budgets were for hundreds of millions of dollars. These problems indicated that the EVM systems were not being updated in a timely manner or were not well monitored since the estimate at completion values were too optimistic and highly unlikely.

Even though EM requires most of its contractors for operations activities to maintain EVM systems, EM's 2017 policy generally does not require that EVM systems be maintained and used in a way that follow EVM best practices. Until EM updates its cleanup policy to require that EVM systems be maintained and used in a way that follow EVM best practices, EM leadership may not have access to reliable performance data to make informed decisions in managing its cleanup work and to provide to Congress and other stakeholders on billions of dollars' worth of cleanup work every year.

GAO, *Nuclear Waste Cleanup: DOE Could Improve Program and Project Management by Better Classifying Work and Following Leading Practices,* GAO-19-223 (Washington, D.C.: February 19, 2019).

Perhaps the biggest challenge in using EVM is the tendency 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 planned costs. A new baseline serves an important management purpose when program goals can no longer be achieved because 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.

All of the challenges discussed above 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 20, we discuss audit criteria related to cost estimating and EVM.

Chapter 2: Cost Analysis and Cost Estimates

The systematic and rigorous application of cost analysis methods provides critical support to program managers and decision authorities. These methods can improve the allocation of resources and handling of program risks. Although the terms cost estimating and cost analysis may be used interchangeably, cost estimating is generally understood to be a subset of activities within the broader scope of cost analysis.

Cost analysis is a discipline used to gain knowledge about costs and is used to develop cost estimates. Cost analysis also can be used to evaluate trade-offs, analyze alternative products or services, or to assess an existing cost estimate. Additionally, cost analysis may focus on understanding past efforts and the influence of various parameters. In contrast, cost estimating is typically used to predict a specific program's cost. Using methods of cost analysis, cost estimating relies on historical data that are adjusted to reflect information about new materials, technology, software, and development teams for the program of interest.

Successful cost analysts typically combine concepts from such varied fields as accounting, budgeting, computer science, economics, engineering, mathematics, operations research, and statistics. Because cost analysis and estimating synthesize expertise from a wide range of disciplines, it is important that the cost analyst either develop broad knowledge of these disciplines or have ready access to experts.

Types of Cost Estimates

Auditors are likely to encounter life cycle cost estimates (LCCEs), which includes program office estimates and independent cost estimates. Auditors may also see other types of cost estimates, such as independent cost assessments (ICAs), budget estimates, rough order of magnitude (ROM) estimates, estimates-at-completion (EACs), and independent government cost estimates (IGCEs).

Life Cycle Cost Estimate

A life cycle cost estimate (LCCE) provides a structured accounting of all labor, material, and other efforts required to develop, produce, operate and maintain, and dispose of a program. The development of a life cycle cost estimate entails identifying and estimating all cost elements that pertain to the program from initial concept all the way through each phase in the program's duration. The program LCCE encompasses all past (or sunk), present, and future costs for every aspect of the program, regardless of funding source.

Life cycle cost estimating informs decision making, especially in the early planning and formulation of an acquisition program. Design trade-off studies conducted in this period can be evaluated on the basis of cost, 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 should become 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.

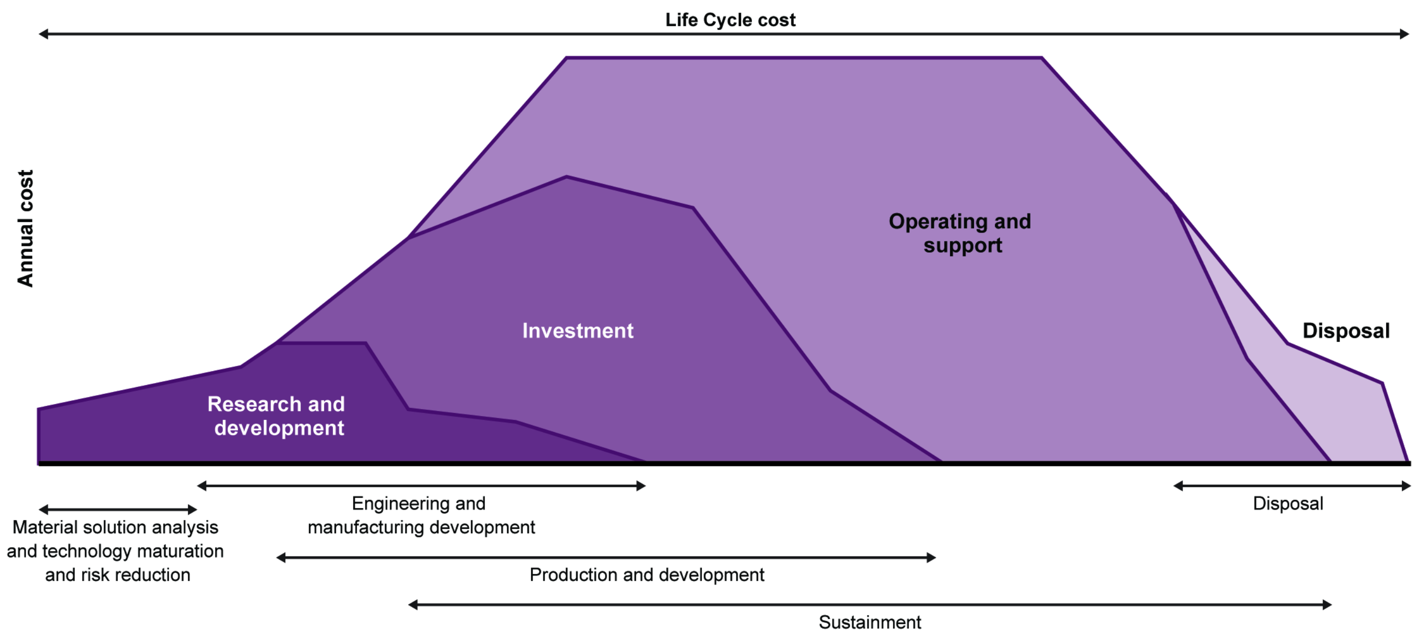
We will generally use the terms development, production, operations and maintenance, and disposal to describe the phases of a program life cycle. However, federal agencies may use different terminology and definitions for the phases of a program life cycle. OMB's *Capital Programming Guide* broadly defines the program acquisition life cycle as including concept analysis, technology definition, requirements planning, acquisition, and operations and maintenance.[7] DOD identifies four phases: research and development, investment, operating and support, and disposal.[8] Other agencies may refer to the research and development and investment phases as the development, modernization, and enhancement phase and include in them acquisition planning and funding. Additionally, agencies may refer to operations and support as "steady state" and include them in operations and maintenance activities.

Regardless of the terminology used to describe the various phases, LCCEs provide a wealth of information about how much programs are expected to cost over time because they include all program costs. Information from LCCEs can be displayed graphically (as shown in figure 2 below) to show what funding is needed at a particular time and when the program is expected to move from one phase to another.

[7]Office of Management and Budget, *Capital Programming Guide: Supplement to Circular A-11, Part 7, Preparation, Submission, and Execution of the Budget* (Washington, D.C.: December 2019).

[8]Department of Defense, Office of the Secretary of Defense – Cost Analysis and Program Evaluation, *Operating and Support Cost Estimating Guide* (Washington, D.C.: March 2014), 2-3 to 2-4.

Figure 2: A Representative Life Cycle Cost Estimate for a System



Source: Adapted from DOD. | GAO-20-195G

Figure 2 illustrates a notional profile of costs over time for a program from its beginning through disposal using DOD life cycle phase terminology. Profiles for programs can vary significantly by system. For example, 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 operating and support costs that are large in comparison to research and development and investment costs. Such operating and support costs are large because the systems can be retrieved and maintained and therefore require ongoing 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.

Table 1 describes the two types of life cycle cost estimates and the level of effort needed to develop them.

Table 1: Life Cycle Cost Estimates

Estimate type	Level of effort and Scope	Description
Program office estimate (POE)	Requires a large team, may take many months to accomplish, and addresses the full life cycle	A POE is the responsibility of the program manager. It should cover the entire life of the program and be phased by fiscal year for all years from initiation of the program to the disposal phase. POEs are used to prepare the resource requirements for translation into programming and budgeting documentation and requests.
Independent cost estimate (ICE)	Usually requires a large team, may take many months to accomplish, and usually addresses the full life cycle	An ICE, conducted by an organization independent of the acquisition chain of command, is based on the same detailed technical and programmatic information used to make the baseline estimate—usually the POE. ICEs are developed to support new programs or conversion, activation, modernization, or service life extensions and to support milestone decisions for programs. ICEs are used primarily to validate program office estimates and are reconciled with them. Because the team performing the ICE is independent, the ICE 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.

Source: GAO, DOD, NIH, OMB, and ICEAA | GAO-20-195G

Other Types of Cost Estimates

Other types of cost estimates also support agency and program decisions. These types of estimates may not include the entire life cycle of the program. Table 2 looks more closely at these types of cost estimates.

Table 2: Other Types of Cost Estimates

Estimate type	Level of effort and Scope	Description
Budget estimate	Requires a large team, may take many months to accomplish, and usually covers only a portion of the LCCE	The budget estimate should be based on the POE or another LCCE such as an ICE. The budget estimate typically covers only the upcoming few years and not the entire life cycle.[a] It must be translated to budget year[b] dollars with the application of inflation and time-phasing, and should identify the appropriation type(s) and account for any funding policies associated with those appropriations.
Rough order of magnitude (ROM) estimate	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	Similar to the “conceptual estimate” defined by OMB, a ROM is developed when a quick estimate is needed and few details are available.[c] Usually based on historical information, it is typically developed to support what-if analyses and can be developed for a particular phase or portion of an estimate or 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 and Scope	Description
Independent cost assessment (ICA)	Requires a small group; may take months to accomplish, depending on how much of the LCCE is being reviewed; usually does not address the program's entire life cycle	An ICA is a non-advocate'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, outside source, or required by agency policy, 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.
Independent government cost estimate (IGCE)	Requires a small group, may take months to accomplish, and covers only the portion of the LCCE phase under contract	An IGCE is conducted for multiple purposes. First, it helps the government to determine budgets for notional contracting actions. Secondly, it serves as a comparison point to check the reasonableness and realism of a contractor's cost proposal. Finally, its details support the contracting officer through the negotiation and award process. IGCEs are helpful to programs in assessing the feasibility of individual emergent tasks to determine if the associated costs are realistic and reasonable.
Estimate at completion (EAC)	Requires nominal effort once earned value management (EVM) data are on hand and have been determined to be reliable; covers only the portion of the LCCE phase under contract. Bottom-up EAC development requires additional effort	An EAC is an assessment of the cost to complete authorized work based on a contractor's historical EVM performance. One method of developing an EAC uses various EVM metrics to forecast the expected final cost. A second method, called a bottom-up or comprehensive EAC, involves a detailed assessment of the effort remaining to estimate cost.

Source: GAO, DOD, NIH, OMB, and ICEAA | GAO-20-195G

[a]OMB states that the budget focuses primarily on the upcoming fiscal year; however, it includes data from the most recently completed year, the current year, and nine years following the budget year.

[b]Throughout this guide we use "budget year" to mean dollars that include the effects of inflation. "Budget year" dollars are often referred to as "then-year" dollars by cost estimators. We use the term "base year" to mean dollars that are expressed in the value of a specific year and do not include the effects of inflation. "Base year" dollars are often referred to as "constant year" dollars." See chapter 9 for more information.

[c]Office of Management and Budget, *Circular A-11* (Washington, D.C.: December 2019).

Additionally, auditors may encounter various analyses which rely upon life cycle cost estimates or other types of cost estimates. These may include analysis of alternatives (AOAs), cost effectiveness analysis, and benefit-cost analysis.

<u>Analyses of alternatives:</u> The AOA process is an analytical study conducted to compare the operational effectiveness, cost, and risks of a number of potential alternatives to address valid needs and shortfalls in operational capability. This process helps ensure that the best alternative that satisfies the mission need is chosen on the basis of the selection criteria, such as safety, cost, or schedule. GAO has identified 22 best practices for an AOA process that are detailed in appendix XI.

Cost effectiveness analysis: Cost effectiveness analysis is a systematic quantitative method for comparing the costs of alternative means of achieving the same stream of benefits or a given objective. A program is cost effective if, on the basis of a life cycle cost analysis of competing alternatives, it is determined to have the lowest costs expressed in present value terms for a given amount of benefits. Cost effectiveness analysis is appropriate when the benefits from competing alternatives are the same or where a policy decision has been made that the benefits be provided.

Benefit-cost analysis: Benefit-cost analysis is a systematic quantitative method of assessing the desirability of government projects or policies when it is important to take a long view of future effects and a broad view of possible side effects. Benefit-cost analyses should include comprehensive estimates of the expected benefits and costs to society based on established definitions and practices for program and policy evaluation.

Significance of Cost Estimates

Cost estimating is a critical element in any acquisition process and helps decision-makers evaluate resource requirements at milestones and other important decision points. It is the basis for establishing and defending budgets and drives affordability analyses. 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, operate, maintain, and dispose of 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:

- source selection,
- assessing technology changes,
- analyzing alternatives,
- performing design trade-offs, and
- satisfying statutory and oversight requirements.

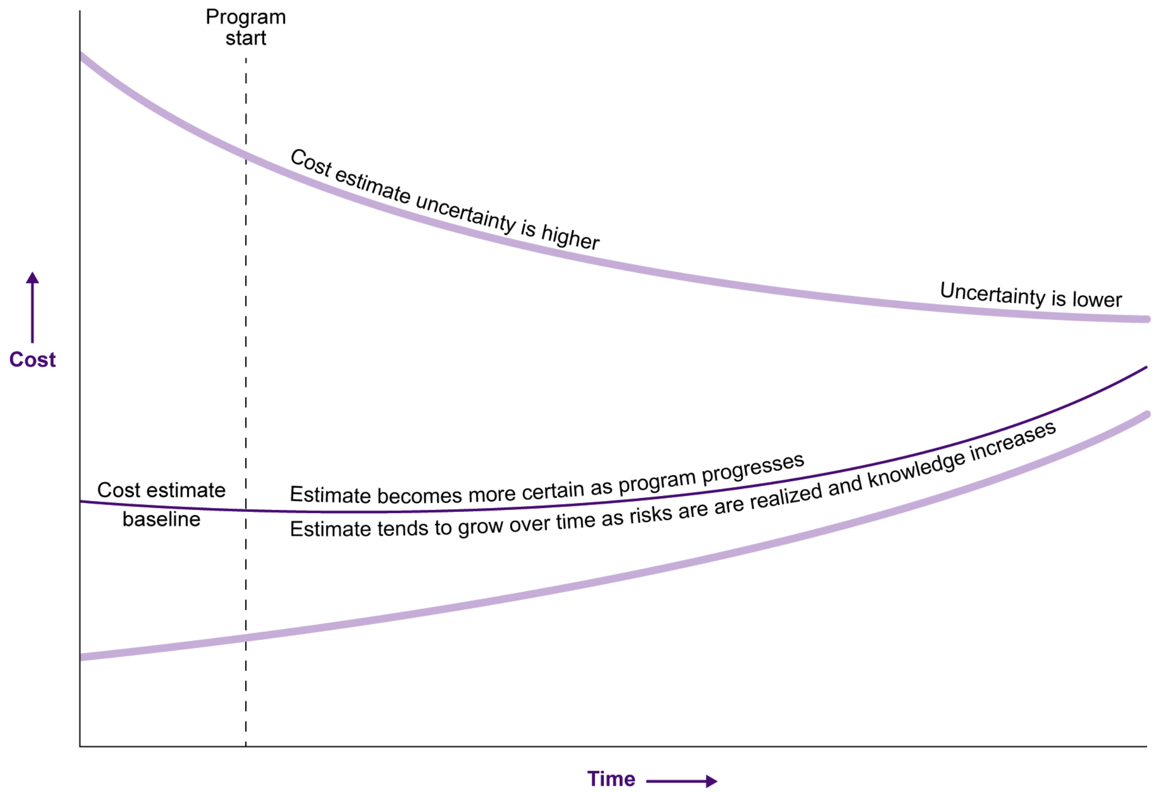
Cost Estimates in Acquisition

An acquisition program focuses on the cost of developing and producing an end item and whether enough resources and funding are available. The end goal of the acquisition process is a program capability that meets users' requirements at an affordable 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 facilitates trade-offs among cost, schedule, and requirements, which allow better decision making in order to increase a program's probability of success.

Acquisition is an event-driven process. Programs typically pass through various milestones or investment decision reviews in which program management is held accountable for program accomplishments. Cost estimates play an important role in these decisions. 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 to ensure it includes all necessary costs to successfully execute the program. 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 programs require similar scrutiny throughout development, where management approves a program's entry to the next phase or stage based on successful completion of prior phases.

Once a cost estimate has been accepted and approved, it should be updated periodically as the program matures. It should also be updated when there are changes in schedules or requirements. Updated estimates give management the latest information on resource needs and assist with decision making. This is especially important early in a program, 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. Thus, 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 do occur, any resulting cost growth is included in an updated cost estimate. This effect of estimates becoming more certain over time is commonly referred to as the "cone of uncertainty" and is depicted in figure 3.

Figure 3: Cone of Uncertainty



Source: GAO. | GAO-20-195G

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. It is important to have a track record of the estimate in order to measure growth from the original estimate.

The Importance of Cost Estimates in Establishing Budgets

A program's approved cost estimate should be 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 finite, budgeting requires a delicate balancing act to ensure that the rate of spending closely mirrors available resources and funding. Additionally, 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.

A reasonable and supportable budget is essential to a program's efficient and timely execution and a reliable estimate is the basis of a reasonable budget. Cost estimates help in assessing the reasonableness of existing budgets and of contractor's proposals. Cost estimates also help program offices justify budgets to the Congress, OMB, and department secretaries, among others. Moreover, cost estimates are often used to help determine how budget cuts may hinder a program's progress or effectiveness.

While contractors occasionally bid unrealistically low to win a competition, low cost estimates can often be attributed to poor cost estimating. Unrealistically low cost estimates occur when contractors are overly optimistic about program challenges and underestimate potential risks. When a program's budget is based on such an estimate, it soon becomes apparent that either the contractor or the customer must pay for a cost overrun, as case study 4 shows.

Case Study 4: Realistic Estimates, from Ford-Class Aircraft Carrier, GAO-17-575

The cost estimate for the second Ford-Class aircraft carrier, CVN 79, did not address lessons learned from the performance of the lead ship, CVN 78. As a result, the estimate did not demonstrate that the program could meet its $11.4 billion cost cap. Cost growth for the lead ship was driven by challenges with technology development, design, and construction, compounded by an optimistic budget estimate. Instead of learning from the mistakes of CVN 78, the Navy developed an estimate for CVN 79 that assumed a reduction in labor hours needed to construct the ship that was unprecedented in the past 50 years of aircraft carrier construction.

After developing the program estimate, the Navy negotiated 18 percent fewer labor hours for CVN 79 than were required for CVN 78. CVN 79's estimate was optimistic compared to the labor hour reductions calculated in independent cost reviews conducted in 2015 by the Naval Center for Cost Analysis and the Office of Cost Assessment and Program Evaluation. Navy analysis showed that the CVN 79 cost estimate may not have sufficiently accounted for program risks, with the current budget likely insufficient to complete ship construction.

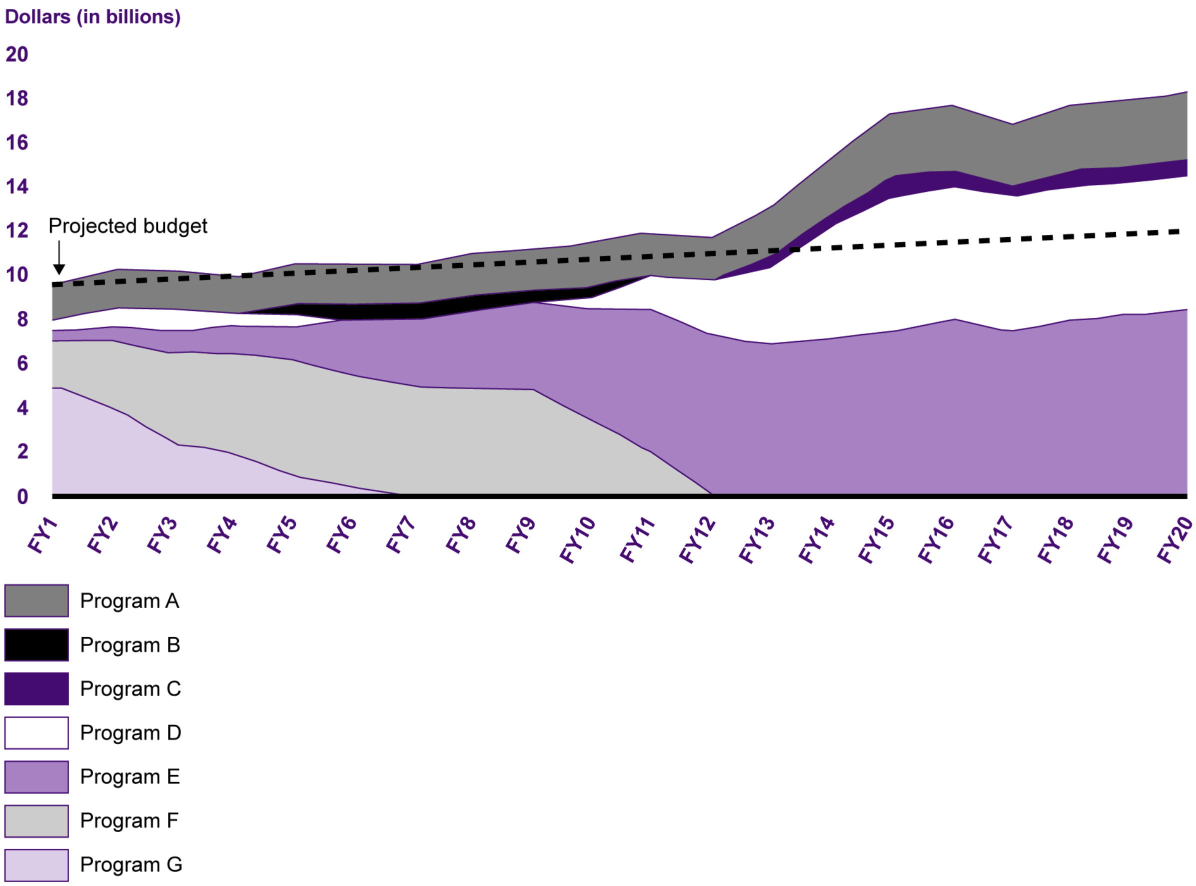
GAO, *Ford-Class Aircraft Carrier: Follow-On Ships Need More Frequent and Accurate Cost Estimates to Avoid Pitfalls of Lead Ship*, GAO-17-575 (Washington, D.C.: June 13, 2017).

Cost Estimates and Affordability

Affordability is the degree to which an acquisition program's funding requirements fit within the agency's overall projected budget. Affordability analyses are not solely the responsibility of cost estimators; an affordability analysis involves agency leadership and its planning, requirements, and acquisition communities. However, a program's affordability depends a great deal on the quality of its cost estimate. By following the 12-step estimating process, estimators help agencies to ensure that they develop and present realistic cost estimates, enabling management to make informed decisions about whether the program is affordable within the portfolio plan.

Decision-makers should consider affordability periodically throughout a program's life cycle. It is important to know the estimate of 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 demonstrates whether a program's acquisition strategy has an adequate budget. It also shows if the agency's overall portfolio is affordable or if programs within the portfolio should be cancelled or restructured (see figure 4).

Figure 4: An Affordability Assessment



Source: DOD. | GAO-20-195G

In figure 4, the costs of seven programs (A–G) are plotted against time. 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 generally satisfied in fiscal years 1–12, but after fiscal year 12, an increasing need for more funding is readily apparent. This is commonly referred to as a bow wave, meaning there is an impending increase in the requirement for additional funds. Availability of these funds will determine the status of the programs such as continuation as planned, cancellation, or restructuring to fit within a revised program budget. 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, so that management can make agency-wide informed decisions about tradeoffs. Case study 5 discusses affordability concerns that must be considered at both the program level and agency level, and considerations that management must make when balancing priorities.

Case Study 5: Affordability Considerations at the Program and Portfolio Levels, from Joint Strike Fighter, GAO-11-325

The Joint Strike Fighter (JSF) is the Department of Defense's (DOD) most costly and ambitious aircraft acquisition, seeking to simultaneously develop and field three aircraft variants for the Air Force, Navy, Marine Corps, and eight international partners. The JSF is critical for recapitalizing tactical air forces and will require a long-term commitment to very large annual funding outlays.

Affordability—both in terms of the investment costs to acquire the JSF and the continuing costs to operate and maintain it over the life cycle—is at risk. Rising aircraft prices erode buying power and make it difficult for the United States and its allies to buy as many aircraft as planned. Quantity reductions could drive additional price increases for future aircraft. Further, cost forecasts have increased as the program matures and more data becomes available. Current JSF life cycle cost estimates are considerably higher than the legacy aircraft it will replace; this has major implications for future demands on military operating and support budgets and plans for recapitalizing fighter forces.

The JSF acquisition demands an unprecedented share of DOD's future investment funding - an annual average of almost $11 billion for the next two decades. The program's size and priority is such that its cost overruns and extended schedules are either borne by funding cuts to other programs or else drive increases in the top line of defense spending. Until now, JSF problems have been addressed either with more time and money or by deferring aircraft procurement to be borne by future years' budgets.

The JSF will have to annually compete with other defense and nondefense priorities for the shrinking discretionary federal dollar. Maintaining senior leadership's increased focus on program results, holding government and contractors accountable for improving performance, and bringing a more assertive, aggressive management approach for the JSF to "live within its means" could help effectively manage growth in the program and limit the consequences on other programs in the portfolio. Controlling JSF future cost growth would minimize funding disruption and help stabilize the defense acquisition portfolio by providing more certainty to financial projections and by facilitating the allocation of remaining budget authority to other defense modernization programs.

GAO, *Joint Strike Fighter: Restructuring Places Program on Firmer Footing, but Progress Still Lags*, GAO-11-325 (Washington, D.C.: April 2011).

While approaches may vary, agencies should consider extending their affordability assessments several years beyond the budgeting time frame to examine long term funding needs of their portfolios. For example, DOD policy is for affordability analyses to address the life cycle of the planned programs in the portfolio, nominally a 30 to 40 year period.[9]

Thus, program LCCEs give decision-makers important information in that not all programs require the same type of funding profile. Different commodities require different phasing of funding and are affected by different cost drivers.

While some programs may not cost as much to develop—for example, development costs in space programs differ from those costs for ships and aircraft—they may require more funding for production and operating and maintenance in the out-years relative to other programs. Line graphs or sand charts like those in figure 4 are often used to show how a program fits within the organizational plan, both overall and by the program's individual components. These types of charts allow decision-makers to determine how and if the program fits within the overall budget. It is therefore important for LCCEs to be both realistic and timely so that they are available to decision-makers as early as possible. Case study 6 demonstrates the importance of realistic estimates to enable program planning for portfolio affordability.

[9]DOD, *Operation of the Defense Acquisition System*, DOD Instruction 5000.02T. Washington, D.C.: January 23, 2020.

Case Study 6: Importance of Realistic LCCEs to inform program and portfolio planning, from Information Technology, GAO-17-281

Information Technology (IT) plays a critical role in the Housing and Urban Development's (HUD) ability to perform its business functions, which involve the management of billions of dollars to carry out its mission. HUD's IT budget covers two categories of spending: (1) operations and maintenance of existing systems, and (2) new investments for modernization (often referred to as development, modernization, and enhancement). Operations and maintenance funds refer to the expenses required for general upkeep of the department's existing systems. Funds for modernization support projects and activities that lead to new systems, or changes and modifications to existing systems that substantively improve capability or performance to better support HUD's mission and business functions.

The majority of HUD's modernization budget request for fiscal year 2017 was identified as supporting four modernization efforts, which were in various phases of planning and development. GAO determined that the cost estimates HUD developed for the four selected IT investments were unreliable. The significant weaknesses in the cost estimates for the selected investments were largely attributed to the department's lack of guidance for developing reliable cost estimates, resulting in cost estimating practices that were decentralized and inconsistent across the department.

Although all of the estimates included costs for specific elements and phases of the investments, none of the estimates included both government and contractor costs of the investment over the life cycle. Because they were not reliable, the IT cost estimates lacked a sound basis for informing the department's investment and budgetary decisions.

GAO, *Information Technology: HUD Needs to Address Significant Weaknesses in Its Cost Estimating Practices*, GAO-17-281 (Washington, D.C.: February 7, 2017).

Chapter 3: The Characteristics of Credible Cost Estimates and a Reliable Process for Creating Them

In this chapter, we introduce the characteristics of a high-quality, reliable cost estimate, the best practices associated with developing those characteristics, and an established, repeatable process that governs the execution of the best practices. We describe how the process, if prudently implemented, results in an estimate that reflects four distinct characteristics of a reliable cost estimate. Finally, we describe how the *Cost Guide* displays this information by presenting each step as its own chapter with associated process tasks and best practices.

The Four Characteristics of a Reliable Cost Estimate

GAO's research has found that a reliable cost estimate is one that is comprehensive, well documented, accurate, and credible. Management minimizes the risk of cost overruns and unmet performance targets by ensuring cost estimates reflect these four characteristics.

Comprehensive cost estimates completely define the program and reflect the current schedule and technical baseline. They are structured with sufficient detail to ensure that cost elements are neither omitted nor double-counted. Where information is limited and judgments must be made, assumptions and exclusions on which the estimate is based are reasonable, clearly identified, explained, and documented.

Well-documented cost estimates can easily be repeated or updated and can be traced to original sources through auditing. Thorough documentation explicitly identifies the primary methods, calculations, results, rationales or assumptions, and sources of the data used to generate each cost element's estimate.

Accurate cost estimates are developed by estimating each cost element using the best methodology from the data collected. Accurate estimates are based on appropriate adjustments for inflation. Their underlying mathematical formulas, databases, and inputs are validated, and the resulting estimates contain few, if any, minor mathematical mistakes. Accurate estimates are based on a historical record of cost estimating and actual experiences from comparable programs. Finally, they are updated regularly to reflect significant changes in the program. Any variances between estimated and actual costs are documented, explained, and reviewed.

Credible cost estimates discuss and document any limitations of the analysis, including uncertainty or bias surrounding source data and assumptions. The estimate's major assumptions are varied to determine how sensitive it is to changes. Credible cost estimates include a risk and uncertainty analysis that determines the level of confidence associated with the estimate. In addition, high-value cost elements are cross-checked with alternative estimating methodologies to validate results. Finally, the estimate is compared with an independent cost estimate conducted by a group outside the acquiring organization.

Best Practices Related to Developing and Maintaining a Reliable Cost Estimate

A number of best practices form the basis of effective program cost estimating. Our research shows that comprehensive, well-documented, accurate, and credible cost estimates are developed by industry and government organizations that systematically implement these best practices. The following list describes the best practices that, if implemented, result in a cost estimate that exhibits the four characteristics.

A comprehensive cost estimate

- includes all life cycle costs;
- is based on a technical baseline description that completely defines the program, reflects the current schedule, and is technically reasonable;
- is based on a WBS that is product-oriented, traceable to the statement of work, and at an appropriate level of detail to ensure that cost elements are neither omitted nor double-counted; and
- documents all cost-influencing ground rules and assumptions.

A well-documented cost estimate

- shows the source data used, the reliability of the data, and the estimating methodology used to derive each element’s cost;
- describes how the estimate was developed so that a cost analyst unfamiliar with the program could understand what was done and replicate it;
- discusses the technical baseline description and the data in the technical baseline are consistent with the cost estimate; and
- provides evidence that the cost estimate was reviewed and accepted by management.

An accurate cost estimate

- is based on a model developed by estimating each WBS element using the best methodology from the data collected;
- is adjusted properly for inflation;

- contains few, if any, minor mistakes;
- is regularly updated to ensure it reflects program changes and actual costs;
- documents, explains, and reviews variances between planned and actual costs; and
- is based on a historical record of cost estimating and actual experiences from other comparable programs.

A credible cost estimate

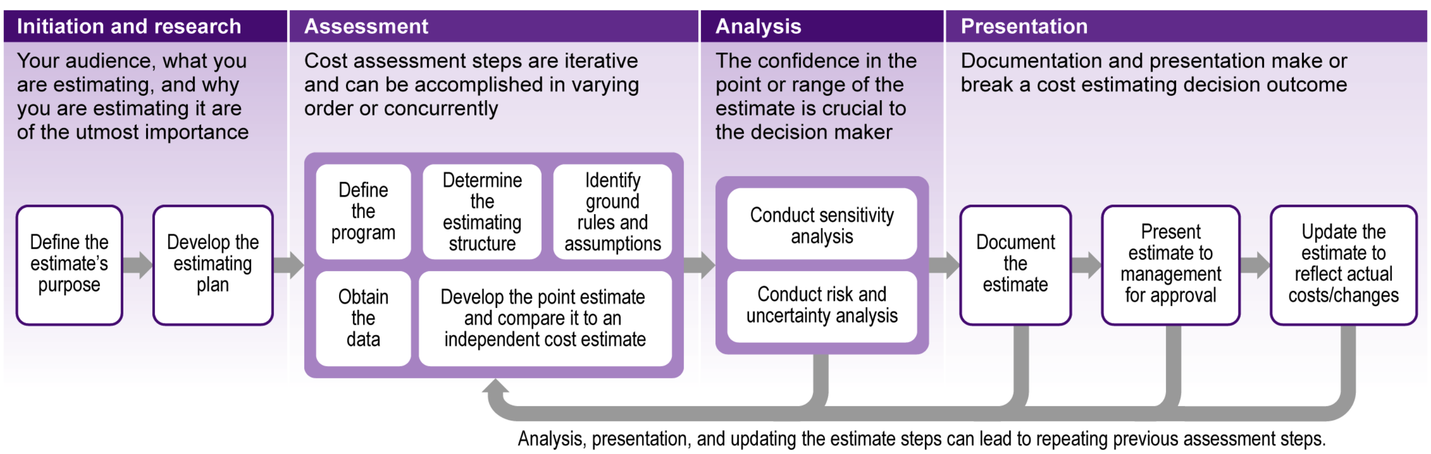
- includes a sensitivity analysis that identifies a range of possible costs based on varying major assumptions, parameters, and data inputs;
- includes a risk and uncertainty analysis that quantifies the imperfectly understood risks and identifies the effects of changing key cost driver assumptions and factors;
- employs cross-checks—or alternate methodologies—on major cost elements to validate results; and
- is compared to an independent cost estimate that is conducted by a group outside the acquiring organization to determine whether other estimating methods produce similar results.

Cost Estimating Best Practices and the Estimating Process

The *Cost Guide* presents the best practices in the context of a 12-step cost estimating process. The cost estimating process provides the foundational guidance for initiating, researching, assessing, analyzing, and presenting a cost estimate. Each of the 12 steps is important for ensuring that cost estimates are developed and delivered in time to support important program decisions. The 12-step process represents a consistent methodology based on industry and government best practices that can be used across the federal government to develop, manage, and evaluate program cost estimates. By following a process of repeatable methods, agencies should be able to produce reliable estimates that can be clearly traced, replicated, and updated to better manage their programs and inform decision-makers of the risks involved.

Relying on a standard process that requires 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 generally results 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 step links cost estimating with actual results obtained from data that are collected by an EVM system. Examining the reasons for variances between the estimate and the final cost allows for lessons learned and an assessment of the effects of risk. It also provides valuable information for strengthening the credibility of future cost estimates by allowing for continuous process improvement. Figure 5 shows the cost estimating process and the related 12 cost estimating steps.

Figure 5: The Cost Estimating Process



Source: GAO. | GAO-20-195G

Briefly, the steps in the cost estimating process are:

1. Define the estimate's purpose: the purpose of the cost estimate is determined by its intended use.
2. Develop the estimating plan: the estimating plan documents the members of the estimating team and the schedule for conducting the estimate.
3. Define the program: a technical baseline description identifies adequate technical and programmatic information on which to base the estimate.
4. Determine the estimating structure: a product-oriented work breakdown structure defines in detail the work necessary to meet program objectives.
5. Identify ground rules and assumptions: establish the estimate's boundaries using a common set of standards and judgments about past, present, or future conditions.

6. Obtain the data: collect and adjust data from existing programs to estimate the cost of a new program.
7. Develop the point estimate: develop the cost estimate for each element and compare the overall point estimate to an independent estimate.
8. Conduct sensitivity testing: examine the effect of changing one assumption or cost driver at a time.
9. Conduct a risk and uncertainty analysis: quantify risk and uncertainty to identify a level of confidence associated with the point estimate.
10. Document the estimate: thoroughly document the estimate such that someone unfamiliar with the estimate can update or recreate it.
11. Present the estimate to management for approval: present the estimate and its underlying methodologies so that management understands and is able to approve it.
12. Update the estimate to reflect actual costs and changes: update the estimate to reflect changes in conditions and report progress in meeting cost goals.

Figure 5 presents the cost estimating process as a series of successive steps, but it is not necessary to follow the steps in order. For example, it is advisable that documentation (step 10) occur throughout the estimating and updating process instead of a large documenting effort at the end. Sensitivity analysis (step 8) and risk and uncertainty analysis (step 9) are often conducted together or result from the same risk analysis output. The fluidity of the process steps is most evident in steps 3-7: defining the program, determining the estimating structure, identifying ground rules and assumptions, obtaining the data, and developing the point estimate. These steps are highlighted as a group in figure 5. They may be executed concurrently or cyclically depending on the phase of the program, the maturity of the cost estimate, the availability of data, and the realization of risks. Additionally, as the cost estimate is updated, the process may be revisited at any step. For example, once variances are examined and justified, analysts may need to reconsider assumptions or refine estimating methods.

As a process that helps agencies run their programs effectively, report reliable information, and comply with applicable laws and regulations, the

12-step cost estimating process also serves as an organizational internal control.[10] This topic is discussed in greater detail in appendix XII.

The 12 steps and the related 18 best practices are presented in table 3.

Table 3: The Twelve Steps and their Best Practices

Step[a]	Best Practice[b]
1. Define the estimate's purpose	The cost estimate includes all life cycle costs.
2. Develop the estimating plan	(See table note[c])
3. Define the program	The technical baseline description completely defines the program, reflects the current schedule, and is technically reasonable.
4. Determine the estimating structure	The cost estimate WBS is product-oriented, traceable to the statement of work, and at an appropriate level of detail to ensure that cost elements are neither omitted nor double-counted.
5. Identify ground rules and assumptions	The estimate documents all cost-influencing ground rules and assumptions.
6. Obtain the data	The estimate is based on a historical record of cost estimating and actual experiences from other comparable programs.
	The estimate is adjusted properly for inflation.
7. Develop the point estimate	The cost model is developed by estimating each WBS element using the best methodology from the data collected.
	The estimate contains few, if any, minor mistakes.
	Major cost elements are cross checked to see if results are similar.
	An independent cost estimate is conducted by a group outside the acquiring organization to determine whether other estimating methods produce similar results.
8. Conduct sensitivity analysis	The cost estimate includes a sensitivity analysis that identifies a range of possible costs based on varying major assumptions and parameters.
9. Conduct risk and uncertainty analysis	A risk and uncertainty analysis is conducted that quantifies the imperfectly understood risks and identifies the effects of changing key cost driver assumptions and factors.
10. Document the estimate	The documentation shows the source data used, the reliability of the data, and the estimating methodology used to derive each element's cost.
	The documentation describes how the estimate was developed so that a cost analyst unfamiliar with the program could understand what was done and replicate it.
	The documentation discusses the technical baseline description and the data in the technical baseline are consistent with the cost estimate.

[10] Control activities are the policies, procedures, techniques, and mechanisms that enforce management's directives to achieve the entity's objectives and address related risks. See GAO, *Standards for Internal Control in the Federal Government*, GAO-14-704G (Washington, D.C.: Sept. 2014).

Step[a]	Best Practice[b]
11. Present the estimate to management for approval	The documentation provides evidence that the cost estimate is reviewed and accepted by management.
12. Update the estimate to reflect actual costs and changes	The cost estimate is regularly updated to ensure it reflects program changes and actual costs.
	Variances between planned and actual costs are documented, explained, and reviewed.

Source: GAO. | GAO-20-195G

[a]Together the 12 steps represent a consistent methodology that can be used across the federal government to develop, manage, and evaluate program cost estimates. The steps are useful to auditors for determining the quality of an agency's process, guidance, and regulations for creating and maintaining a high quality estimate.

[b]If implemented systematically, the best practices result in a cost estimate that is comprehensive, well documented, accurate, and credible. The best practices are useful to auditors for determining the reliability of a life cycle cost estimate.

[c]Step 2 does not have an associated best practice because it does not result in a definitive attribute of the cost estimate. Instead, failing to fully implement step 2 is a cause of why best practices may not have been fully met.

Chapter 16 describes how auditors can use the 12 steps and the 18 best practices as criteria. The best practices can be used to assess the reliability of a life cycle cost estimate and to determine the extent to which an estimate is comprehensive, well documented, accurate, and credible. The steps can be used to determine the quality of an agency's process, guidance, and regulations for creating and maintaining an estimate. Accordingly, chapters in the *Cost Guide* that describe the steps present 1) a list of process tasks that supports the creation and evaluation of cost estimating guidance, policies, and directives, and 2) the associated best practices useful for evaluating the extent to which a cost estimate reflects the intent of the step, and thus is reflective of a reliable, high-quality estimate.

Chapter 4: Step 1: Define the Estimate's Purpose

The purpose of a cost estimate is determined by its intended use, which 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 for cost estimates include providing data for trade studies, independent reviews, and baseline changes.

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 requested or required by law or policy. 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, among other things, without regard to funding source or management control—must be provided to the decision-maker for consideration. As another example, 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. 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.

Once the cost analysts know the context of the estimate and the customer's needs, they can determine the estimate's scope by its intended use and the availability of data. The maturity of the program will influence the quantity of detail for the cost estimate. For example, early in the life cycle the program 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. 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 provide 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 information, analysts will find it difficult to identify and estimate all of the cost elements. It may be better to develop the estimate at a relatively higher work breakdown structure (WBS) level, for example, at the system level, to ensure capturing all the lower-level elements. (Work breakdown structures are discussed in chapter 7.) This is the value of parametric cost 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, performance, or complexity in advance of detailed design definition.

Including All Costs in a Life Cycle Cost Estimate

As we described in chapter 2, a life cycle cost estimate provides a structured accounting of all labor, material, and other efforts required to develop, produce, operate and maintain, and dispose of a particular program. A life cycle cost estimate therefore encompasses all past (or sunk), present, and future costs for every aspect of the program, regardless of funding source.

A life cycle cost estimate should include both government and contractor costs of the program over its full life cycle, from inception of the program through design, development, production, operations and maintenance, and disposal. If items are excluded from the estimate, they should be documented and justified. By accounting for all costs, life cycle cost estimates enhance decision making and allow for design trade off studies to be evaluated on the basis of cost as well as on a technical and performance basis. A life cycle cost estimate will help management successfully plan program resource requirements and make wise decisions.

If the life cycle cost estimate does not include all costs, then the estimate most likely cannot fully meet the comprehensive characteristic of a high-quality cost estimate. Additionally, the estimate may not meet the well-documented, accurate, or credible characteristics. (We describe these characteristics in greater detail in chapter 16.) For example, if the cost estimate is missing some cost elements, then the estimate may not be credible because the total cost will be underestimated and risks and uncertainty associated for missing elements will not be accounted for in a quantitative risk and uncertainty analysis.

Survey of Step 1

Process Tasks

- Cleary define the estimate's purpose.
- Determine the estimate's overall scope.
- Determine the required level of detail for the estimate, which should be consistent with the level of detail available for the program.

Best Practices

The cost estimate includes all life cycle costs

- The cost estimate includes both government and contractor costs of the program over its full life cycle, from inception of the program through design, development, deployment, and operation and maintenance to retirement of the program. Items excluded from the estimate have been documented and justified.

Likely Effects if Criteria Are Not Fully Met

- If the life cycle cost estimate does not include all costs, then the estimate most likely cannot fully meet the comprehensive characteristic of a high-quality cost estimate and also may not meet the well-documented, accurate, or credible characteristics. For example, if the cost estimate is missing some cost elements, then the estimate may not be credible because the total cost will be underestimated and risks and uncertainty associated for missing elements will not be accounted for in a quantitative risk and uncertainty analysis.

Chapter 5: Step 2: Developing the Estimating Plan

Because 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. Therefore, the cost estimating team must manage a great deal of risk—especially for programs that are highly complex or on technology's cutting edge. A well-trained, centralized, and multidisciplinary cost estimating team that is allowed ample time to create estimates will appreciably improve an agency's ability to develop and maintain reliable cost estimates.

Team Composition and Organization

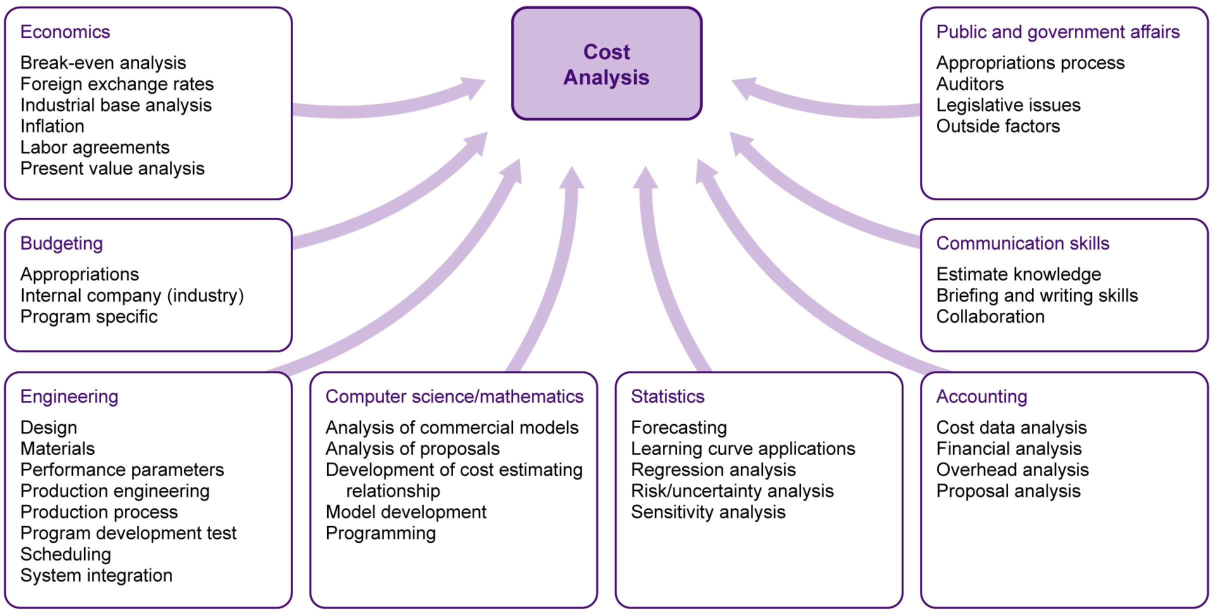
Program office cost estimates are normally prepared by a multidisciplinary team with functional skills in financial management, engineering, acquisition, logistics, scheduling, mathematics, and/or communications.[11] The team should also include participants or reviewers from centers, facilities, and laboratories, among others, that are affected in a major way by the estimate.

Ideally, the estimating team is composed of people who have experience in estimating all cost elements of the program. Because 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.

A cost analyst should possess a variety of skills to develop a high-quality cost estimate that satisfies the 12 steps of a reliable cost estimate.

[11]Because 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. GAO's *Schedule Assessment Guide* (GAO-16-89G) has more information on creating and maintaining reliable schedules.

Figure 6: Disciplines and Concepts in Cost Analysis



Source: GAO. | GAO-20-195G

Each discipline in figure 6 applies to cost estimating. 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. In addition, cost estimators with good presentation skills who defend their cost estimate with solid facts and reliable data stand a better chance of convincing decision-makers to use the estimate as the basis for program funding. Finally, cost estimators need to have solid interpersonal skills, because working and communicating with subject matter experts is vital for understanding program requirements.

Study Plan and Schedule

An analytic approach to cost estimates typically includes a written study plan detailing a schedule of specific tasks, responsible parties, and due dates. Because 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.

For estimates of complex programs, 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.

Analysts should develop and tailor an estimate plan with a scope that aligns with the available data with the estimate's purpose. For a program in development that is estimated primarily with parametric techniques and factors, the scope might be at a higher level of the WBS. As the program enters production, a more detailed estimate is 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.[12]

It is important 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. 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 reliable 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

[12]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 of approaches or changes in direction and methods. 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.

months. If, however, that budget estimate were simply an update to a previous estimate, it could be done faster. The more detail required, the more time and staff the estimate will require.

After the customer has defined the task, the cost estimating team should create a detailed schedule to complete the cost estimate 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, they need additional resources to complete the effort. If additional resources are not available, the estimate's scope must be reduced.

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. Site visits are invaluable to cost estimators and auditors to see what is being developed and how engineering and manufacturing are executed. 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.

Even an estimate that meets all the best practices detailed in this Guide is less useful if it is not ready when needed. Timeliness is as important as quality. However, the quality of a cost estimate may be hampered if the time to develop it is compressed. 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.

Cost Estimating Team

Centralizing the cost estimating team 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 Assessment and Program Evaluation office (CAPE) in the Office of the Secretary of Defense. Its cost estimates are produced by a centralized group of government personnel to ensure long-term institutional knowledge and no bias toward results. Some individuals 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, because program offices typically fund an effort and because program management personnel typically rate the analysts' performance. However, one 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.

Furthermore, organizations that develop their own centralized cost estimating function outside the acquiring program office 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.

Finally, 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 suggest 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

Because 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, ICEAA'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 cost professional certification offered by AACEI; it requires candidates to have the requisite experience and the ability to pass a rigorous written exam. The Defense Acquisition University also provides three levels of certification in cost estimating which require the candidate meet education and experience requirements and complete several courses in acquisition and estimating topics. Several associations and other organizations also offer certifications in the area of cost estimating.[13]

Cost estimators should have both the requisite formal training and substantial on-the-job training to develop cost estimates and keep those estimates updated. Continuous learning by participating in cost estimating and EVM workshops 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 workshops 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.

Survey of Step 2

Process Tasks

- Ensure the cost estimating team's composition is commensurate with the assignment. That is,
  - 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; and

[13]For example, Naval Postgraduate School offers a Master's degree in cost estimating and the Guild of Project Controls has certification programs in cost management, planning, and project controls.

    - Team members' experience, qualifications, certifications, and training are identified.
- Develop a written study plan that describes the cost estimating approach and includes a schedule to complete the cost estimate.
- Ensure the team has access to the necessary subject matter experts.
- Ensure the team has adequate time to develop a high-quality estimate, including the time needed to conduct site visits and collect data.

Chapter 6: Step 3: Define the Program - Technical Baseline Description

Definition and Purpose

Key to developing a reliable 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 bound the cost estimate. The amount of information contained in the technical baseline directly affects the overall quality and flexibility of the estimate. Less information generally results in more assumptions being made, thus increasing the uncertainty associated with the estimate. Without this information, the cost estimator will not be able to identify the technical and program parameters that underpin the cost estimate and the quality of the cost estimate will be compromised. 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 technical baseline should document the underlying technical and program assumptions necessary to develop a cost estimate and update changes as they occur. The objective is to provide a common description of the program—including a detailed technical, program, and schedule description of the system—from which all life cycle cost estimates (LCCEs) will be derived. The technical baseline can be a single document or several documents stored in one location. It is also important that the technical baseline contain no cost data so that it can be used as the common baseline for independently developed estimates.

In addition to providing a comprehensive program description, the technical baseline is used to support 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 effect on cost.

Process

In general, program offices are responsible for developing and maintaining the technical baseline throughout the life cycle, because they possess the most knowledge of their programs. 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 program. The program manager approves the technical baseline to ensure that it contains all information necessary to define the program's systems and to 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.

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 provides the best available information at any point in time. To try to create an inclusive view of the program, the program office should make assumptions about the unknowns and these should be agreed on by management. The assumptions and their corresponding justifications should be documented in the technical baseline. The technical baseline should also identify the level of risk associated with the assumptions so that the estimate's credibility can be determined.

Contents

Since the technical baseline is intended to serve as the baseline for developing LCCEs, it should provide information on development, testing, production, operations and maintenance, planned upgrades, and disposal. When multiple alternatives are under consideration, in general, a separate technical baseline should be prepared for each alternative. 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 4 describes typical technical baseline elements.

Table 4: 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
Software description	Includes type of software, software sizing metrics, functionality, development schedule
Work breakdown structure	Identifies the cost and technical data needed to develop the estimate

Element	Description
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
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
Environmental plan	Includes how the environment may be impacted or any environment liability
Changes from the previous technical baseline	Includes a tracking of changes, with a summary of what changed and why

Source: DOD, DOE, and ICEAA. | GAO-20-195G

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 because a lack of defined requirements can lead to cost increases and delays in delivering services, as case study 7 illustrates.

Case Study 7: Defining Requirements, from Defense Management, GAO-14-82

Given its strategic location, Guam serves as an important staging base and operating location for mobilizing U.S. military forces and equipment within Asia and the western Pacific. In 2006, the United States and Japan planned to relocate 17,600 U.S. Marines and dependents from Japan to Guam. However, in 2012, representatives from the countries developed a revised plan under which 6,300 Marines and dependents would relocate to Guam.

Despite the reduction of Marines and dependents relocating to Guam, DOD had not yet revalidated the public infrastructure requirements based on the revised realignment plan or differentiated between requirements needed to address long-standing conditions and those related to the realignment. At the time of our assessment, the revalidation was not expected to be completed until 2015. Even so, DOD had requested over $400 million for Guam public infrastructure projects in its budget requests since fiscal year 2012. However, it was unclear if all of the infrastructure projects were necessary given the reduction in forces. For example, if DOD decided to locate the Marines on the naval base that handles all of its own water/wastewater needs, public water/wastewater improvements would not have been needed to support the Marines.

GAO reviewed DOD's $1.3 billion cost estimate for improvements to Guam's water and wastewater systems used to support budget requests for fiscal years 2013 and 2014. GAO determined that the estimate minimally met the best practice criteria for three characteristics of a reliable cost estimate—comprehensive, well documented, and accurate—and did not satisfy best practice criteria for the credible characteristic.

GAO determined that the estimate was not comprehensive, in part because the water and wastewater systems estimate did not include a technical baseline describing the scope and technical details of the program. A brief discussion and description of individual projects were provided in a technical memorandum, but none of the water or wastewater projects were sufficiently defined to understand the scope of work. In addition, there was no indication that the projects' scope or complexity had been updated to reflect more current environmental studies or reports, infrastructure inspections, or other reviews. Understanding the program—including the acquisition strategy, technical definition, characteristics, system design features, and technologies to be included—is key to developing a credible cost estimate. Without these data, the cost estimator will not be able to identify the technical and program parameters that will bound the cost estimate.

GAO recommended that, to provide DOD and Congress with sufficient information regarding the requirements and costs associated with DOD's Guam realignment plans and the public infrastructure necessary to support that realignment, the Secretary of Defense should direct the Department of the Navy's Joint Guam Program Office in concert with the Office of Economic Adjustment to fully incorporate the best practices identified by GAO for developing high-quality cost estimates as future cost estimates for Guam public infrastructure projects are developed. As a result of GAO's recommendation, in August 2015 DOD followed the standards set forth in GAO's Cost Estimating and Assessment Guide and revised its cost estimates for public infrastructure needs on Guam. In doing so, DOD reduced its estimate and future budget requests.

GAO, *Defense Management: Further Analysis Needed to Identify Guam's Public Infrastructure Requirements and Costs for DOD's Realignment Plan,* GAO-14-82 (Washington, D.C.: December 17, 2013).

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 4, each program's aspects are unique.

Key System Characteristics and Performance Parameters

Each system has unique physical and performance characteristics; analysts need specific knowledge about these characteristics 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 will vary from one program to another, several general characteristics have been identified in the various guides we reviewed. Table 5 lists general characteristics shared within several system types. Table 5 is not intended to be exhaustive.

Table 5: General System Characteristics

System	Characteristic
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 (for example, airframe unit weight, combat, empty, maximum gross, payload, structure)
	Wetted area
	Wing (for example, wingspan, wing area, wing loading)
Automated information systems	Architecture
	Commercial off-the-shelf (COTS) software used
	Customization of COTS software
	Expansion factors
	Memory size
	Processor type
	Proficiency of programmers
	Programming language used
	Software sizing metric

System	Characteristic
Construction	Ability to secure long-term visas
	Changeover
	Environmental impact
	Geography
	Geology
	Liability
	Location (for example, land value, proximity to major roads, relocation expenses for workers)
	Material type (for example, 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

System	Characteristic
	Launch vehicle
	Mission and duration
	Orbit type
	Pointing accuracy
	Satellite type
	Thrust
	Weight and volume
Tanks and trucks	Engine
	Height
	Horsepower
	Length
	Weight
	Width
	Payload

Source: DOD and GAO. | GAO-20-195G

Once a system's unique requirements have been defined, they should 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. Because it is evolutionary, earlier versions of the technical baseline will necessarily include more assumptions and, therefore, more uncertainty. These assumptions should be replaced with information as they become known; consequently, the level of uncertainty associated with the assumptions will decline.

Survey of Step 3

Process Tasks

In a technical baseline document or group of documents, identify

- The program's purpose and its system and performance characteristics;
- All system configurations;
- Any technology implications;
- The program acquisition schedule and acquisition strategy;
- The relationship to other existing systems, including predecessor or similar legacy systems;

- Support (e.g., manpower, training) and risk items;
- System quantities for development, test, and production; and
- Deployment and maintenance plans

Best Practices

The technical baseline description completely defines the program, reflects the current schedule, and is technically reasonable.

- A documented technical baseline description exists and resides in one location.
- The technical baseline description has been developed by qualified personnel such as system engineers.
- The technical baseline description has been updated with technical, program, and schedule changes.
- The technical baseline description contains sufficient detail of the technical characteristics, risk, and the like, based on the best available information at the time.
- The technical baseline description has been approved by management.

Likely Effects If Criteria Are Not Fully Met

- Without an adequate understanding of the acquisition program—such as the acquisition strategy, technical definition, characteristics, system design features, and included technologies—the cost estimator will not be able to identify the technical and program parameters that underpin the cost estimate and the quality of the cost estimate will be compromised.
- Unless the technical baseline is maintained and updated in preparation for program reviews, milestone decisions, and major program changes, the credibility of the cost estimate will suffer.
- Without explicit documentation of the basis of a program’s estimates, it will be 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.

Chapter 7: Step 4: Determine the Estimating Structure - Work Breakdown Structure

A work breakdown structure (WBS) deconstructs a program's end product into smaller specific elements that are suitable for management control. The WBS is the cornerstone of every program because it defines in detail the work necessary to accomplish a program's objectives. The WBS provides a consistent framework for planning and assigning responsibility for the work, and is an essential element for identifying activities in a program's integrated master schedule. The WBS is initially set up when a program is established and becomes successively detailed over time as more information becomes known about the program. 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.

A WBS provides a basic framework for a variety of related activities including estimating costs, developing schedules, identifying resources, and determining where risks may occur. 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—enabling quick identification of cost and schedule variances.

WBS Concepts

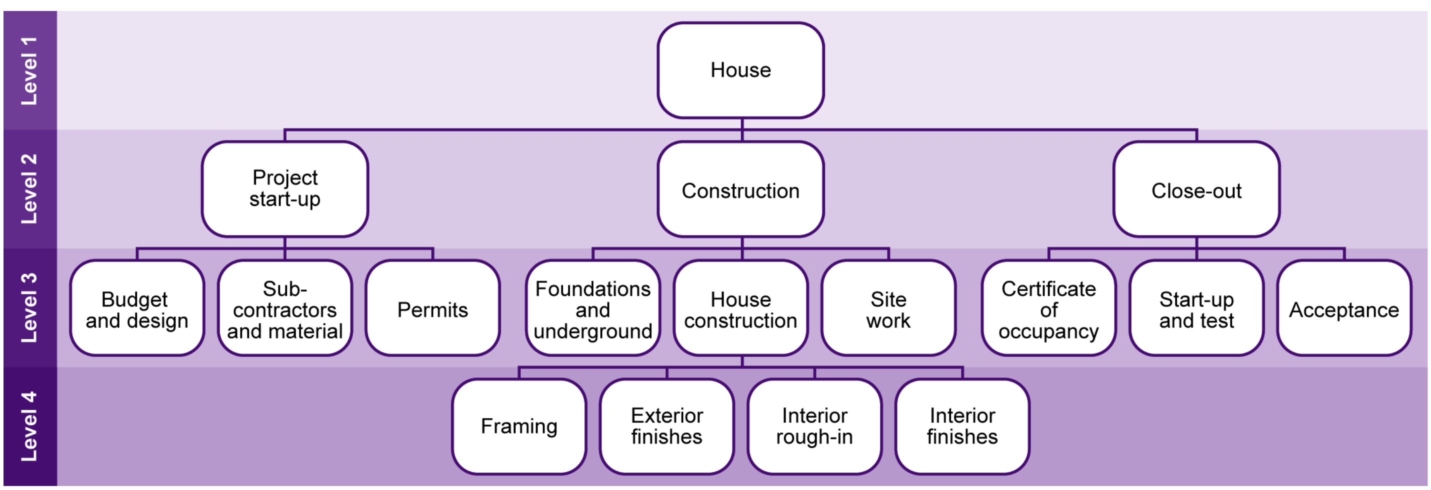
A WBS diagrams effort in small discrete pieces, or elements, to show how each element relates to the others and to the program as a whole. It can be thought of as an illustration of what work will be accomplished to satisfy a program's requirements. Elements such as hardware, software, and data are further broken down into specific lower-level elements. The lowest level of the WBS is defined as the work package level. By breaking work down into smaller elements, management can more easily plan and schedule the program's activities and assign responsibility for the work.

A WBS breaks down product-oriented elements into a hierarchical parent-child structure that shows how elements relate to one another as well as to the overall end product. A well-defined WBS clearly delineates the logical relationship of all program elements and helps promote accountability by identifying work products that are independent of one another. 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.

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. A WBS also facilitates establishing the schedule, cost, and earned value management (EVM) baseline. 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. It also 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. 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.

The number of levels in a WBS 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 the third level contains the subsystems for each segment. These relationships are illustrated in figure 7, which depicts a simple construction WBS.

Figure 7: A Product-Oriented Work Breakdown Structure



Source: GAO. | GAO-20-195G

In figure 7, all level 2 elements also have level 3 subcomponents. For some level 2 elements, level 3 is the lowest level of breakdown; for other level 2 elements, lower levels are required. The hierarchical parent–child relationship shows logical connections and relationships and leads to 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 7, construction is a child of the house system but the parent of foundations and underground, house construction, and site work. In a WBS, the sum of a parent's children must equal the parent. Thus, in figure 7, the sum of framing, exterior finishes, interior rough-in, and interior finishes must be equal to the level 3 parent house construction. In this way, the WBS ensures that each element is defined and related to only one work effort.

Case study 8 highlights problems that can occur when this best practice is not followed.

Case Study 8: Program Level Work Breakdown Structure, from Plutonium Disposition Program, GAO-14-231

The Department of Energy's (DOE) National Nuclear Security Administration (NNSA), a separately organized agency within DOE, manages the Plutonium Disposition program to dispose of surplus weapons-grade plutonium by burning it as mixed oxide (MOX) fuel—a mixture of plutonium and uranium oxides—in specially modified commercial nuclear reactors. In 2012, DOE forecasted cost increases of close to $3 billion over the previous estimates for the program's two construction projects, the MOX facility and the Waste Solidification Building (WSB) for disposing of waste from the MOX facility. GAO was asked to review these cost increases and the life cycle cost estimate.

GAO's assessment of NNSA's process for developing its draft life cycle cost estimate found, in part, that the estimate was only partially comprehensive. GAO found that work breakdown structures were developed for the MOX and WSB projects and other components of the program, but that NNSA had not formalized a program-level work breakdown structure. A typical work breakdown structure provides a clear picture of what needs to be accomplished, how the work will be done, and a basis for identifying resources and tasks for developing a cost estimate. Without a program-level work breakdown structure, NNSA could not ensure that its life cycle cost estimate captured all relevant costs, which could lead to cost overruns.

GAO recommended that to identify lessons learned from and provide assurance of preventing recurrence of cost increases for the MOX facility and WSB, and to develop reliable cost estimates for the Plutonium Disposition program, the Secretary of Energy should direct the DOE and NNSA Offices of Acquisition and Project Management and the NNSA office responsible for managing the Plutonium Disposition program, as appropriate, to revise and update the program's life cycle cost estimate following the 12 key steps described in the GAO Cost Estimating and Assessment Guide for developing high-quality cost estimates, such as conducting an independent cost estimate to provide an objective and unbiased assessment of whether the estimate can be achieved. In 2017, NNSA directed its Office of Cost Estimating and Program Evaluation to develop a new life cycle estimate for the plutonium disposition program based on NNSA's preferred approach of dilute and dispose. That estimate was completed in March 2018. The estimate was directed to be done in accordance with GAO cost estimating and assessment best practices.

GAO, *Plutonium Disposition Program: DOE Needs to Analyze the Root Causes of Cost Increases and Develop Better Cost Estimates,* *GAO-14-231* *(Washington, D.C.: February 13, 2014).*

A WBS may sometimes be organized by function rather than by product. A functional WBS categorizes effort by activities or processes, such as manufacturing, engineering, or quality control. But because a product-oriented WBS reflects cost, schedule, and technical performance on specific portions of a program, it represents a cost estimating best practice. For example, an overrun on a specific item in figure 7 (for example, framing) might cause program management to change a specification, shift funds, or modify the design. If the WBS was functionally based—for example, organized by carpenters instead of framing—then management would not have the right information to get to the root cause of the problem. Hence, elements at the second or third level of the WBS should be structured according to products or deliverables. Examples of elements that are not products are:

- 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);[14]
- types of funds used in program acquisition 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 them, 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—that is, special equipment needed to produce, handle, or assemble an item—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. Moreover, a WBS dictionary should state where the functional elements fall within the products and how the statement of work elements come together to

[14]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.

make specific products.[15] A WBS dictionary is a document that describes in brief narrative format what work is to be performed for each WBS element.

Common WBS Elements

In addition to including product-oriented elements, every WBS includes program management as a level 2 element, as well as other common elements like integration and assembly, government furnished equipment, and government testing. Table 6 lists and describes common elements that that support a program. For example, systems engineering, program management, integration, and testing are necessary support functions for developing, testing, producing, and fielding hardware or software elements.

Table 6: 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)
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 under development; 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

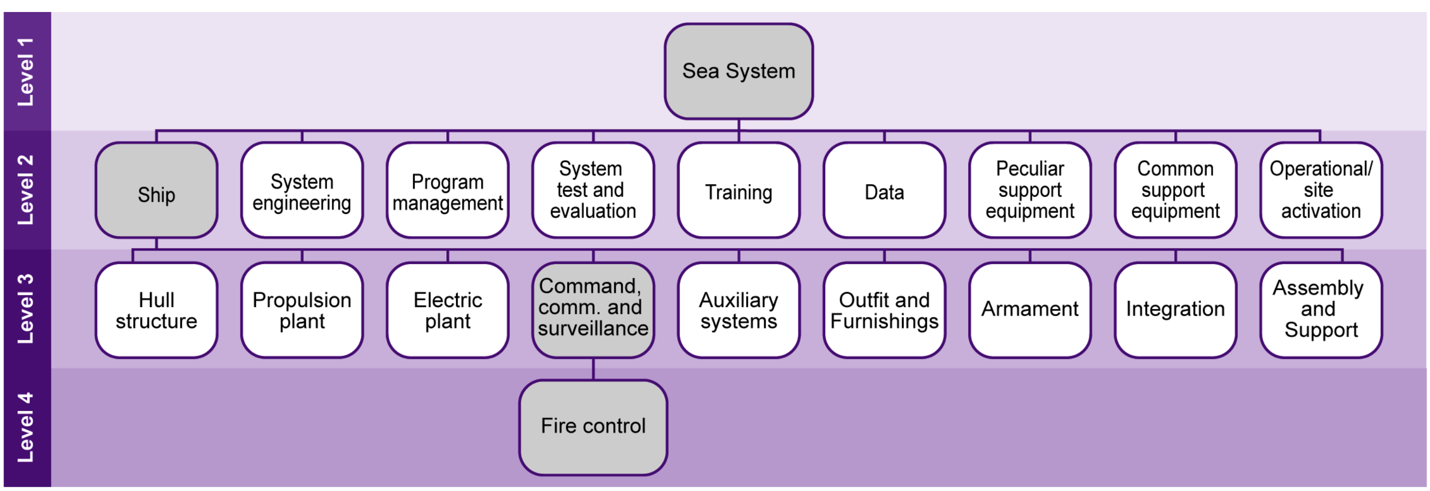
[15] In addition to product-oriented and functional breakdown structures, costs may be categorized in a cost element structure (CES) that groups costs by system or appropriation.

Common element	Description
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. | GAO-20-195G

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, because the WBS should be the starting point for developing the detailed schedule. Figure 8 shows a program WBS, including common elements, for a sea system.

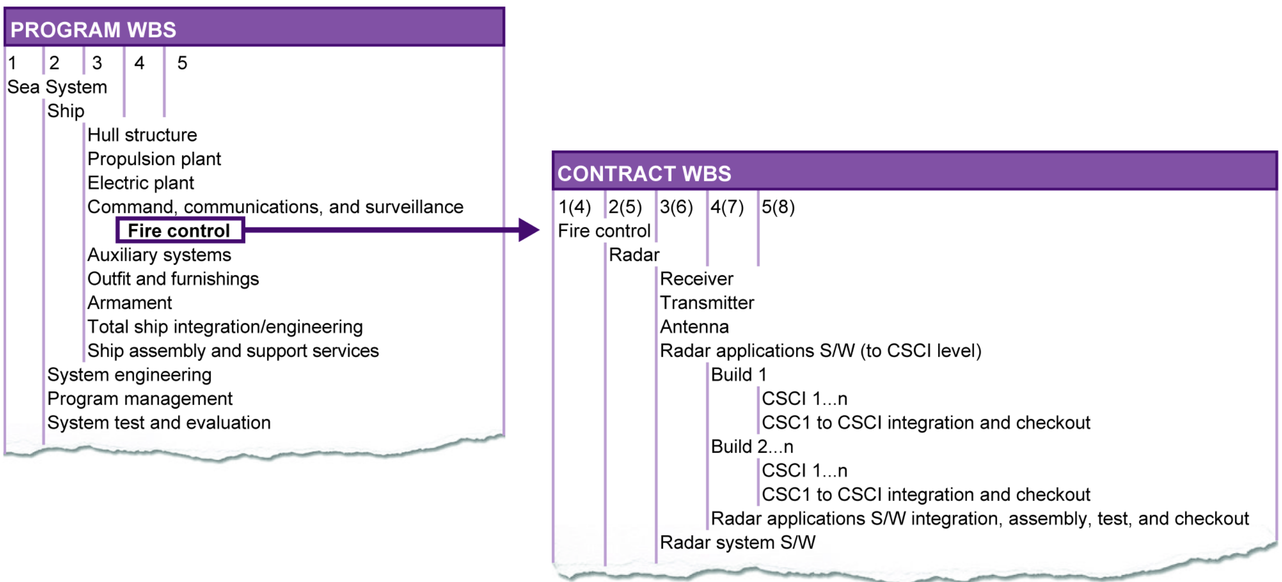
Figure 8: A Work Breakdown Structure with Common Elements



Source: DOD. | GAO-20-195G

The WBS in figure 8 encompasses the whole program. The contractor may also develop a contract WBS that extends the lower-level components to reflect its responsibilities. See figure 9.

Figure 9: A Contract Work Breakdown Structure



Source: DOD. | GAO-20-195G

Figure 9 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 4 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 4 in the program WBS. This shows how a subcontractor would break a level 4 item down to lower levels to accomplish the work, which when rolled up to the prime WBS, would show effort at levels 4–8.

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 over time, the WBS will also be updated to 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. Elements of a WBS may vary by phase because different activities are required for development, production, operations, and support.

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.

It is important that each WBS be accompanied by a dictionary of the various WBS elements and their hierarchical relationships. In a WBS dictionary, each element is presented in an outline to show how it relates to the next higher element to ensure clear relationships. With minor changes and additions, the WBS dictionary can be converted into a statement of work. 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, because the WBS is product oriented, it is closely related to and structured similarly to an indented bill of materials for the primary product. Like the WBS, the dictionary should be updated when changes occur. After the program is baselined, updating the WBS should be part of a formal process.

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 difficulty in comparing costs from one contractor or program to another, resulting in substantial expense when collecting and reconciling contractor cost and technical data.

The standardized WBS 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 for setting up the EVM performance measurement baseline. Relying on a standardized WBS can enable program managers to better plan and manage their work and helps in updating the cost estimate with actual costs—the final step in our 12 steps to develop a high-quality cost estimate.

A standardized product-oriented WBS can help define high-level milestones and cost driver relationships that can be repeated on future applications. In addition to helping the cost community, standardized WBSs can result in better portfolio management. Programs reporting to a standardized WBS enable leadership to make better decisions about where to apply contingency 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 report in the same format.

Appendix VI provides examples of standardized WBSs developed by government agencies and private organizations. The standardized WBS should be tailored to fit each program. In some cases, the 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 element structure not double count costs that could be included in more than one cost element. While the structure is flexible, children should be assigned to only one parent.

WBS and Scheduling

The WBS should be used as the outline for the schedule, using the levels of indenture down to the work package level. Because the WBS defines the work in lower levels of detail, its framework provides the starting point for defining all activities 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 may be copied into the scheduling 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. High-level summary activities and detail activities in the schedule should map directly to the WBS to ensure that the schedule encompasses the entire work effort. GAO's *Schedule Assessment Guide* has more information on WBS and scheduling.[16]

WBS and EVM

By breaking the work into smaller and 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 are 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. 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 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 schedule that allows for further understanding of program cost and schedule variances. When the work is broken down into small pieces, progress can be linked to the schedule for better assessments of cost, technical, schedule, and performance issues. The WBS also enhances program control by tying the contractual work scope to the schedule.

[16]GAO, *Schedule Assessment Guide: Best Practices for Project Schedules*, GAO-16-89G (Washington, D.C.: December 2015).

WBS and Risk Management

The WBS is 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 may also be used to monitor risks using the EVM system.

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. In addition, risk items can be mapped to activities in the schedule and the results can be examined through a schedule risk analysis.[17]

WBS Benefits

Establishing a 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, because the work in phases frequently overlaps;
- providing a common language for government and contractors to determine an appropriate level of reporting; and
- providing a common basis and framework for the EVM system and the schedule, facilitating consistency in understanding program cost and schedule performance. Because the link between the requirements, WBS, the statement of work, and schedule provides specific insights into the relationship between cost, schedule, and performance, all items can be tracked to the same WBS elements.

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,

[17]More information on best practices for schedule risk analysis can be found in GAO, *Schedule Assessment Guide: Best Practices for Project Schedules*, GAO-16-89G (Washington, D.C.: December 2015).

expenditures, and cost and technical performance. Without a WBS, a program is most likely to encounter problems, as case study 9 illustrates.

Case Study 9: Developing Work Breakdown Structure, from 2020 Census, GAO-15-225

The U.S. Census Bureau planned to significantly change the methods and technology it used to count the population with the 2020 Decennial Census, such as offering an option for households to respond to the survey via the Internet. This involved developing and acquiring IT systems and infrastructure to support the collection and processing of Internet response data.

GAO was asked to review the Bureau's efforts to deliver an Internet response option for the 2020 census. Among other objectives, GAO was asked to assess the reliability of estimated costs and savings for Internet response. To do this, GAO reviewed Bureau studies, cost estimates, project plans, schedules, and other documentation.

GAO concluded that the Internet response option cost estimate was not comprehensive. The Internet response option cost estimate included costs from 2010 to 2020 and provided a subset of assumptions for researching, testing, and deploying an Internet response option. While the estimate was structured around these high-level cost elements, these elements were not defined, and therefore it was not clear whether all costs associated with the Internet response option were included. Bureau officials stated that the estimate was not developed based on a work breakdown structure with defined elements because the 2020 Census program was not mature enough to have such a structure at the time the initial estimate was developed. They stated that the estimate would be updated to reflect the program's work breakdown structure once the preliminary design decision was made. However, a work breakdown structure should have been initially set up when the program was established and successively updated with more detail over time as more information became known about the program.

GAO recommended that to ensure that the Bureau was better positioned to deliver an Internet response option for the 2020 Decennial Census, the Secretary of Commerce should direct the Under Secretary for Economic Affairs to direct the Director of the Census Bureau to ensure that the estimated costs associated with the Internet response option were updated to reflect significant changes in the program and to fully meet the characteristics of a reliable cost estimate. The Department of Commerce agreed with our recommendation and took steps to implement it. In August 2017, the Census Bureau finalized its Census Enterprise Data Collection and Processing (CEDCAP) Cost Analysis Requirements Description (CARD), which included a basis for estimating the costs associated with the Internet response option. Subsequently, in December 2017, the Bureau finalized its updated 2020 Decennial life cycle cost estimate that included the CEDCAP CARD as an input to the estimate. GAO's April 2018 analysis of the updated cost estimate found that the Bureau had made significant improvements in its cost estimation process across the four characteristics of a reliable estimate. As a result, the Bureau was better positioned to deliver an Internet response option for the 2020 Decennial Census.

GAO, *2020 Census: Key Challenges Need to Be Addressed to Successfully Enable Internet Response*, GAO-15-225 (Washington, D.C.: February 5, 2015).

Survey of Step 4

Process Tasks

- Define a work breakdown structure (WBS) that is standardized and product-oriented.
- Ensure the cost estimate WBS matches the schedule and earned value management WBS, if applicable.
- Describe each WBS element in a WBS dictionary.
- Update the WBS as the program becomes better defined to reflect changes as they occur.

Best Practices

The cost estimate WBS is product-oriented, traceable to the statement of work, and at an appropriate level of detail to ensure that cost elements are neither omitted nor double-counted.

- The WBS clearly outlines the end product and major work of the program.
- In addition to hardware and software elements, the WBS contains program management and other common elements to ensure that all work is covered.
- The WBS contains at least 3 levels of indenture and the sum of the children elements equal their parent elements.
- The cost estimate WBS matches the schedule WBS, as well as the earned value management WBS if applicable.
- The WBS is standardized so that cost data can be collected and used for estimating future programs.
- The WBS is updated as the program becomes better defined and to reflect changes as they occur.

  A WBS dictionary exists that defines what is included in each element and how it relates to others in the hierarchy.

Likely Effects If Criteria Are Not Fully Met

- Without a WBS, the program lacks a 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.
- If a cost estimate does not specifically break out common costs, such as government furnished equipment (GFE) costs, or does not include

an associated work breakdown structure (WBS) dictionary, one cannot ensure that the estimate includes all relevant costs.

- Without a standard, product-oriented WBS to facilitate the tracking of resource allocations and expenditures, an organization may have difficulties sharing data among programs, comparing and reconciling costs between contractors, and updating the cost estimate with actual costs.

Chapter 8: Step 5: Identify Ground Rules and Assumptions

Cost estimates are typically based on limited information and therefore are dependent on several suppositions that make it possible to complete the estimate. These suppositions are called ground rules and assumptions. Ground rules and assumptions (GR&As) typically define the estimate's scope and establish baseline conditions on which the estimate is based.

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, and
- provide a basis for the cost estimate that documents areas of potential risk that can be identified and eventually treated.

Ground rules and assumptions are distinct even though they are often grouped together.

Ground Rules

Ground rules represent a common set of agreed upon 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. For example, the technical baseline requirements discussed in chapter 6 represent cost estimate ground rules by which cost analysts can conduct the estimate.

Assumptions

Assumptions represent a set of judgments about past, present, or future conditions postulated as true in the absence of positive proof. Without firm ground rules, the analyst is responsible for making assumptions that allow the estimate to proceed. In other words, assumptions are required only when no ground rules have been provided. The analyst must ensure that assumptions are based 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 affect 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 on which the estimate was structured. Failing to do so can lead to overly optimistic assumptions that influence the cost estimate, to cost overruns, and to inaccurate estimates and budgets. (See case study 10.)

Case Study 10: The Importance of Assumptions, from *Columbia Class Submarine*, GAO-19-497

The Navy plans to invest approximately $128 billion to research, develop, and purchase the replacement for 14 Ohio class nuclear-powered ballistic missile submarines—the current sea-based leg of the nation's strategic nuclear deterrent. According to the Navy, the lead Columbia class submarine will need to make its first patrol in fiscal year 2031 in order to avoid a deterrence gap; the Ohio class submarines begin to retire in 2027. The Navy has identified the 12-submarine Columbia class program as its top acquisition priority and has set an aggressive schedule to deliver the lead submarine in fiscal year 2027, followed by a period of testing before the first patrol occurs.

The Navy's procurement cost estimate of $115 billion to construct Columbia class submarines was not reliable because it did not reflect likely program costs and risks. GAO found that the cost estimate substantially met the criteria for the comprehensive characteristic of a reliable cost estimate, and partially met the criteria for the remaining three characteristics.

In particular, GAO found that the cost estimate did not accurately reflect program costs because it was based on overly optimistic labor hour assumptions. The Navy estimated that it would need $115 billion to design and construct 12 submarines and Navy cost estimators identified labor costs as a primary source of cost risk. The Navy anticipated that it would need 12 million labor hours to directly construct the lead submarine. This represented 17 percent fewer labor hours than what was needed for the lead Virginia class submarine, when adjusted for weight differences. To develop this estimate, Navy estimators relied heavily on historical labor hour data from the construction of the lead Virginia class submarine and cost data from the Ohio class submarine program for unique ballistic submarine components, such as missiles. However, the labor hour estimate was overly optimistic—with assumptions on construction efficiencies that were either unsubstantiated or unprecedented compared to Virginia class and other shipbuilding historical data.

Compared to the Navy's estimate, Columbia's estimated touch labor hours, as calculated by other organizations, were more conservative. For example, the Congressional Budget Office questioned the Navy's assumption that ballistic submarines are less expensive to build than attack submarines, after accounting for weight differences. They estimated that for the overall class, including the lead and follow-on submarines, the Navy would more likely realize an 8 percent reduction rather than the 19 percent reduction estimated by the Navy. If the program's optimistic assumptions were not realized, the program may have required more funding than originally planned to construct the Columbia class

GAO, *Columbia Class Submarine: Overly Optimistic Cost Estimate Will Likely Lead to Budget Increases*, GAO-19-497 (Washington, D.C.: April 8, 2019).

Global and Element-Specific Ground Rules and Assumptions

GR&As can be either global or element specific. Global GR&As apply to the entire estimate, while element-specific GR&As are driven by each WBS element's detailed requirements. GR&As are more pronounced for estimates in the development phase, when 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 to apply to many. 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.[18]

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 the manufacturing and the technical community should be involved in developing the program schedule, but often information is insufficient and assumptions must be made.

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 program 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 a negative reaction from the customer. Likewise, the customer may be unwilling to report cost or schedule risk due to fear that the program could be canceled. See the GAO *Schedule Assessment Guide*

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

for more information on creating and maintaining reliable integrated master schedules.[19]

Management may impose cost limitations because of budget constraints. The GR&As should then clearly explain the cost 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.

Estimates should be time phased if program costs 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. However, great peaks or valleys in annual funding should be investigated and explained because 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 as a 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 enables comparing separate estimates. 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 budget year dollars that include inflation. At a minimum, the analyst should clearly explain the inflation index, source, and approval authority in the estimate documentation. Inflation rates should be standardized across similar programs, because they are all conducted in the same economic environment, and priority choices between them should not hinge on

[19]GAO, *Schedule Assessment Guide: Best Practices for Project Schedules*, GAO-16-89G (Washington, D.C.: December 2015).

different assumptions about what is essentially an economic scenario common to all programs.

Some programs originate from two or more agencies working together to achieve common program goals. When this happens, agreements should lay out each agency's area of responsibility. 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.

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

- life cycle phases and operations concepts;
- 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, such as quantities and technology assumptions. The element-specific GR&As carry the most uncertainty and therefore should be checked for realism and be well documented in order for the estimate to be considered credible. Without analyzing the effects of an invalid assumption on the cost and schedule of a program, cost estimators and management will not have a full understanding of the effects of changing ground rules and assumptions.

Assumptions, Sensitivity, and Risk Analysis

Every estimate is uncertain because assumptions must be made about future projections. Sensitivity analysis examines how changes to key assumptions and inputs affect the estimate and can help mitigate uncertainty. Best practice cost models incorporate sensitivity analyses without altering the model so that the effect of varying inputs can be quickly determined (more information is in chapters 11 and 12). For example, a decision-maker may challenge the assumption that 5 percent of the installed equipment will be needed for spares, and asks that the factor be raised to 10 percent. A sensitivity analysis would show the cost impact of this 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. Often, 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 baselines.

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 be considered. Indeed, risks from all sources, including external, organizational, and even program management practices, in addition to the technical challenges, need to be addressed as well.

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, whereas "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 collect all assumptions in a single location so that risk and sensitivity analysis can be performed efficiently and quickly.

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 reported to management. This is especially important when the schedule is 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.

Cost estimators and auditors should be wary of overly optimistic technology forecasts. It is well known that program advocates tend to underestimate the technical challenges facing the development of a new system. (For more information see GAO's *Technology Readiness Assessment Guide*)[20]. 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. Technology maturity assumptions also tend to be optimistic. Having reviewed the experiences of DOD and commercial technology development, GAO found that programs that relied on technologies with a demonstrated 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

[20]GAO, *Technology Readiness Assessment Guide: Best Practices for Evaluating the Readiness of Technology for Use in Acquisition Programs and Projects*, GAO-20-48G (Washington, D.C.: January 2020).

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 study 11 provides an example of the impact of underestimating technology maturity.

Case Study 11: Technology Maturity, from Columbia Class Submarine, GAO-18-158

Additional development and testing were required to demonstrate the maturity of several Columbia class submarine technologies that were critical to performance, including the Integrated Power System, nuclear reactor, common missile compartment, and propulsor and related coordinated stern technologies. As a result, it was unknown whether they would work as expected, be delayed, or cost more than planned. Any unexpected delays could postpone the deployment of the lead submarine past the 2031 deadline.

GAO found that the Navy underrepresented the program's technology risks in its 2015 Technology Readiness Assessment (TRA) when it did not identify these technologies as critical. Development of these technologies was key to meeting cost, schedule, and performance requirements. A reliable TRA serves as the basis for realistic discussions on how to mitigate risks as programs move forward from the early stages of technology development. Not identifying these technologies as critical meant Congress may not have had the full picture of the technology risks and their potential effect on cost, schedule, and performance goals as increasing financial commitments were made. The Navy was not required to provide Congress with an update on the program's progress, including its technology development efforts, until fiscal year 2020—when $8.7 billion for lead ship construction would have already been authorized. Periodic reporting on technology development efforts in the interim could have provided decision-makers assurances about the remaining technical risks as the Navy asked for increasing levels of funding.

Consistent with GAO's identified best practices, the Navy intended to complete much of the submarine's overall design prior to starting construction to reduce the risk of cost and schedule growth. However, the Navy awarded a contract for detail design while critical technologies remained unproven—a practice not in line with best practices that led to cost growth and schedule delays on other programs. Proceeding into detail design and construction with immature technologies can lead to design instability and cause construction delays. The Navy planned to accelerate construction of the lead submarine to compensate for an aggressive schedule, which may have led to future delays if the technologies were not fully mature before construction started in 2021.

GAO, *Columbia Class Submarine: Immature Technologies Present Risks to Achieving Cost, Schedule, and Performance Goals*, GAO-18-158 (Washington, D.C.: December 21, 2017).

Once the risk and 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 on which the estimate was based. When possible, the cost estimator should request an updated technical baseline in which the new assumptions have been incorporated as ground rules.

Survey of Step 5

Process Tasks

- Document all cost-influencing ground rules and assumptions.
- Document the rationale and historical data that support the ground rules and assumptions.
- Include input from the technical community when developing ground rules and assumptions.
- Document risks associated with assumptions and trace to specific WBS elements.

Best Practices

The estimate documents all cost-influencing ground rules and assumptions.

- There are defined ground rules and assumptions and the rationale and historical data to support them are documented.
- The ground rules and assumptions have been developed by estimators with input from the technical community.
- Risks associated with assumptions have been identified and traced to specific WBS elements. For example, effects related to budget constraints, delayed program content, dependency on other agencies, and technology maturity have been identified.
- Cost-influencing assumptions are used as inputs to the sensitivity and uncertainty analyses.

Likely Effects if Criteria Are Not Fully Met

- If management is not informed of cost estimating ground rules and assumptions, it will not fully understand the conditions on which the estimate was structured. The subsequent rejection of even a single assumption by management could invalidate many aspects of the cost estimate.
- Overly optimistic assumptions may influence the cost estimate, leading to inaccurate estimates and budgets.
    - Without analyzing the effects of an invalid assumption on the cost and schedule of a program, cost estimators and management will

not have a full understanding of the effects of changing ground rules and assumptions.

- Unless assumptions are documented with their sources and supporting historical data, decision-makers will not understand the level of certainty around the assumption or the cost estimate.

Chapter 9: Step 6: Obtain the Data

Data are the foundation of every cost estimate. The quality of the data affects the estimate's overall credibility. Depending on the data quality, an estimate can range anywhere from a rough guess to a highly defensible cost position. Reliable cost estimates are rooted in historical data. Estimators usually develop estimates for new programs by relying on data from programs that already exist and then making adjustments for any differences. Thus, collecting valid and useful historical data is a key step in developing a sound cost estimate.

The challenge of data collection 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. Collecting data 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. Only after these tasks have been performed should the estimator begin to develop an initial data collection plan.

Data Collection

The data collection plan should emphasize the collection of current and relevant technical, programmatic, cost, and risk data. Data collection is a lengthy process and continues throughout the development of a cost estimate and through program execution. Many types of data need to be collected: technical, schedule, program, and cost data. Data can be collected in a variety of ways, such as from databases of past projects, interviews, surveys, data collection instruments, focus groups, and market assessment studies. After the estimate is complete, the data need to be well documented, protected, and stored for future use in databases. 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 organization history.

Cost estimates require a continual influx of current and relevant cost data to remain credible. 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 consult 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. Case study 12 below highlights the importance of having historical data.

Case Study 12: Addressing Risks, from F-35 Sustainment, GAO-16-439

Central to F-35 sustainment is the Autonomic Logistics Information System (ALIS)—a complex system supporting operations, mission planning, supply-chain management, maintenance, and other processes. ALIS had experienced developmental issues and schedule delays that had put aircraft availability and flying missions at risk. The National Defense Authorization Act for Fiscal Year 2016 included a provision that GAO review the F-35's ALIS. GAO assessed, among other things, the extent to which DOD had credibly and accurately estimated ALIS costs.

DOD had estimated total ALIS costs to be about $16.7 billion over the F-35's 56-year life cycle, but performing additional analyses and including historical cost data would have increased the credibility and accuracy of DOD's estimate.

For example, while GAO found that the DOD substantially met some best practices in their estimate for the ALIS program for an accurate cost estimate by properly adjusting for inflation and not including mathematical errors, the estimate used contractor-provided data for material costs instead of actual ALIS costs or historical cost data from analogous programs that would have made the estimate more accurate. Cost estimating officials said that they did not base their ALIS estimates on historical cost data because they believed that there were no programs analogous to ALIS. For example, there is a logistics system for the Air Force's F-22 program—also a fifth-generation aircraft—but officials stated that it was far less complex than ALIS and did not include all of ALIS's applications and intended functions. However, multiple versions of ALIS have been fielded since 2010 and using historical data on known ALIS costs, as well as analogous data from the F-22 or other programs, would make the estimate more accurately representative of likely sustainment costs.

GAO's *Cost Estimating and Assessment Guide* states that a cost estimate should be based on historical data—both actual costs of the program and those of comparable programs—which can be used to challenge optimistic assumptions and bring more realism to a cost estimate.

GAO- *F-35 Sustainment: DOD Needs a Plan to Address Risks Related to Its Central Logistics System*, GAO-16-439 (Washington, D.C.: April 14, 2016).

Cost estimates must be based on realistic schedule information.[21] 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, early cost estimates are aligned with the baseline schedule. But, estimators should be aware of changes in the schedule because schedule changes likely lead to cost changes. Furthermore,

[21]GAO's *Schedule Assessment Guide* (GAO-16-89G) provides information on how to create a reliable schedule.

seeking input from schedule analysts can provide valuable knowledge about how aggressive a program's schedule may be.

Additionally, backup data should be collected for performing cross-checks, and risk data should be collected to support sensitivity analysis and risk and uncertainty analysis.[22] This takes time and usually requires travel to meet with technical experts. It is important to plan ahead and schedule adequate time for these activities. Scheduling insufficient time may affect the estimator's ability to collect and understand the data, which can result in a lower-quality cost estimate.

A common issue in data collection is inconsistent data definitions between historical programs and 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 instead resulted in more costs because of initial learning curve problems? Knowing the history behind the data allows for their proper use in future estimates.

Data may not always be available, accessible, or complete. For example, some agencies may not have cost databases. Data may be accessible only at the summary level, and information may not be sufficient to break them down to the lower levels needed to estimate various WBS elements. Data may also be incomplete. For instance, data 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 classified or considered competition sensitive. In these cases, the cost estimator may have to change the estimating approach to fit the data that are available.

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),

[22] For additional discussion of risk data, see chapter 12.

material and its overhead dollars, facilities capital cost of money,[23] and profit associated with various activities. Program cost estimators often do not have details about specific dollar amounts, 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 relationships change over time and require adjustments when cost estimating relationships are being developed or revised.

Program and technical data provide context for cost data, which by themselves may be meaningless. Consider these two examples:

- Veteran Administration hospital utilities cost $100,000.
- An aircraft consumes 500 gallons of fuel per hour.

In the Veteran Administration hospital example, technical and program parameters that would provide insight into the specific utilities and the time frame the utilities were consumed are missing. In the aircraft example, a cost estimator would need to know what type of aircraft consumes 500 gallons per hour—a light jet or a long-range jet—and what type of fuel is consumed.

It is essential that cost estimators plan for and gain access, when feasible, to cost, technical, and program data in order to develop a complete understanding of what the data represent. Without this

[23]Facilities capital cost of money is an imputed cost related to the cost of contractor capital committed to facilities.

understanding, a cost estimator may not be able to correctly interpret the data, leading to a potential misapplication of the data.

Sources of Data

Because all cost estimating methods are data-driven, analysts must know the best data sources. Table 7 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. Because they are 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 likely find such data of little use.

Table 7: 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. | GAO-20-195G

Cost estimators should understand whether and how data were changed before deciding whether they will be useful. For this reason, it is always better to use actual costs rather than estimates as data sources because actual costs represent the most accurate data available. While secondary data should not be the first choice, they may be all that is available. In these cases, the cost estimator should seek to understand 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. Cost estimators should collect actual cost data from a list of similar and legacy programs. Because 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 and bring more realism to the estimate. For example, a review of the average labor rates for similar tasks on other programs can be a powerful cross-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 for a specific contractor across a variety of programs. Contractor cost trends allow the cost estimator to establish adjustment factors if they are relying on proposal data for cost estimates. Additionally, insights can be obtained on cost accounting structures to allow for an understanding of how a certain contractor charges items such as other direct costs and overhead.

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

Contract performance reports (CPRs) and cost and software data reports are excellent sources of historical cost data for DOD programs. More information on CPRs can be found in chapter 19.

Cost data reports are often used in estimating analogous programs, with 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 other WBS areas such as data, program management, or systems engineering. If the cost estimator can establish costs for the major deliverables, such as hardware or software, a factor may be applied for other areas of the WBS based on historical data available from cost reports. Rate and factor agreements contain rates and factors negotiated between the contractor and the government. 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 the agreements represents negotiated direct labor, overhead, general and administrative data, and facilities capital cost of money. These agreements may cover myriad factors, depending on each contractor's accounting and cost estimating structure. Typical factors include 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 may 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.

Contractor proposals also provide cost data. However, a contractor proposal is a document that represents the contractor's best estimate of cost, and proposals tend to be influenced by the amount the customer can spend. Therefore, proposal data should be viewed with caution, and care should be taken to determine if the proposal data are supportable. During source selection in a competitive environment, for instance, lower proposed costs may increase the chances of receiving a contract award. In this situation, cost estimators should analyze the cost data for realism. While often overly optimistic, a proposal can nonetheless provide useful information, such as:

- 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;
- 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.

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 cost estimator must scrutinize them in light of the following issues:

- Do the data require normalization to account for differences in base years, inflation rates, 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?

- 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 are more likely to be underestimated.
- 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, are the definitions the same?

Once these questions have been answered, the next step is to assess the validity of the data before they can be used to predict 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. For example, the contract type to be used in a future procurement—such as 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. To accommodate the second limitation, an experienced cost estimator can either adjust the data (if applicable) or collect new data.

A cost analyst should 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 understanding 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 scatterplot of the data. A scatterplot provides a wealth of visual information about the data, allowing the analyst to determine outliers, relationships, and trends. In a scatterplot, cost is typically treated as the dependent variable (the y-axis). Independent variables depend on the data collected, but are typically technical—such as weight, lines of code, and speed—or operational parameters—such as crew size and flying hours.

The scatterplots provide visual information about the dispersion in the data set, which is important for determining risk. In addition, 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 confirm cost drivers, but using scatterplots is an excellent way to identify potential drivers.

The cost estimator should also calculate descriptive statistics to characterize and describe the data. Important measures and statistics include sample size, mean, standard deviation, and coefficient of variation. The coefficient of variation is calculated by dividing the standard deviation by the mean. The resulting percentage can be used to compare the extent of variation within data sets.

Visual displays of the descriptive statistics help discern differences among groups. Bar charts, for example, are useful for comparing means. Histograms can be used to examine the distribution of different data, the frequency of values, and for determining potential outliers.

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 scatterplots can help validate an engineering judgment because they can quickly point out any outliers.

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. Instead, a cost estimator should provide adequate documentation as to why an outlier was removed. The 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 simply an extreme case, the cost estimator should retain the data point; otherwise, it will appear that the estimator was trying to manipulate the data. Removing an extreme case should rarely be done because historical data are necessary for capturing the natural variation within programs.

Data Bias

While collecting data, the estimator needs to be aware of any potential biases within the data. In particular, data collected through subject matter expert interviews have the potential to be biased.

Bias can originate from different sources, such as over-optimism, group think, dominating personalities, inexperience, or pressure from management. For example, motivational bias is a source of bias that arises when interviewees feel threatened (whether justifiably or unjustifiably) if they give their true thoughts about a program. This threat is typically from fear of being punished by someone in authority. Confidence bias occurs when the estimator is overly optimistic about the success of the program. Other forms of bias include a tendency to give more weight to recent events than earlier events, to assume patterns where none exist, and to assign connections to coincidences.

EVM Data Reliability

As we describe in chapter 20, an EVM system should be validated to ensure that, among other things, it provides reliable data for managing the program and reporting its status. Before using EVM data, analysts should ensure that the data are reliable by

- 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 are reasonable. For example, the auditor should review all WBS elements in the cost reports to determine whether there are data anomalies (chapter 19 describes several measures for EVM data anomalies). Despite the fact that EVM data anomalies should be rare and fully explained in variance analysis reports, we have found programs that submit reports with these types of errors.

Data Normalization

The purpose of data normalization is to make a given data set consistent with and comparable to other data used in the estimate. Because data can be gathered from a variety of sources, they are often in different forms. They therefore need to be adjusted before being compared or used as a basis for projecting costs. Cost data are adjusted in a process called normalization, which removes the effects of external influences. The objective of data normalization is to improve data consistency so that comparisons and projections are more valid. Data are normalized in several ways: by cost units, sizing units, key groupings, and technology maturity.

Cost Units

Cost units primarily adjust for inflation so 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 when adjusted for the effects of inflation. In addition to inflation, the cost estimator needs to understand what the cost represents. For example, some data may represent only direct labor while other data include overhead and fee. Cost data should also 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. Costs may also be adjusted for currency conversions.

Sizing Units

Sizing units normalize data to common units—for example, cost per foot, cost per pound, and dollars per software line of code. When normalizing data for unit size, it is important to define exactly what the unit represents. For example, does a software line of code include carriage returns or comments? Cost estimators should clearly define the sizing metric 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 different characteristics from those of submarines, but the space shuttle has characteristics distinct from those of a satellite. Costs should also be grouped by type. For example, costs should be broken out between recurring and nonrecurring or fixed and variable costs.

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 a like for like comparison. A properly defined WBS dictionary is necessary to avoid inconsistencies.

Technology Maturity

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 changes in cost due to changes in technology by predicting the timing and degree of change of technological parameters associated with the design, production, and use of devices.

Recurring, Nonrecurring, Fixed, and Variable Costs

Cost data should be separated into recurring and nonrecurring costs because one-time nonrecurring costs will skew the costs for recurring production units.

Nonrecurring Costs

Nonrecurring costs only occur once. These include 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 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; and
- developing, acquiring, producing, and checking all tooling, ground handling, software, and support equipment and test equipment.

Recurring Costs

Recurring costs occur periodically as items are produced or services are 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.

An important reason for differentiating recurring from nonrecurring costs is because of their application to learning curves. Cost improvement, or learning, is generally associated with repetitive actions or processes, such as those directly tied to producing an item again and again. Therefore, learning curve theory applies only to recurring costs. Appendix VII provides more information on learning curves.

Costs can also be categorized as fixed or variable. 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.

Inflation Adjustments

In the development of an estimate, cost data must be expressed in like terms. This is usually accomplished by adjusting costs for inflation to express them in a base year that will serve as a point of reference for a fixed price level. Adjusting for inflation is an important step in cost estimating. If the inflation index used is not correct, the resulting estimate could overstate or understate the cost of the program, as case study 13 illustrates.

Case Study 13: Documenting Inflation, from Coast Guard, GAO-12-741

From fiscal years 2005 through 2011, the physical condition of the Coast Guard's legacy vessels was generally poor, and the Coast Guard had taken two key actions to improve the vessels' condition: reorganizing its maintenance command structure and implementing sustainment initiatives for portions of its legacy vessel fleet. GAO was asked to study the conditions of the legacy fleet, in part by assessing the extent to which the Coast Guard's cost estimating process had followed established best practices. GAO found that the Coast Guard's process for estimating related legacy vessel maintenance costs did not fully reflect relevant best practices.

The Coast Guard's process for estimating annual legacy vessel maintenance costs was not considered fully accurate because although Coast Guard officials told us that the data they provided to us incorporated an inflation index of three percent for all years based on the consumer price index, they could not provide us with documentation explaining why the Coast Guard chose to use this inflation rate or how it was applied to the data. Applying inflation indexes is an important step in cost estimating because, in the development of an estimate, cost data must be expressed in the same terms. If the inflation index used is not correct, cost overruns can result. Ensuring that its annual-depot level cost estimates for legacy vessel fleet maintenance incorporate established best practices would have better positioned the Coast Guard to use its cost estimates to more effectively allocate available resources in the constrained federal budget environment.

GAO recommended that to strengthen the comprehensiveness, documentation, and accuracy of the Coast Guard's annual depot-level maintenance cost estimates for its legacy vessel fleet, the Secretary of Homeland Security should direct the Commandant of the Coast Guard to ensure that the Coast Guard's annual depot-level maintenance cost estimates conform to cost-estimating best practices. In July 2013, the Coast Guard issued the Government Estimating for Ship Repair Process Guide, which the Coast Guard reported was to incorporate best practices for cost estimating that could be adapted for use in estimating the cost of legacy vessel repairs. The document made improvements in each of the three relevant characteristics: comprehensiveness, documentation, and accuracy.

GAO, *Coast Guard: Legacy Vessels' Declining Conditions Reinforce Need for More Realistic Operational Targets,* GAO-12-741 (Washington, D.C.: July 31, 2012).

Adjusting for inflation correctly is necessary if the cost estimate is to be reliable. Inflation rates are used to convert a cost from its budget year into a constant base year so that comparisons may be made across years. 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 base-year dollars to eliminate the distortion that would otherwise be caused by overall price-level changes. This requires the transformation of historical or actual cost data into base-year dollars.

For budgeting purposes, however, the estimate must be expressed in budget year dollars to reflect the program's projected annual costs by appropriation. This requires adjusting for inflation to convert from base-year to budget 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 is lower than expected, applying the wrong inflation rate will result in a higher cost estimate. When inflation is higher than projected, the estimate forecasts costs that will not be sufficient to keep pace with inflation. Thus, it is imperative that inflation assumptions be well documented and that the cost estimator always perform sensitivity analysis to study the effects of changes on the projected rates.

Selecting the Proper Indexes

The cost estimator will not have to construct an index to adjust for inflation but will select one. Often, the index is directed by higher authority, such as OMB. In this way, all programs can be compared and aggregated since they are all using the same economic assumptions. This does not mean that the projected inflation rates are correct—in fact, inflation rates are difficult to forecast—but, program comparisons will not be skewed by different assumptions about inflation. When the index is not directed, a few general guidelines can help the cost estimator select the correct index. Because all indexes measure the overall rise in prices 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 professional 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. Although the market basket for the selected index may never exactly match the components in the program's cost estimate, the closer the match, the better the estimate.

Weighted indexes are used to convert constant, base-year dollars to budget 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 budget 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 adjustments for inflation can be performed properly.

Schedule risk can affect the magnitude of inflation in a cost estimate. The amount of the estimate due to inflation is often estimated by applying a monthly inflation 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 inflated by 30 months might now be inflated for 36 months. Even if the cost estimate in today's dollars is an accurate estimate, a schedule slip would affect the amount of the inflation adjustment.

In addition, the question of inflating the amount of contingency arises. Some cost estimating systems calculate the contingency on base-year dollars but do not adjust the contingency for inflation, perhaps because they do not have a way to determine when the contingency will be spent. However, some assumption should be made regarding the phasing of contingency because it represents additional money needed to complete the statement of work, and it will be affected by inflation just as is any other funding.

Data Documentation

After the data have been collected, analyzed, and normalized, they must be documented and archived for future use. One way to keep a large amount of historical data viable is to continually supplement them with new or updated data, such as a new system's actual costs, new contracts, and updated vendor quotes.

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 cost 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.

Thus, previous estimates can provide the cost estimator with valuable data and can also save time because they provide a structure from which to develop the new cost estimate. They also help avoid repeating effort because the cost estimator can leverage off the work of others.

Survey of Step 6

Process Tasks

- 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, 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.

Best Practices

The estimate is based on a historical record of cost estimating and actual experiences from other comparable programs.

- The estimate is based on historical data and the data are applicable to the program.
- The data are reliable.

- There is enough knowledge about the data source to determine if the data can be used to estimate accurate costs for the new program.
- If EVM data are used, the EVM system has been validated against the EIA-748 guidelines.

The estimate is adjusted properly for inflation.

- The cost data are adjusted for inflation so that they could be described in like terms and to ensure that comparisons and projections are valid. The final estimate is converted to budget year dollars.

Likely Effects if Criteria Are Not Fully Met

- Without sufficient background knowledge about the source and reliability of the data, the cost estimator cannot know with any confidence whether the data collected can be used directly or need to be normalized or otherwise modified.
- Unless cost estimators know the factors that influence a program's cost, they may not capture the right data.
- If cost estimators do not determine whether proposal data deviate from other similar data, they may introduce bias into the cost estimate.
- If outliers are removed from a data set without justification, the data may not capture the natural variation within program costs.
- If data are not properly normalized, the data set may be inconsistent with other data used in the estimate, the effects of external influences may not be removed, and comparisons and projections may not be valid.
- When adjusting for inflation, if the index used is not correct the resulting estimate could overstate or understate the cost of the program.
- Unless data are documented and archived for future use, more effort will be required to develop and document the current cost estimate, and cost estimates for future programs will not benefit from the research and analysis already conducted.
- Lack of historical data will leave the cost estimator without insight into actual costs of similar programs, including any cost growth since the original estimate. As a result, the estimator will be prevented from challenging optimistic assumptions and bringing more realism to the cost estimate.

- If it cannot be established that EVM data are from a compliant system, analysts will lack the necessary assurance that the EVM data are free from errors and anomalies that can skew and distort analyses.

Chapter 10: Step 7: Develop the Point Estimate

In this chapter, we discuss step 7 in the cost estimating process. This step pulls all the information together to develop the point estimate. 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 12 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
- sum the WBS element estimates to develop the overall point estimate.

We have already discussed how to develop a work breakdown structure, ground rules and assumptions, and collect and normalize the data into constant base-year dollars. 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 costs 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 is the program estimate. The parametric method relates cost to one or more technical, performance, cost, or program parameters through a statistical relationship.

The method selected 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. A variety of cost estimating methods will typically be used over the life of a program. Table 8 gives an overview of the strengths, weaknesses, and applications of the three methods.

Table 8: 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." | GAO-20-195G

Other cost estimating methods include:

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

The examples that follow are meant to provide an elementary understanding of the estimating methods. For more advanced treatments of these topics, the reader is encouraged to review additional references.

Analogy Cost Estimating Method

An analogy takes into consideration that no new program, no matter how advanced it may be technologically, represents a totally new system. Most new programs evolve from programs already fielded that have had new features added 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 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 for the new program 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 called 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 should 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, because analogies are one-to-one comparisons, the historical and new systems should have a strong parallel. Table 9 shows how an analogy works.

Table 9: 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	?	(16,000/12,000) x $5.2 million = $6.9 million

Source: ICEAA (International Cost Estimating and Analysis). Cost Estimating Body of Knowledge. Vienna, Va.: 2013. | GAO-20-195G

The equation in table 9 assumes a linear relationship between engine cost and the amount of thrust. Note that 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 opinion on engine costs), it is difficult 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 the reasonableness of technical program drivers with program experts to determine whether they are significant cost drivers.

Analogy relies a great deal on expert opinion to modify the existing system data to approximate the new system. When possible, the adjustments should be quantitative rather than qualitative, avoiding subjective judgments as much as possible. Even when an analyst is using a more detailed cost estimating technique, an analogy can provide a useful cross-check.

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 overly 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, the 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 14 highlights what can happen when technical parameter assumptions are overly optimistic.

Case Study 14: 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 Cost Analysis Improvement Group (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.: November 17, 2006).

Several questions should be asked when the analogy method is used as an estimating technique.

- 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?

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. It 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 for time-phasing the estimate and applying learning curves, if applicable. (Learning curves are discussed later in this chapter and in appendix VII.) Typically, cost estimators work with engineers to develop the detailed estimates. The cost estimator’s focus is to get detailed information from the engineer that is reasonable, complete, and consistent with the program’s ground rules and assumptions. The cost estimator should find additional data to validate the engineer’s estimates.

The underlying assumption of this method is that actual costs are good predictors of future costs. Thus, the engineering build-up method is normally used during the program’s production phase when the program’s configuration is stable and actual cost data are available. It is assumed that data from the development phase can be used to estimate the cost for production. As illustrated in table 10, the build-up method is used when there is enough detailed information about building an item—such as number of hours and number of parts—and the manufacturing process to be used.

Table 10: An Example of the Engineering Build-Up Cost Estimating Method

Problem	Similar component	Solution	Result
Estimate labor hours for the sheet metal element 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 for F/A-18 inlet nacelle x 1.2 (variance factor) = 2,400 touch labor hours; and 2,400 labor hours x 1.48 (1+support labor factor) = 3,552 total labor hours (touch labor plus support labor) estimate for new aircraft inlet nacelle sheet metal
Estimate labor hour cost for the sheet metal of the inlet nacelle for a new aircraft		Apply average labor hour rate for manufacturing firm personnel to labor hours	Total labor hour cost = total labor hours x average labor hour rate

Source: ICEAA (International Cost Estimating and Analysis). Cost Estimating Body of Knowledge. Vienna, Va.: 2013. | GAO-20-195G

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, and
- it gives good insight into major cost contributors.

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.

As with the analogy method, several questions should be asked regarding engineering build-up to check the accuracy of the estimating technique.

- Was each WBS cost element defined in enough detail to use this method correctly?
- Were 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?
- Was 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?

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 include 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 potential cost drivers for a particular program.

Sources for these cost drivers are often found in the technical baseline or program technical data. It is important that the attributes used in a parametric estimate 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 costs in the future. This method is often used when little is known about a program except for a few key characteristics like weight, volume, or speed.

Using a parametric method requires access to historical data, which may be difficult to obtain. If these 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 the analogy method, 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 periodically reviewed 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 can 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 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. 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 is expected to contain 1 million software lines of code and the data points for a software CER are 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 scatterplots and other methods, the cost estimator should verify the selected cost drivers by discussing them with engineers. For example, in software development, the environment—that is, the extent to which the requirements are understood and the strength of the programmers' skill and experience—are usually major cost drivers. 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 parameter unit (e.g., pound or miles per hour). 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. Because 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.

More complex CERs are developed using regression techniques so that statistical inferences may be drawn. To perform a regression analysis, analysts first determine what relationship exists between cost (dependent variable) and its various drivers (independent variables). This relationship is determined by developing a scatterplot of the data. If the relationship is linear, they can be fit by a linear regression. If the relationship is not linear and transformation of the data does not produce a linear fit, nonlinear regression can be used. 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 associated with the regression equation.

Table 11 contains a parametric cost estimating example.

Table 11: 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: ICEAA (International Cost Estimating and Analysis). Cost Estimating Body of Knowledge. Vienna, Va.: 2013. | GAO-20-195G

In table 11, 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 because no work is required.

Although we do not show any CER statistics for this example, the CERs should always be presented with their statistics to enable the cost estimator to understand the level of variation within the data and model its effect with an uncertainty analysis.

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

Statistical significance is the most important factor for deciding whether the 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 .15 would mean there was a 15 percent probability that a variable was not statistically significant. Statistical significance is determined by both the regression as a whole and each regression variable.

Among important regression measures and statistics are R-squared, the F statistic, and the t statistic.

R-squared

The R-squared (R2) value measures the strength of the association between the independent and dependent (or cost) variables. The R2 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 R2 is the better. An R2 of 91 percent in the example in table 11, for example, would mean that the number of workstations (NW) would explain 91 percent of the variation in site activation costs, indicating that it may be a good cost driver.

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.

Several questions can be asked regarding the parametric method to check the accuracy of the estimating technique.

- Is there a valid statistical relationship, or CER, between historical costs and program, physical, and performance characteristics?
- How logical is the relationship between key cost drivers and cost?
- Is 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 (R2) 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?

The Parametric Method: Further Considerations

The statistics described in the section above are just some of the ways that can be used to validate a CER. Once the measures and 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 to demonstrate that it can predict costs within an acceptable range of accuracy. To do this, analysts use a data set different from the one used to generate the equation and observe whether 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. For the CER to be accurate, the new and historical programs should have similar functions, objectives, and program factors, such as acquisition strategy, or results could be misleading. Analysts should 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 obtain good results. All cost data should be converted to a constant base year. In addition, labor and material costs should be broken out separately because 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. Additionally, 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. The procedures should 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.[24]

There are several advantages to parametric cost estimating, including:

- Versatility: If the data are available, parametric relationships can be derived at any level, whether system or subsystem component. As the design changes, CER inputs 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 as a whole) and a calculated standard error that can be used in risk analysis. This information can 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 have been 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 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 outside the input range used to develop the CER.

[24]CER calibration compares independent data to model output values. For instance, one method of calibration is adjusting CER factors so that the model output is consistent with actual known costs (independent data).

- 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. Depending on the model, the underlying database may contain cost, technical, and programmatic data at the system, component, and subcomponent level. Parametric models typically consist of several interrelated CERs. They may involve extensive use of CERs that relate cost to multiple independent non-cost variables. Databases and computer modeling may be used in these types of parametric cost models.

Access to the underlying data of parametric models may be limited because many models are proprietary, meaning the data are not publicly available. Therefore, when the inputs to the parametric models are qualitative, as often happens, they should be objectively assessed. In addition, parameters should be selected to tailor the model to the specific hardware or software product being estimated.

Parametric models are 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, analysts should demonstrate that it replicates known data to a reasonable degree of accuracy. In addition, the model should demonstrate that the cost–to–non-cost 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 system, subsystem, or component being estimated.
- Cost estimates are based on a database of historical data.
- They can be calibrated to match a specific development environment.

The disadvantages of parametric cost models include:

- Their results depend on the quality of the underlying database.

- They require many inputs that may be subjective.
- Accurate calibration is required for valid results.

Expert Opinion

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. Expert opinion is generally considered overly subjective, but it can still be useful in the absence of data. It is possible to alleviate subjectivity by probing further into the experts' opinions to determine if they are based on real data. If so, the analyst should attempt to obtain the data and document the sources.

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 refrain from asking experts to estimate costs for anything outside the bounds of their expertise, and they should 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 results of CERs that have been extrapolated to use data significantly beyond the data range.
- 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.

Because of its subjectivity and lack of supporting documentation, expert opinion should be used sparingly.

Questions to be asked regarding the use of expert opinion as an estimating method include:

- Have the experts provided estimates within the area of the expertise?
- Is the opinion supported by quantitative historical data? If so, can these be used instead of opinion?
- How did the estimate account for the possibility that bias influenced the results?

Other Estimating Methods: Extrapolation from Actual Costs

Extrapolation uses the actual past or current costs of an item to estimate its future costs. There are several variants of extrapolation, including:

- averages, the most basic variant, use 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
- estimates at completion, which use actual cost and schedule data to develop estimates with EVM techniques; EACs can be calculated with various techniques to take current performance into account.

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 should be made or another method should be used. When using extrapolation techniques, it is essential to have accurate data at the appropriate level of detail. 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;
- credibility and reliability for estimating costs; and
- ability to be applied at different levels of data—labor hours, material dollars, and 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.

Questions regarding the use of extrapolation as an estimating method follow.

- Were cost reports used for extrapolation validated as accurate?
- Was the cost element at least 25 percent complete before using its data to support 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?

Other Estimating Methods: Learning Curves

The cost estimating methods discussed in this chapter can identify the cost of a single item. However, a cost estimator may need to determine whether that cost is for the first unit, the average unit, or every unit. Additionally, 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 CER that assumes that as the quantity of units 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 more physically and mentally adept at it. Supervisors, in addition to realizing these gains, become more efficient in managing their workers 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 the assembly line and the placement of tools and material to help 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 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. Conversely, more automated tasks achieve less learning. Thus, higher automation leads to less learning, while lower automation levels may yield more learning.

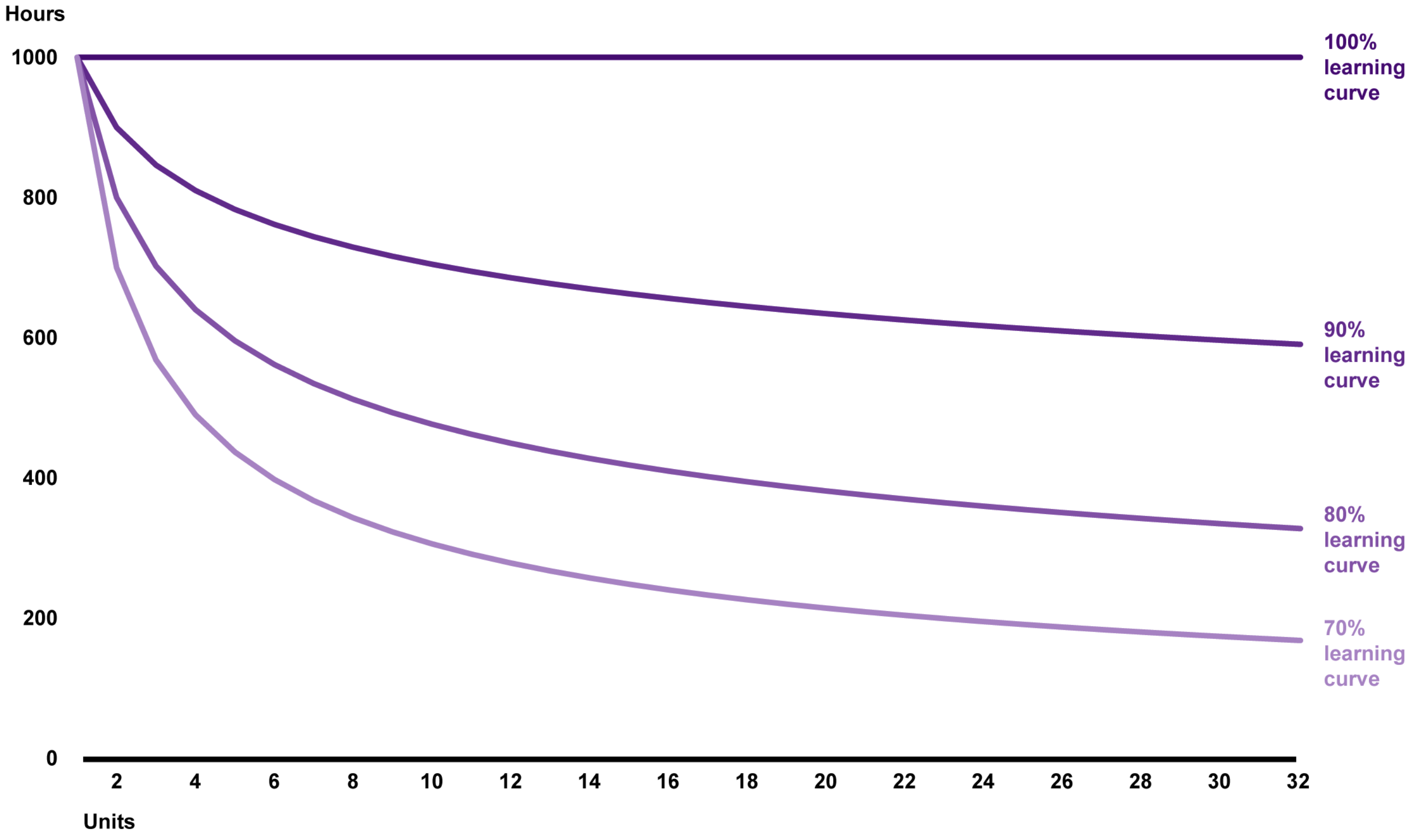
In competitive business environments, market forces require suppliers to improve efficiency to survive. As a result, some suppliers may competitively price their initial product release at a loss, with the expectation that future cost improvements will make up the difference. This strategy can also discourage competitors from entering new markets. For the strategy to work, the anticipated improvements must materialize or the supplier may go out of business because of high losses.

Researchers have observed that learning causes a decrease in labor hours per production unit over time, which informed the formulation of the learning curve. The equation Y = AXb models the concept of a constant learning curve slope (b) that affects a change in labor hours or cost (Y) given a change in units (X).[25] The unit formulation states that as the total quantity doubles, the cost decreases by some fixed percentage.[26] Figure 10 illustrates how hours per unit can vary by learning curve.

[25]b = log (slope) /log (2).

[26]See appendix VII for a more detailed discussion of the two ways to develop learning curves – unit formulation and cumulative average formulation.

Figure 10: A Learning Curve



Source: GAO. | GAO-20-195G

Figure 10 shows how an item's manufacturing time decreases as its quantity increases. 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 important 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 is to look at company history for similar efforts and calculate it from those efforts. The slope can also be derived from an analogous program. The analyst can 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, tanks, 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 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 first unit cost using the standard learning curve formula $Y = AX^b$.

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).

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. 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. 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. The effect of production on learning curves is discussed in greater detail in appendix VII.

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 to avoid skewing the results. 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; and
- the government program office culture (or environment) is sufficiently known.

Questions regarding the use of learning curves as an estimating method include:

- How were first unit costs 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?
- Were production rate effects considered? How were production break effects determined?

Pulling the Point Estimate Together and Comparing to an Independent Cost Estimate

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

- validate the estimate through a quality control process by looking for errors like incorrect spreadsheet formulas, double-counting, omitted costs, and mismatched costs between documents;
- perform cross-checks on cost drivers to see if results are similar;
- perform a sensitivity analysis to examine the effects of changing ground rules and assumptions (Step 8);
- conduct a risk and uncertainty analysis to assess the variability in the point estimate (Step 9); and
- update the model as more data become available or as changes occur and compare the results against previous estimates (Step 12).

These steps help validate the estimate. The cost estimator should also compare the estimate to an independent cost estimate (ICE) and the two estimates should be reconciled. An ICE gives an objective measure of whether the point estimate is reasonable. Differences between the estimates should be examined and discussed to achieve understanding of overall program risk and to adjust risk around the point estimate.

An ICE is considered one of the best and most reliable methods for validating an estimate. ICEs are typically performed by organizations higher in the decision-making process than the office performing the baseline estimate, and that are independent of the acquisition chain of command. An ICE provides an independent view of expected program costs that tests the program office's estimate for reasonableness. Therefore, ICEs can provide decision-makers with additional insights 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 and ground rules that 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 can also 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 to 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, different 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, as in case study 15.

Case Study 15: Independent Cost Estimates, from *Coast Guard Acquisitions*, GAO-18-600

To maintain heavy polar icebreaking capability, the Coast Guard and the Navy collaborated to acquire up to three new heavy polar icebreakers (HPIBs) through an integrated program office. The Navy planned to award a contract in 2019. GAO has found that before committing resources, successful acquisition programs begin with sound business cases, which include plans for a stable design, mature technologies, a reliable cost estimate, and a realistic schedule.

GAO's review of the heavy polar icebreaker cost estimate—performed by the Naval Sea Systems Command Cost Engineering and Industrial Analysis Group (NAVSEA 05C)—determined it partially met the best practices associated with being credible, in part because the cost estimate was not fully reconciled with a comparable independent cost estimate. While the Naval Center for Cost Analysis performed an independent cost estimate of the HPIB, it used a different methodology from NAVSEA's, and its estimate was based on an earlier version of the indicative ship design and associated technical baseline. NAVSEA officials told GAO that before the Coast Guard's ship design team updated the indicative ship design and technical baseline, NAVSEA met twice with Naval Center for Cost Analysis to reconcile their results. However, NAVSEA officials told GAO that due to the speed at which the program was progressing, no reconciliation occurred after the ship design team finalized the indicative ship design. While GAO did not find any specific ground rules and assumptions that differed between the two estimates, some ship characteristics had changed, such as the weight estimates for propulsion and auxiliary systems, among others. The use of two different technical baselines created differences in the two estimates and made them less comparable to one another.

GAO, *Coast Guard Acquisitions: Polar Icebreaker Program Needs to Address Risks before Committing Resources*, GAO-18-600

Two potential issues with ICEs are the degree of independence of the estimating team and the depth of the analysis. The degree of independence depends on how far removed the estimating team 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 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 become overly optimistic.

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. While an ICE reveals to 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.

The second issue with an ICE is the depth of the review. 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 the program office's estimate for the other costs. While these types of cost reviews are useful to management, not all provide the thoroughness and 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 ground rules and assumptions. A synopsis of the estimates and their differences is then documented, justified, and presented to management. Using this information, decision-makers use the ICE or independent review to validate whether the program estimate is reasonable.

It is important that cost estimators and organizations independent of the program office validate that all cost elements are reliable and can be justified by acceptable estimating methods, adequate and valid data, and detailed documentation. Independent reviewers help ensure that the estimate is free from bias. Validating a cost estimate 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, accurate, and reflects realistic assumptions.

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. The ICE team is typically outside the acquisition chain, is not associated with the program, and has nothing at stake with regard to program outcomes or funding decisions.

Some ICEs are mandated by law, such as those for DOD's major acquisition programs—these programs are required to develop ICEs for major program milestones. The history of the myriad of DOD programs clearly shows that ICEs are usually higher, and tend to be closer to actual program cost, than baseline estimates. Thus, if a program cost estimate is close to ICE results, the program is more likely to request funding at a reasonable level.

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 15.)

Survey of Step 7

Process Tasks

- Develop the cost model, estimating each WBS element, using the best methodology from the data collected 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.

Best Practices

The cost model is developed by estimating each WBS element using the best methodology from the data collected.

- If analogy is used, adjustments are reasonable and based on program information, physical and performance characteristics, and the like.
- If the build-up method is used, the work scope is well defined, the WBS sufficiently detailed, a detailed and accurate materials and parts list is available, the estimate is based on specific quantities, and an auditable source is provided for labor rates.
- If the parametric method is used, the size of the data set is sufficient and homogeneous data were available for developing the cost estimating relationship (CER). Parametric models are calibrated and validated using historical data.
- If CERs are used, the statistics are provided and they are reasonable. The CER inputs are within the valid dataset range.
- Expert opinion is used sparingly and the estimates account for the possibility that bias influenced the results.
- If learning curves are used, they represent manual, complex, and repetitive labor effort. If production is not continuous, production breaks are incorporated.

The estimate contains few, if any, minor mistakes.

- The estimate does not contain mistakes, such as numbers that do not sum properly, costs that do not match between documents, and the like.
- The program uses a quality control process to ensure the cost estimates contains few, if any, mistakes.

Major cost elements are cross-checked to see if results are similar.

- Major cost elements are cross-checked to see if results are similar.

An independent cost estimate is conducted by a group outside the acquiring organization to determine whether other estimating methods produce similar results.

- An ICE was performed by an organization outside of the program office’s influence.
- The depth of the ICE analysis was sufficient to allow reconciliation between the ICE and the program office estimate.
- The ICE is based on the same technical baseline and ground rules as the program office estimate.

Differences between the ICE and the program office estimate are documented and justified.

Likely Effects if Criteria Are Not Fully Met

- Unless alleviated by probing further into the experts' opinions, the expert opinion method should be considered subjective. Expert opinion should be used sparingly and the estimates should account for the possibility that bias influenced the results.
- Without access to a detailed cost model, one cannot be certain that all WBS cost estimate calculations are accurate and account for all costs. Validating that a cost estimate is accurate requires thoroughly understanding and investigating how the cost model was constructed.
- Unless an estimate employs cross-checks, the estimate will have less credibility because stakeholders will have no assurance that alternative estimating methodologies produce similar results.
- Without an ICE, decision-makers will lack insight into a program's potential costs because ICEs frequently use different methods and are less burdened with organizational bias. Moreover, ICEs tend to be more conservative by forecasting higher costs than the program office.
- A program estimate that has not been reconciled with an ICE has an increased risk of proceeding underfunded because an ICE provides an objective and unbiased assessment of whether the program estimate can be achieved.

Chapter 11: Step 8: Conduct Sensitivity Analysis

As a best practice, a sensitivity analysis should be included in all cost estimates because it examines the effects of changing cost estimate inputs, or parameters, and underlying assumptions. Sensitivity analysis involves recalculating the cost estimate with different quantitative values for selected inputs to compare the results with the original estimate. If a small change in the value of a factor yields a large change in the overall cost estimate, the results are considered sensitive to that factor.

Sensitivity Analysis in Cost Estimating

Typically performed on high-cost and high-risk elements, sensitivity analysis examines how the cost estimate is affected by a change in a parameter or assumption. For example, it might evaluate how the point estimate varies with different assumptions about system reliability values, or how costs vary in response to additional system weight growth.

Factors that have the most effect on the cost estimate warrant further study to ensure that the best possible value is used. This analysis helps assure decision-makers that sensitive parameters and assumptions have been carefully investigated and the best possible values have been used in the final point estimate. If the cost estimate is found to be sensitive to several factors, the estimate's input values and underlying assumptions should be reviewed.

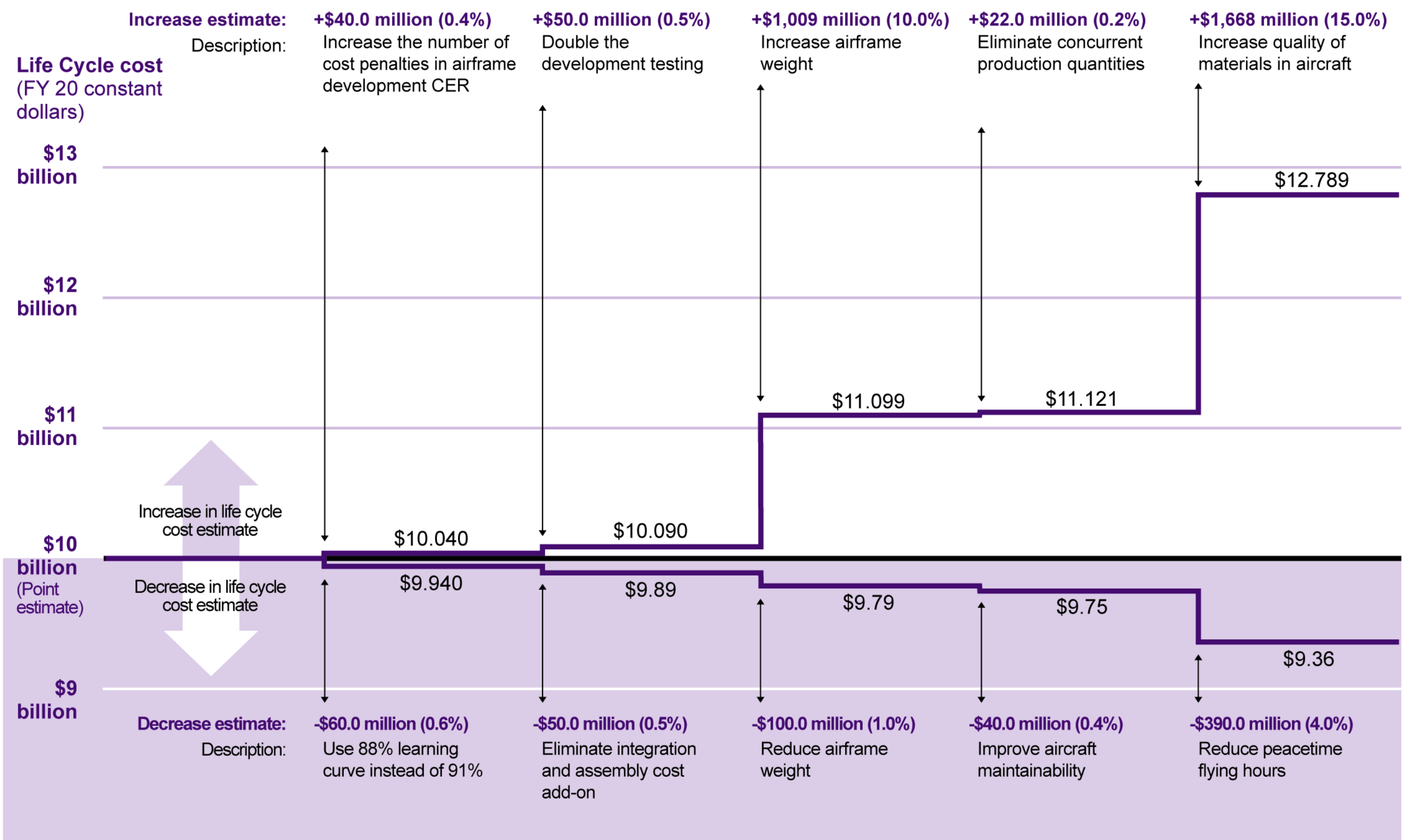
A sensitivity analysis can provide useful information for the system designer because it highlights elements that are cost sensitive. In this way, sensitivity analysis can be useful for identifying areas where more design research can result in less production cost or where increased performance can 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 and assumptions.

Sensitivity analysis also helps decision-makers choose a program alternative. For example, it can help a program manager determine how sensitive a program is to changes in gasoline prices and at what gasoline price a program alternative is no longer attractive. 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 missions. It can provide important information for an analysis of alternatives that may result in the choice of a different alternative from the original recommendation. This can happen because, like a cost estimate, an analysis of alternatives 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 factors. In an analysis of alternatives, sensitivity is determined by how much a parameter or assumption must change to result in an alternative that differs from the one recommended in the original analysis. For example, a parameter is considered sensitive if a change of 10 percent to 50 percent results in a different alternative; it is considered very sensitive if the change is less than 10 percent. [27]

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 make a decision based on a range of potential costs that surround a point estimate—with the reasons behind what drives that range—than a point estimate alone. 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 11 shows how identifying sensitivity can provide decision-makers with valuable insight.

[27] See appendix XI; best practice 17, perform sensitivity analysis.

Figure 11: A Sensitivity Analysis that Creates a Range around a Point Estimate



Source: GAO. | GAO-20-195G

Figure 11 illustrates how certain assumptions affect the estimate. For example, increasing the quality of materials in the aircraft has the biggest effect on the cost estimate—adding $1.668 million to the point estimate while using a learning curve of 88 percent instead of 91 percent reduces the estimate by $60 million. Using similar visuals can quickly explain what-if analyses that can help management make informed decisions.

As shown in figure 11, sensitivity analysis makes 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 specific factors that could be potential sources of risk and to 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 following case study demonstrates how the lack of a sensitivity analysis affects a cost estimate for the Joint Intelligence Analysis Complex.

Case Study 16: Sensitivity Analysis, from *Joint Intelligence Analysis Complex,* GAO-17-29

DOD’s Joint Intelligence Analysis Complex (JIAC), which provides critical intelligence support for the U.S., European, and Africa Commands and U.S. allies, is located in what DOD has described as inadequate and inefficient facilities at RAF Molesworth in the United Kingdom. To address costly sustainment challenges and instances of degraded theater intelligence capabilities associated with the current JIAC facilities, the Air Force planned to spend almost $240 million to consolidate and relocate the JIAC at RAF Croughton in the United Kingdom. GAO was asked to review the analysis associated with consolidating and relocating the JIAC and assess the extent to which DOD’s cost estimate for the JIAC consolidation at RAF Croughton aligned with best practices.

GAO assessed the cost estimate for the military construction project to consolidate and relocate the JIAC and found that it partially met three and minimally met one of the four characteristics of a reliable cost estimate defined by GAO best practices. For example, it minimally met the credibility standard because it did not contain a sensitivity analysis; such analyses reveal how the cost estimate is affected by a change in a single assumption. Without a sensitivity analysis to reveal how a cost estimate is affected by a change in a single assumption, the cost estimator cannot fully understand which variable most affects the cost estimate.

The use of a sensitivity analysis was not specified in cost estimation guidance for MILCON projects by either DOD or the Air Force. According to Office of the Secretary of Defense and Air Force officials, a sensitivity analysis is part of the underlying unit cost development, because costs are developed through the use of both historical data and industry averages. Officials further stated that the Office of the Secretary of Defense used actual data underpinned by relevant sensitivity and range analyses to develop its cost estimates. For example, Office of the Secretary of Defense and Air Force officials said that the Office of the Secretary of Defense used the DOD Selling Price Index—which averaged three commonly accepted national indexes for construction price escalation—to calculate actual project award cost data. However, for sensitivity analysis to be useful in informing decisions, careful assessment of the underlying risks and supporting data related to a specific MILCON project is also necessary. In addition, the sources of the variation should be well documented and traceable. Without conducting a sensitivity analysis to identify the effect of uncertainties associated with different assumptions, DOD and the Air Force increased the risk that decisions would be made without a clear understanding of the effects of these assumptions on costs.

GAO, *Joint Intelligence Analysis Complex: DOD Needs to Fully Incorporate Best Practices into Future Cost Estimates*, GAO-17-29 (Washington, D.C.: November 2016).

Steps in Performing a Sensitivity Analysis

For sensitivity analysis to reveal how the cost estimate is affected by a change in a single parameter or assumption, the cost estimator must examine the effect of changing one factor at a time while holding all others constant. This allows for an understanding of which factor most affects the cost estimate. By examining each factor independently, the cost estimator can evaluate the results to discover which parameters or assumptions most influence the estimate.

A valid sensitivity analysis typically has five steps:

1. identify assumptions and parameters, including key cost drivers, as factors for sensitivity testing;
2. re-estimate the total cost of the program by varying one of these factors between two set amounts—for example, maximum and minimum or performance thresholds;[28]
3. document the results;
4. repeat steps 2 and 3 until all factors identified in step 1 have been tested independently; and
5. evaluate the results to determine which factors affect the cost estimate most and document the results.

Identifying Factors for the Sensitivity Analysis

The first step of a sensitivity analysis requires analysts to identify the factors to be varied. The sources of variation should be well documented and traceable. Simply varying factors by a subjective plus or minus percentage is not useful and does not constitute a valid sensitivity analysis.

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 factors. Some factors that are often varied in a sensitivity analysis are:

- a shorter or longer life cycle;
- the volume, mix, or pattern of workload;

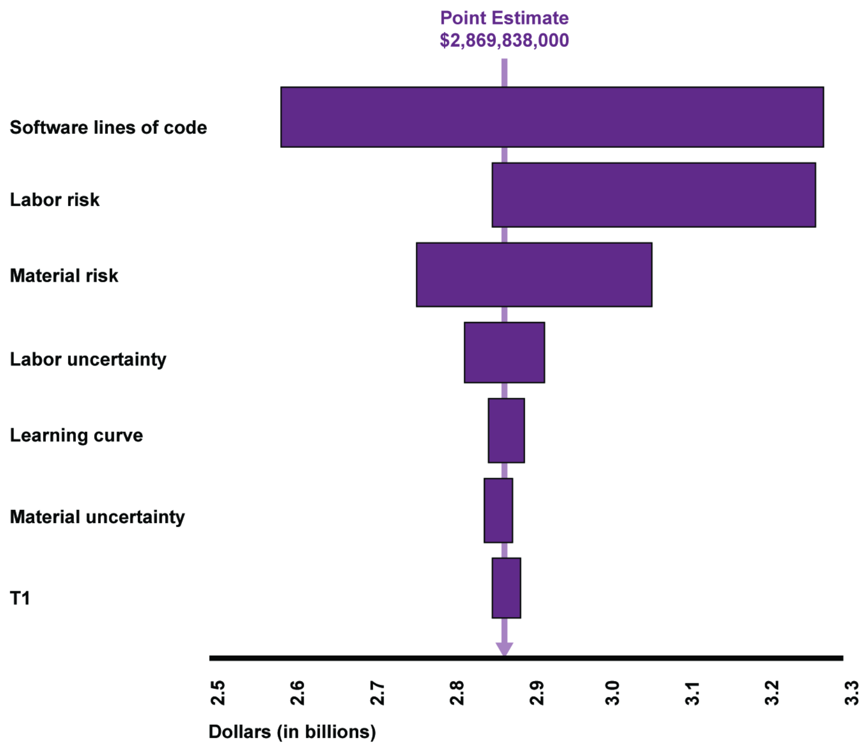
[28]The ranges should be documented during data collection and cost estimating (steps 6 and 7 of the 12-step process).

- 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 or dual sourcing, among others;
- labor rates; and
- growth in software size or amount of software reuse.

In a sensitivity analysis, the cost estimator should always include the factors that are most likely to change, such as an assumption that was made for lack of knowledge or one that is outside the program office's control.

Another method for identifying parameters is to examine artifacts from related analyses, such as risk and uncertainty analysis. One such artifact is a tornado chart, a special type of bar chart that shows which parameters have the greatest effect—positive or negative—on the overall point estimate (figure 12 is an example).

Figure 12: Tornado Chart for a Sensitivity Analysis



Source: GAO. | GAO-20-195G

Determining which parameters are key cost drivers can be done in several ways. One way to determine key cost drivers is to calculate the proportion of each cost element to the total cost. Those input variables affecting the highest proportion cost elements should be varied in a sensitivity analysis. However, analysts may want to consider the parameters contributing to high-risk cost elements as well, even if they are not cost drivers, because these elements may become schedule drivers.

Many factors that should be tested are determined by the assumptions and performance characteristics outlined in the technical baseline description and associated assumptions. There should be a clear link between the technical baseline parameters, assumptions, and the cost model input values examined by cost estimators in the sensitivity analysis

The Limitations of Sensitivity Analysis

A sensitivity analysis reveals critical factors that most affect the estimate results and can sometimes yield surprises. Therefore, the value of sensitivity analysis to decision-makers lies in the additional information and understanding it brings. For example, a sensitivity analysis can help engineers make technical trade-offs and can help program managers make key acquisition and program management decisions.

However, sensitivity analysis does not yield a comprehensive sense of the overall possible range of the estimate. Rather, it examines only the effect of changing one factor at a time. In some cases, a sensitivity analysis can be conducted to examine the effect of multiple factors changing in relation to a specific scenario. But the risk of several factors varying simultaneously and the effect on the overall point estimate should be understood. Whether the analysis is performed on only one cost driver or several within a single scenario, sensitivity analysis tries to isolate the effects of changing one variable at a time, while risk and uncertainty analysis examines the effects of many variables changing all at once. In the next chapter, we discuss risk and uncertainty analyses that vary more than one factor at a time to better understand a program's overall risk.

Survey of Step 8

Process Tasks

- Identify assumptions and parameters, including key cost drivers, as factors for sensitivity testing.
- Test the sensitivity of cost elements to changes in identified factors.
- Document the results, including those factors that are most sensitive to change.

Best Practices

The cost estimate includes a sensitivity analysis that identifies a range of possible costs based on varying major assumptions and parameters.

- The following steps were taken: key cost drivers, ground rules, and assumptions were identified as factors;
- Cost elements representing the highest percentage of cost were determined and their assumptions were examined;
- The total cost was re-estimated by varying each factor; and
- Results were documented and outcomes were evaluated for factors most sensitive to change.

Likely Effects if Criteria Are Not Fully Met

- Without a sensitivity analysis that reveals how the cost estimate is affected by a change in a single factor, stakeholders will not fully understand which variable most affects the cost estimate.
- An agency that fails to conduct sensitivity analysis to identify the effect of uncertainties associated with different assumptions increases the chance that decisions will be made without a clear understanding of these impacts on costs.
- Carefully assessing the underlying risks and supporting data, and documenting the sources of variation, is necessary for a sensitivity analysis to be useful in making informed decisions.
- Simply varying factors by applying a subjective plus or minus percentage that does not have a valid basis is not useful and does not constitute a valid sensitivity analysis. For management to make informed decisions there should be a clear link between the technical baseline parameters, assumptions, and cost model inputs examined by cost estimators in the sensitivity analysis.

Chapter 12: Step 9: Conduct Risk And Uncertainty Analysis

In the previous chapter, we discussed sensitivity analysis and how it is useful for identifying cost drivers by determining how sensitive the estimate is to changes in input parameters, developing ranges of potential costs, and performing what-if analyses. By understanding which input variables have a significant effect on a program's final costs, management can devote resources to acquire better knowledge about those inputs to respond to their risks. But while sensitivity analysis measures the effects of changing one parameter at a time, in reality, many parameters can change at the same time. Quantitative risk and uncertainty analysis uses statistical techniques to predict the probability of successfully executing a program within its budget by capturing the cumulative effect of program risks and uncertainty.

A risk and uncertainty analysis is one way to ascertain whether a program is realistically budgeted because it can determine the probability associated with achieving the cost estimate for the program. The analysis provides a way to assess the variability in the estimate by quantifying cost, schedule, and technical risks. A cost estimator can model such effects as changing technical parameters, schedule delays or accelerations, labor productivity, and changing missions, thus creating a range of potential costs. A range of costs is more useful to decision-makers than a point estimate because a range helps them better understand program risk.

A risk and uncertainty analysis requires the cost estimating team to collect program risk data.[29] Risk data should be derived from a quantitative risk assessment and should not be based on arbitrary percentages or factors. A risk assessment is a part of the program's overall risk management process in which risks are identified and analyzed and potential consequences are determined. As risks are identified and prioritized, risk response plans are developed and incorporated into the program's cost estimate and schedule, as necessary. Ultimately, management needs to understand that a risk and uncertainty analysis is only as good as the comprehensiveness of risks and uncertainties quantified at a point in time. Without a risk and uncertainty analysis, the program estimate will not reflect the degree of uncertainty and a level of confidence cannot be given about the estimate.

[29]The term "risk data" comprises the parameters and data sets that are used in performing a risk and uncertainty analysis. These data are both cost and non-cost and may include costs, durations, performance parameters, and requirements, among other types. Risk data also include statistics and factors used to define probability distributions used in simulations.

Unless a range of costs is provided, decision-makers will lack information on cost, schedule, and technical risks, and will not have insight into the likelihood of executing the program within the budget.

We have found that budgeting to a risk-adjusted estimate is critical to successfully achieving a program's objectives. Programs have developed overly optimistic estimates with narrow uncertainty ranges for many reasons: cost estimators may have minimized program risk, ignored data outliers, relied on historical data that may not have been representative of a new technology, or assumed higher productivity than what had previously been achieved. In addition, decision-makers may influence the estimate with bias for political or budgetary reasons. For example, they may assume that a new program will perform much better than its predecessor in order to fit the program within an unrealistic budget, or just to sell the program. To counter over-optimism and bias, a risk analysis must consider all risks and uncertainty as completely and objectively as possible. Case study 17 provides an example of performing an inadequate risk and uncertainty analysis.

Case Study 17: Incomplete Risk and Uncertainty Analysis, from *Coast Guard Acquisitions*, GAO-18-600

To maintain heavy polar icebreaking capability, the Coast Guard—a component of the Department of Homeland Security (DHS) — and the Navy are collaborating to acquire up to three new heavy polar icebreakers through an integrated program office. The National Defense Authorization Act for Fiscal Year 2018 included a provision for GAO to assess issues related to the acquisition of the icebreaker vessels. In addition, GAO was asked to review the heavy polar icebreaker program's acquisition risks.

GAO found that the Coast Guard did not have a sound business case in March 2018 when it established the cost, schedule, and performance baselines for its heavy polar icebreaker acquisition program, because of risks in four key areas, one of which was the program cost estimate. The life cycle cost estimate that informed the program's $9.8 billion cost baseline substantially met GAO's best practices for being comprehensive, well documented, and accurate, but only partially met best practices for being credible. In particular, the cost estimate failed to quantify the range of possible costs over the entire life of the program.

GAO found that the Navy only modeled cost variation in the detail design and construction portion of the program, and excluded from its analyses any risk impacts related to the remainder of the acquisition—operating and support and disposal phases—which altogether comprised about 75 percent of the life cycle cost. Without performing a risk and uncertainty analysis on the entire life cycle cost of the three ships, it was not possible for the Navy to determine a level of confidence associated with the overall cost estimate. By not quantifying important risks, the Navy may have underestimated the range of possible costs for about three-quarters of the entire program.

GAO, *Coast Guard Acquisitions: Polar Icebreaker Program Needs to Address Risks before Committing Resources*, GAO-18-600 (Washington, D.C.: September 4, 2018).

Risk and Uncertainty

The terms risk and uncertainty are often used interchangeably, but they have distinct definitions in program risk analysis. Simply stated, risk and its outcomes can be quantified in some definite way, while uncertainty cannot be defined because of ambiguity. Additionally, uncertainty is always present, while risks may or may not occur. Uncertainty and risk events may contain elements of both opportunity and threat.[30]

A risk is a potential event that could affect the program positively or negatively. A negative or unfavorable event is a threat or harm, and a

[30]Definitions of risk and uncertainty are interrelated and vary across organizations, government agencies, and even fields of study. For example, some organizations consider risk as only the unfavorable outcome of an uncertain event.

positive or favorable event is an opportunity or improvement. Risk events that can be listed and defined should be included in a program's risk register[31] in the form of threats and opportunities.

Uncertainty refers to a situation in which little to no information is known about the outcome. Uncertainty may arise because of the inherent variability in the actions of individuals and organizations working toward a plan. Errors may result from historical data inconsistencies or cost estimating equations and factors used to develop the estimate. Finally, biases are often found in estimating program costs and developing program schedules.

As we describe in the following sections, threats and opportunities, as well as uncertainty, can be incorporated and quantified to some degree using cost risk and uncertainty analysis.[32]

The Need for Cost Risk and Uncertainty Analysis

Because risks and uncertainty occur, there is always a chance that the actual cost will differ from the estimate. Thus, cost estimates are forecasts based on the best information available at the time. Assumptions regarding resource availability and productivity, required effort, and availability of materials, among other things, allow for the determination of the program estimate. In addition, programs have risks—in the form of threats and opportunities—that may lead to increased or decreased program costs. If these risks are not accounted for and analyzed, cost estimators may underestimate or overestimate program costs. Some threats to the program that could arise are changes in requirements that cause schedule delays, test failures that require rework, the unavailability of critical resources, software defect rates being higher than estimated, development of unproven technology taking longer than expected, and late deliveries of subcontracted components. Opportunities to the program may include improvements to labor productivity, more efficient production techniques, or an accelerated schedule from concurrent activities.

Lack of knowledge about the future is only one possible reason for the difference between actual and estimated costs. There is also inherent

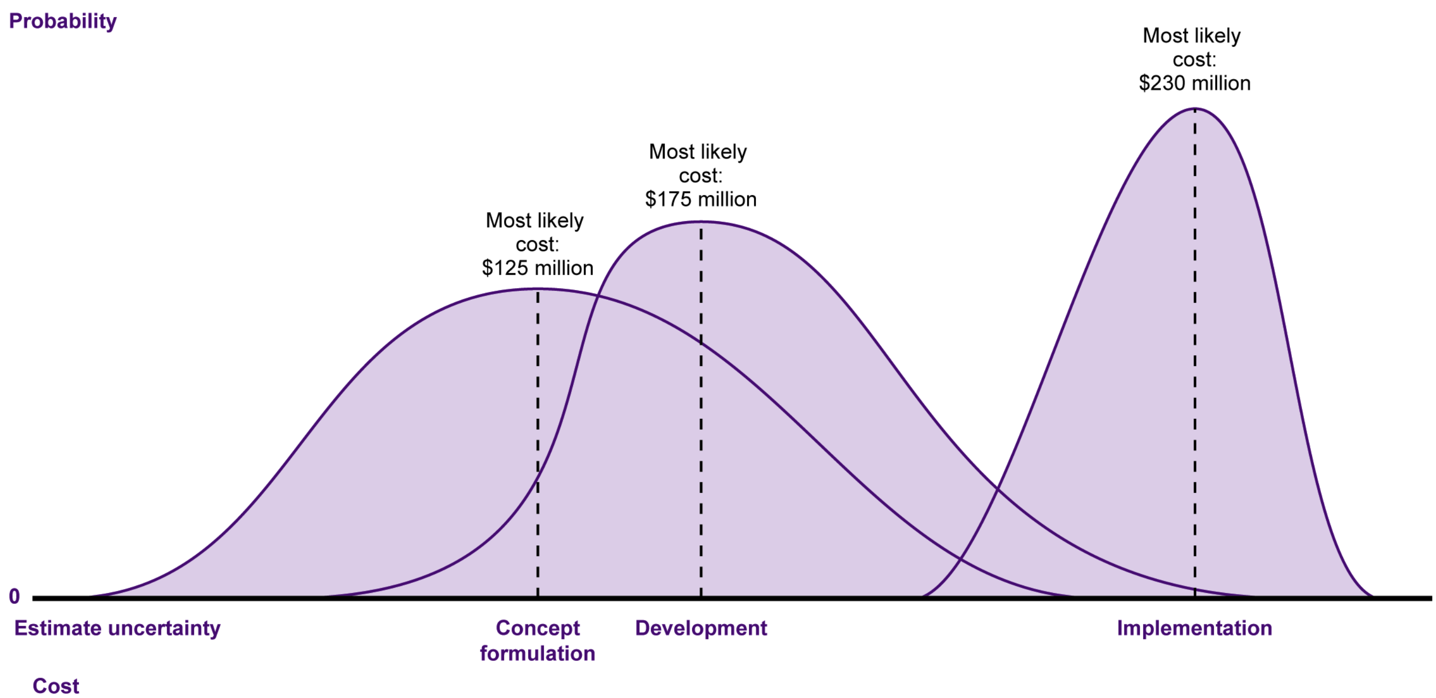
[31]A risk register is a document that contains all identified program risks. It may also include the following information for each risk: risk handling actions taken or planned, estimated probability of risk occurrence, and the potential consequence on program cost and schedule if the risk is realized.

[32]These techniques are designed to capture general uncertainties about the future, not unforeseen catastrophic events such as major earthquakes and hurricanes.

uncertainty in estimated costs caused by, for example, estimating error, and perhaps, estimating bias. The biases may be cognitive—that is, based on estimators' inexperience—or motivational, where management intentionally reduces the estimate or shortens the schedule to make the program appeal to stakeholders. Cost estimates should account for both risk and uncertainty. There will always be some aspect of the unknowable, and there will never be enough data available in most situations to develop a known distribution of possible costs or parameters affecting cost estimates.

A program estimate typically has a greater range of potential costs at the beginning of a program because less is known about the program's detailed requirements, and the potential for program changes is greater. As a program matures, general program requirements are refined into clearer and more detailed requirements, thus narrowing the range of costs. However, more refined requirements can lead to cost increases, as illustrated in figure 13.

Figure 13: Notional Changes in Cost Ranges across the Life Cycle



Source: GAO. | GAO-20-195G

The notional example in figure 13 shows that as the estimate increases, the range around the estimate decreases. As the program matures, a better understanding of the risks is achieved, and some risk is either retired or some form of risk response lessens the potential cost or effect on schedule.

Thus, a point estimate by itself provides no information about the underlying uncertainty of the estimate and is insufficient for making good decisions about the program. Using a risk and uncertainty analysis, a cost estimator can inform decision-makers about a program's potential range of costs and cost drivers. Management, in turn, can use these data to decide whether the program fits within the overall risk range of the agency's portfolio.

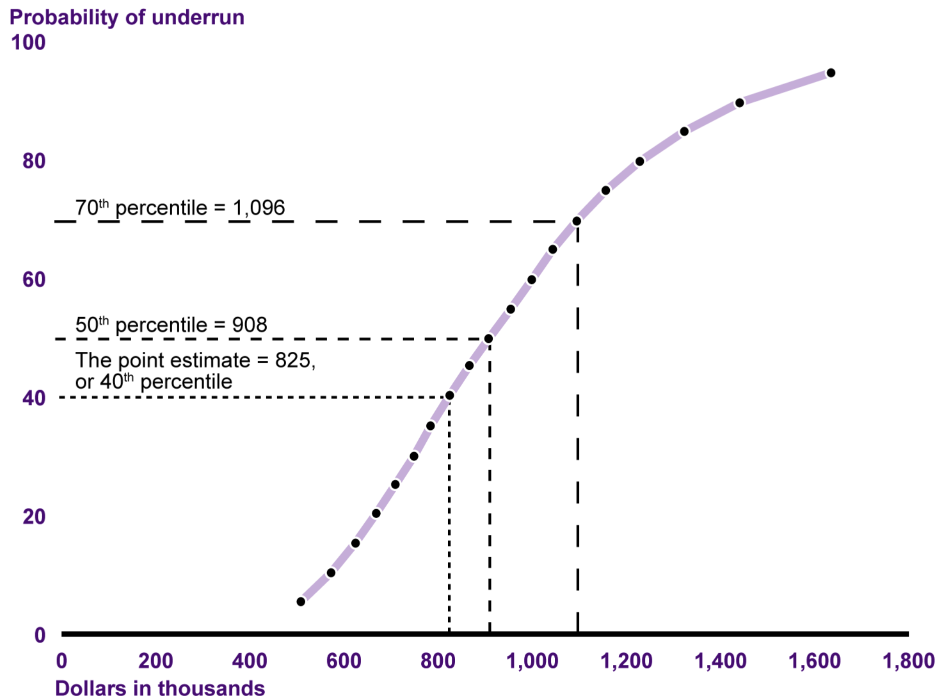
Conducting a Cost Risk and Uncertainty Analysis

To perform a risk and uncertainty analysis,[33] WBS elements or risk drivers are assigned probability distributions of possible values. Statistical software randomly draws from each distribution and the cost results are summed for each iteration. This random drawing from distributions and total summation is repeated thousands of times. The resulting cumulative distribution curve displays the probability associated with the range of possible total program costs. Because the simulation's inputs are probability distributions, the outputs are also distributions. The total cost distribution tends to be a lognormal distribution because many of the underlying distributions tend to be skewed to the right—that is, there is a greater probability of large overruns than large underruns. In setting up the simulation, any identified causality may be modeled.

The total cost distribution may be converted to a cumulative distribution function, or an S curve. An S curve is particularly useful for portraying the confidence level, or percentile, of a cost estimate. Figure 14 shows an example of a cumulative probability distribution with various estimate values mapped to their corresponding percentiles.

[33]Alternative approaches to Monte Carlo simulation exist and are in use throughout the cost estimating community. For example, the Department of Defense and the National Aeronautics and Space Administration, *Joint Agency Cost Schedule Risk and Uncertainty Handbook* (Washington, D.C.: March 12, 2014) describes the scenario-based, method of moments, historical data references, and risk scoring methodologies. We discuss the 3-point and risk driver methodologies using Monte Carlo simulation because experts in the cost community consider them best practices.

Figure 14: A Cumulative Distribution Function, or S Curve



Sources: GAO and NASA. | GAO-20-195G

Management can use an S curve to choose a defensible level of contingency. In figure 14, the S curve shows that the likelihood is about 40 percent that the final cost of the program will be $825,000 or less. Cost contingency is calculated by comparing the point estimate with that of the simulation result at a desired level of confidence. For example, a program manager planning for a confidence level at the 70th percentile would budget at $1,096,000, about $271,000 more than the point estimate. Likewise, the program has an equal chance of overrunning or underrunning its budget at $908,000, which is at the 50 percent confidence level and the median of the distribution. At this confidence level, the program would require $83,000 of contingency. Note that the mean, or average, of the distribution will usually be greater than the 50 percent confidence level because of the greater probability of overruns. The estimator should identify the cumulative probability associated with the point estimate and the estimate at management's level of desired confidence.

Without a risk and uncertainty analysis, management cannot determine a defensible level of contingency that is necessary to cover increased costs resulting from unexpected design complexity, incomplete requirements, technology uncertainty, and other risks and uncertainty.

Cost Risk Analysis Data and Methods

A risk and uncertainty analysis can be conducted by a three-point estimate methodology, a risk driver approach, or a combination of both.

Cost Risk Analysis with Three-Point Estimates

Three-point estimates typically use a minimum, most likely, and maximum[34] to describe the range of possible costs for each element. To capture cost estimate risk and uncertainty, analysts may collect various estimates from subject matter experts, use data from actual program performance, or use historical data from similar programs. Table 12 shows a traditional approach to cost risk analysis with three-point estimates applied directly to the WBS elements of a nominal cost estimate for the air vehicle of an Unmanned Aerial Vehicle (UAV) program. In an actual cost risk analysis, these estimates would be developed from a combination of historical data and in-depth interviews with persons who are knowledgeable in each area of the program.

Table 12: Ranges of Cost by WBS

WBS element	WBS description	Minimum cost ($K per air vehicle)	Most likely cost ($K per air vehicle)	Maximum cost ($K per air vehicle)
1.1	Airframe	17,955	19,645	21,785
1.2	Propulsion	8,500	10,553	13,000
1.3	Communications	4,000	4,306	5,100
1.4	Navigation	4,100	4,305	4,650
1.5	Central Computer	550	600	650
1.6	Software	32,300	35,547	52,500
1.7	IAT&CO[a]	1,950	2,136	2,600

Source: GAO. | GAO-20-195G

[a]IAT&CO is integration, assembly, test and check-out

[34]The minimum and maximum values may not be the actual minimum and maximum of the possible range of costs. Expert opinion has been shown to represent only 60 percent to 85 percent of the possible outcomes, so cost estimators sometimes make adjustments to account for a wider range. Further discussion is included later in this chapter.

For this example, the UAV program is procuring 32 air vehicles. Summing the most likely costs yields an estimate of $77 million per air vehicle, which results in a point estimate of $2.47 billion for all 32 air vehicles.

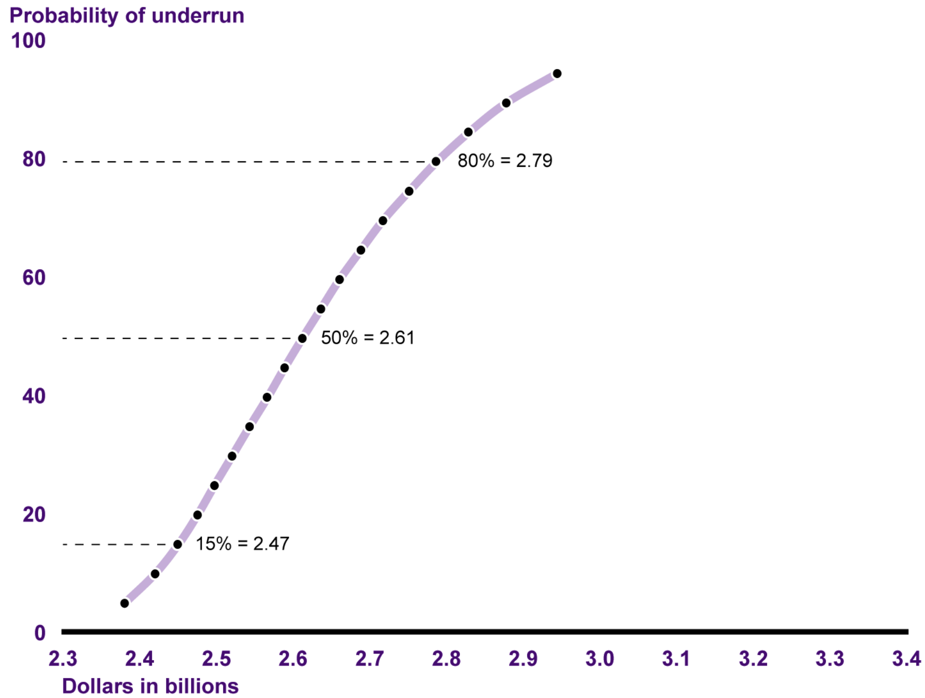
To model the risks in the simulation, the risks are typically represented as triangular distributions, but other distributions can also be used. Choosing the right probability distribution for each WBS element is important for accurately capturing risk and uncertainty. For any WBS element, selecting the probability distribution should be based on how effectively it models actual outcomes. Because different distributions model different types of risk, knowing the shape of the distribution helps to visualize how the risk will affect the overall cost estimate uncertainty. (Appendix X gives a variety of probability distribution shapes that are used for modeling cost risk.) Thus, the shape of the distribution should be determined by the characteristics of the risks they represent.

For a cost estimating relationship (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. A CER input may also be uncertain and have a probability distribution that describes its range.

Once the distributions have been established, a statistical simulation—typically a Monte Carlo simulation—uses random sampling to select specific costs from each WBS element probability distribution, and a new program cost estimate is calculated.[35] The simulation repeats this random selection thousands of times, creating a new program cost estimate with each iteration. The resulting probability distribution displays the range of possible program costs along with their confidence levels, as seen in figure 15.

[35]The most common technique for combining the individual elements and their distributions is the Monte Carlo simulation. In the simulation, the distributions for each cost element are treated as individual populations from which random samples are taken. A Monte Carlo simulation randomly generates values for uncertain variables multiple times to simulate a model.

Figure 15: Air Vehicle Cost Cumulative Probability Distribution from a Three-Point Estimate



Source: GAO. | GAO-20-195G

Figure 15 shows that once risks and uncertainty are accounted for, the program cost at the 50 percent confidence level is $2.61 billion, which is $140 million higher than the point estimate of $2.47 billion. The cumulative distribution shows that the likelihood is about 15 percent that the program will cost $2.47 billion or less given the costs and the risk ranges used—an optimistic estimate in light of the risks to the program. Conversely, a program manager that desired an 80 percent confidence level would budget for a program cost of $2.79 billion, or about $320 million more than the point estimate.

One disadvantage of using three-point ranges to represent all the risk in an analysis is that probability distributions for costs cannot be attributed to individual risk events. It can be difficult to know or quantify the multiple risks inherent in the historical data. Similarly, it is difficult to quantify the risks in interviewees' inputs. For the example in table 12, a program manager may suggest a worst-case scenario of $22 million per airframe. However, the higher cost may be caused by lack of materials, poor labor productivity, or some combination of those risks. It is also possible that an interviewee has increased the pessimistic estimate to account for general uncertainty in addition to discrete risks. Therefore, the result of the three-point method is a recommended amount of cost contingency that covers both quantified risks and some level of uncertainty, but gives no indication which risks are most likely to affect the program cost.

Cost Risk Analysis with Risk Drivers

A second method to determine estimate uncertainty is the risk driver approach. It quantifies the probabilities of risks from the risk register occurring, and what their effects on WBS element costs will be if they do. With this approach, a probability distribution of the risk impact on the cost—expressed as a multiplicative factor—is estimated and the risks are assigned to specific WBS elements. If a risk does not occur in an iteration of the Monte Carlo simulation, then the cost does not change for that element. Using this method, cost risk is estimated from the identified program risks and their expected effects on WBS elements.

The risk driver approach focuses on risks and their contribution to cost contingency, as well as on risk mitigation. Analysts can assign a risk to multiple WBS elements and the costs of some elements can be influenced by multiple risks. In this way, the risk driver method is used to examine how various risks may affect the program cost estimate. Table 13 shows a subset of possible risks associated with the construction of the UAV.

Table 13: Air Vehicle Risks, Likelihood, and Cost Effects

Risk	Likelihood of risk	Effect on cost: Minimum	Effect on cost: Most likely	Effect on cost: Maximum
Material is late or defective	80%	100%	105%	130%
Complex airframe producibility will lead to increased manufacturing time	25	100	110	125
GFI deliveries are delayed	20	90	100	115
Hiring and retention are affected by changing economy	15	95	110	135

Source: GAO. | GAO-20-195G

According to table 13, the most likely risk in the program involves timely delivery of quality material and the least likely risk involves a changing economy that may affect the contractor's ability to hire and retain employees at the prevailing wage.

In addition to including discrete threats and opportunities, analysts can include risks that represent ambiguity about the future. The existence of these ambiguities is known (that is, their likelihood is 100 percent) but their effects are uncertain. For example, the productivity of labor will affect the cost of many elements in some way, but whether the overall effect is positive (an opportunity) or negative (a threat) is uncertain and depends in part on bias in the point estimate. Cost analysts can also include some element of general uncertainty. For example, to account for natural variability around each of the element estimates, analysts can include an uncertainty to represent a global estimating error. Table 14 identifies some uncertainties for the UAV program.

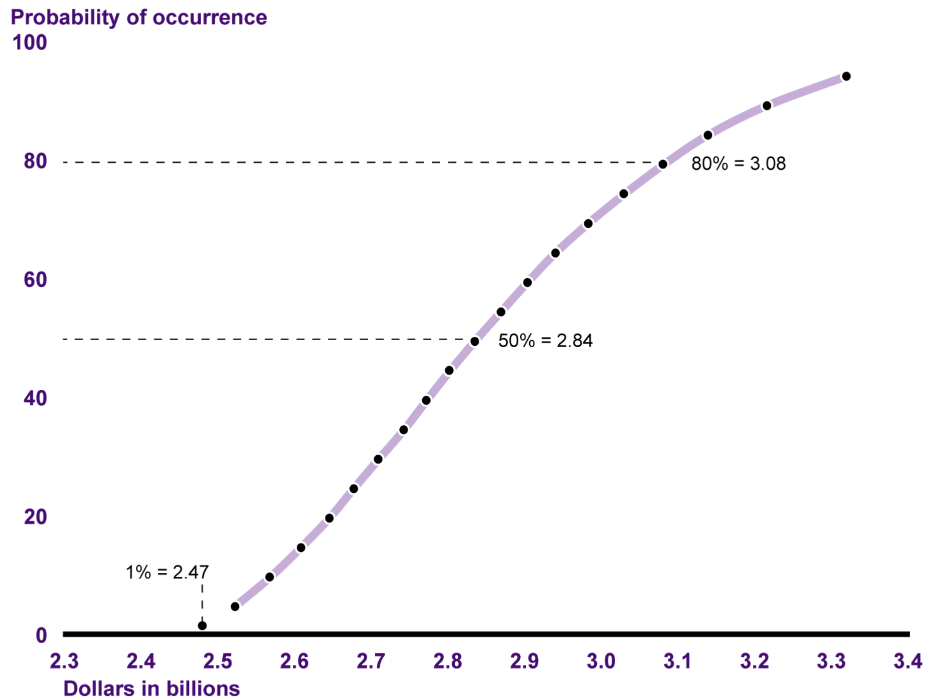
Table 14: Air Vehicle Uncertainty and Cost Effects

		Effect on cost		
Uncertainty	**Likelihood**	**Minimum**	**Most likely**	**Maximum**
Labor productivity	100%	97%	100%	105%
Cost estimating errors	100	97	100	106
Software sizing errors	100	76	100	140

Source: GAO. | GAO-20-195G

With the risk driver method, the risks and uncertainties shown in tables 13 and 14 will appear as factors that multiply the costs of the elements they are assigned to if they occur in the iteration. Once the risks and uncertainties are assigned to WBS elements, a simulation is run. The results may be similar to those in figure 16.

Figure 16: Air Vehicle Cost Cumulative Probability Distribution from a Risk Driver Simulation



Source: GAO. | GAO-20-195G

In this instance, there is about a 1 percent probability that the program will cost $2.47 billion or less. If the program manager chose the 80th percentile, the estimated program cost would be $3.08 billion, including an amount of $615 million for contingency. In this case, the risk driver method has caused a wider spread of uncertainty compared to the three-point method. By combining the two methods, three-point estimates may be used to represent bias and uncertainty, while risk drivers are used to represent identifiable risk events that may be mitigated. When combining methods, it is important that risks not be double counted in the simulation.

Collecting Risk and Uncertainty Data

High-quality data are central to a successful risk and uncertainty analysis. The validity of the results of the analysis depends on analysts' knowledge of and experience with a program's risks. If the risk and uncertainty analysis has been poorly executed or is based upon low-quality data, management may get a false sense of security that all risks have been accounted for and that the analysis is based on sound data. When this happens, program decisions will be based on bad information. Similarly, if cost estimators focus on only the risks that most concern the program office or contractor rather than a broad range of potential risks, program decisions may be based on poor quality information. Case study 18 illustrates the effects of a limited risk and uncertainty analysis and its subsequent improvement.

Case Study 18: Risk and Uncertainty Analysis, from *2020 Census*, GAO-16-628 and GAO-18-635

For the 2020 Census, the Census Bureau intended to limit its per-household cost to not more than that of the 2010 Census, adjusted for inflation. To achieve this goal, the Bureau significantly changed how it conducted the census, in part by re-engineering key census-taking methods and infrastructure. In October 2015, the Bureau estimated that with its new approach, it could conduct the 2020 Census for a life cycle cost of $12.5 billion, in contrast to its estimate of $17.8 billion to repeat the design and methods of the 2010 Census (both in constant 2020 dollars). In 2016, Congress asked GAO to evaluate the reliability of the life cycle cost estimate the Bureau submitted to Congress in October 2015. GAO reviewed (1) the extent to which the Bureau's life cycle cost estimate met best practices for cost estimation; (2) the extent to which the Bureau's key cost assumptions were supported by field tests, prior studies, and other evidence-based analysis; and (3) the extent to which the Bureau identified and accounted for key risks facing the 2020 Census within its risk and uncertainty analyses of its life cycle cost estimate.

GAO found that Census Bureau carried out a risk and uncertainty analysis for the 2020 Census life cycle cost estimate, but only for a portion of estimated costs for fiscal years 2018 to 2020. According to Bureau officials, they scoped the analysis narrowly to those 3 years when most of the census costs occur. GAO found that, as a result, the Bureau's risk and uncertainty analysis covered $4.6 billion, only about 37 percent of the $12.5 billion total estimated life cycle cost, and less than one-half of the total estimated cost of the census during future fiscal years.

The Bureau used management discretion to determine how much contingency to add on top of the remaining costs. An additional 10 percent was added for fiscal years 2018 through 2020, for a total additional contingency of $829 million. However, officials were not able to justify the 10 percent factor and there was no Bureau documentation justifying the additional contingency. Because the Bureau only carried out its uncertainty analysis on a portion of the cost estimate, GAO could not determine if it fully identified the level of risk associated with the estimate. Nor could GAO validate the Bureau's reported confidence level of the total life cycle cost estimate or how it related to the Bureau's total contingency.

In 2018, GAO evaluated the reliability of the Bureau's revised life cycle cost estimate for the 2020 Census and the extent to which the Bureau was using it as a management tool. GAO found that the Bureau had made significant progress in improving its ability to develop a reliable cost estimate. In particular, the Bureau improved its risk and uncertainty analysis methodology for the 2017 life cycle cost estimate. Bureau analysts used a combination of modeling based on Monte Carlo simulation and other methods to develop the contingency estimates. GAO found that the Bureau substantially met the best practice of risk and uncertainty analysis for the 2017 estimate. In addition, in 2018 the Bureau established roles and responsibilities for oversight and approval of cost estimation processes, created a detailed description of the steps that should be taken to produce a high-quality cost estimate, and clarified the process for updating the cost estimate and associated documents over the life of a project.

GAO, *2020 Census: Census Bureau Needs to Improve Its Life cycle Cost Estimating Process*, GAO-16-628 (Washington, D.C.: June 30, 2016) and GAO, *2020 Census: Census Bureau Improved the Quality of Its Cost Estimation but Additional Steps Are Needed to Ensure Reliability*, GAO-18-635 (Washington, D.C.: September 17, 2018).

Because collecting data to support the risk and uncertainty analysis can be a formidable effort, it should be done when the data are collected to develop the point estimate, if possible. Potential sources of risk and uncertainty can include:

- Economic – labor rate assumptions and inflation indexes
- Cost estimating – learning curve assumptions, cost estimating relationship error, and optimistic savings from new processes
- Programmatic –lack of resources
- Requirements – changes in specifications, procurement quantities, and system architecture
- Schedule – testing failures, optimistic task assumptions, and procurement delays
- Technology – success of unproven technologies, optimistic reuse assumptions, and design changes

Historical data should be used to derive risk data when possible. However, risk data must often be derived from in-depth interviews or in risk workshops. When expert opinion is used for risk and uncertainty data, it is essential that subject matter experts (SMEs) who are directly responsible for or involved in the workflow activities be interviewed. Estimates derived from interviews should be formulated with a consensus of knowledgeable technical experts and should be coordinated with the same people who manage the program and its risk mitigation watch list. Employees involved in the program from across the entire organization should be considered for interviews. Lower-level employees have valuable information on day-to-day tasks in specific areas of the program, including insight into how individual risks might affect their workflow responsibilities. Managers and senior decision-makers have insight into all or many areas of the program and can provide a sense of how risks might affect the program as a whole.

The starting point for the risk interviews is the program’s existing risk register. Interviewees are asked to provide their opinions on threats and opportunities and should be encouraged to introduce additional potential risk events that are not on the risk register. If unbiased data are to be collected, interviewees must be assured that their opinions on threats and opportunities will remain anonymous. They should also be guaranteed non-attribution and should be provided with an environment in which they are free to brainstorm on worst and best case scenarios. It is particularly important to interview SMEs without an authoritative figure in the room to avoid motivational bias. Motivational bias arises when interviewees feel (whether justifiably or unjustifiably) uncomfortable giving their honest thoughts about a program. This typically results from fear of being penalized by someone in authority. Most commonly, interviewees are labeled trouble makers or are ostracized from the team if their worst case scenario is worse than management's opinion. Risk workshops may exhibit social and institutional pressures to conform, perhaps to get consensus or to shorten the interview session. The organization may greatly discourage introducing a risk that has not been previously considered, particularly if the risk is sensitive or may negatively affect the program. If an interviewee is accompanied by someone, risk analysts cannot guarantee that the interviewee's responses are unbiased.

One way to avoid the potential for experts to be success oriented when choosing the upper and lower extremes of the distribution 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 extremes to account for the fact that being overly optimistic usually results in programs costing more and taking longer than planned. Studies have shown that, at best, subject matter experts identify 70 percent of the possible uncertainty range. Thus, it is necessary to skew the tails of the probability distributions to account for this possibility in order to more accurately represent the overall risk. One method of accounting for this aspect of expert input involves assuming that the experts' minimum and maximum represent the 15th percentile and the 85th percentile of the distribution and adjusting the distribution accordingly.

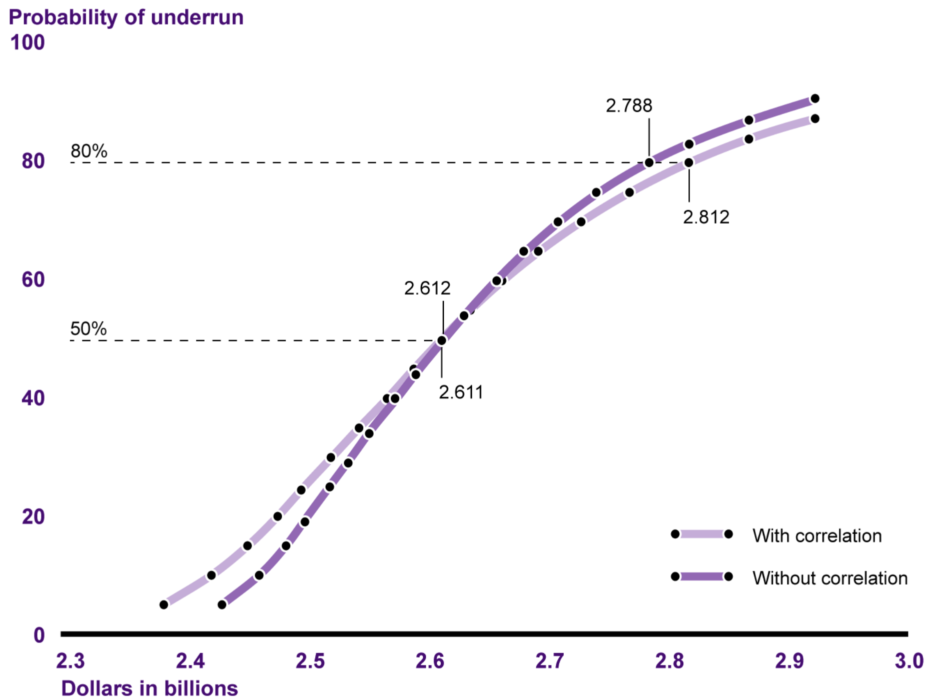
Organizations should develop and publish default distribution bounds that cost estimators can use when risk data are not objective or available. Furthermore, to ensure that best practices have been followed and to prevent errors, some experts suggest vetting the risk and uncertainty analysis through a core group of experts to ensure that results are robust and valid.

Correlation between Cost Elements

Positive correlation occurs when two WBS elements are both influenced by the same factor and can be expected to vary in the same direction within their own probability distributions in any consistent scenario. Correlation might be positive and fairly strong if, for instance, the contractor's productivity is expected to be similar for multiple elements that have been bid. Unless correlation is specified between these element costs in a simulation, certain iterations or scenarios would have some elements that cost more and others that cost less in their respective ranges during an iteration. This would be inconsistent with the idea that they all react to the same assumptions about the contractor's productivity. Specifying correlations between cost elements ensures that each iteration represents a scenario in which program costs are consistently higher or lower in their ranges together. Correlation prevents the simulation from inappropriately 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. Because the program cost estimate is the sum of the cost elements, if the costs are higher together or lower together, there is a chance that total program cost will be very high or very low. Therefore, correlation affects the low and high values in the simulation results because correlated elements tend to reinforce one another. In practice, if an organization decides to focus on the 80th percentile, correlation matters; correlation does not matter as much around the 50th percentile.

Figure 17 shows the effect of including correlation between WBS elements in the three-point risk simulation for the airframe production. In this example, 90 percent correlation was added between related elements. 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 can be used to set the correlation coefficients. Assuming this degree of correlation, we get the result shown in figure 17.

Figure 17: Cumulative Probability Distributions with and without Correlation



Source: GAO. | GAO-20-195G

Notice that the correlation has widened the overall distribution. The 50th percentile is nearly the same in both cases, $2.611 billion without correlation and $2.612 billion with correlation. However, the 80th percentile increases by $24 million when correlation is added.

To properly capture 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 inherently 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.

In cases where dependencies are not modeled, it may be necessary to assign correlation to 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 assigned to some elements of 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. A larger wing would likely require a larger engine than was originally estimated. If this risk effect is not accounted for in the cost model, it must be inserted into the risk scenario.

One of the advantages of a CER-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.

To determine correlation factors, estimators may 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 a nominal correlation between elements than to have no correlation input at all.[36]

Assigning a risk to multiple WBS elements with the risk driver method causes the elements to be correlated, negating the need for correlation factor estimates. If the risk occurs on one assigned element during the simulation, it occurs on all the assigned elements. If there are some risks assigned to one element but not another, correlation will be less than 100 percent. Modeling correlation with risk drivers avoids the difficult task of estimating a number of pair-wise correlations.

Correlation should never be ignored. Doing so can significantly affect the cost risk analysis by understating the probability distribution, resulting in a false sense of confidence in the estimate. In particular, high-risk programs should be expected to have a wide range of possible costs.

Cost Contingency

Using information from the S curve, management can determine the contingency needed to reach a specified level of confidence. The difference between the point estimate and the cost estimate at the desired percentile determines the required contingency.

Decision-makers choose the level of confidence at which to set the budget. Because each program is different, there are no set rules as to what level of contingency is sufficient for program success. The amount of contingency that should be allotted to a program above the point

[36]Department of Defense and the National Aeronautics and Space Administration, *The Joint Agency Cost and Schedule Risk Handbook* (Washington, D.C.: March 12, 2014) says that several academic papers have suggested a default correlation of 0.25 while others have recommended 0.45 or 0.63. The handbook recommends using 0.3 as a default.

estimate depends on the level of risk the agency is willing to accept for that program. While no specific confidence level is considered a best practice, budgeting to the mean of the S curve is a common practice. The amount of contingency should be based on the level of confidence with which management chooses to fund a program, based on the values reported in the S curve.[37]

For a high risk program, adopting a higher confidence level estimate (70 or 80 percent) can be used to (1) increase the organization's confidence in success within the program's budget, (2) make some provision for risks unknown at the time but likely to appear as the program progresses, and (3) reduce the likelihood that the organization will have to re-baseline the program because the program's contingency is expended before program completion. However, budgeting to a higher confidence level for multiple projects within a portfolio can result in an unaffordable portfolio budget and limit the number of programs that can be funded within that portfolio.[38]

Using an S curve, decision-makers can understand what the likelihoods of different funding alternatives imply about program success. Another benefit of using an S curve is that management can proactively monitor a program's costs because they know the likelihood of incurring overruns. Early knowledge of potential risks enables management to prepare contingency plans to monitor and respond to risks once the program is under contract. In addition, having adequate funding is essential for optimal program execution because it can take many months to obtain necessary funding to address an emergent program issue. Such delays in obtaining funding can also create cost growth. Also, additional funding may have to come from other programs, which affects those programs' ability to execute.

A program may entail much uncertainty, and the amount of contingency funding identified may exceed available funding levels. Management may gain insight from the risk analysis by acting to reduce risk to make the

---

[37]Because cost distributions tend to be right skewed, the mean of the distribution tends to fall somewhere between the 55 and 65 percentiles. Therefore, a program funded at the 50th percentile still has a greater chance of a large overrun than a large underrun.

[38]Research has shown that budgeting each program in a portfolio at its 80th percentile can result in budgeting the portfolio above the 95th percentile. The total portfolio budget will be larger than needed to successfully execute the programs. Anderson, Timothy P., "The Trouble with Budgeting to the 80th Percentile," Aerospace Corporation, (Washington, D.C.: Nov 15, 2006).

program affordable. Management may also examine different levels of contingency to understand what level of confidence the program can obtain.

Allocating, Phasing, and Converting a Risk Adjusted Cost Estimate

By selecting a contingency amount, the program estimate becomes a “risk-adjusted” estimate. Because contingency is calculated as a lump sum from the S curve, it may be necessary to allocate it throughout the WBS, phase it across future years, or convert it to budget year dollars. Allocating, phasing, and converting risk-adjusted estimates present their own sets of modeling challenges.

Allocation

Allocating contingency throughout the WBS may be necessary for a number of reasons. Analysts may want to inform the risk management process by forecasting which elements may require significant portions of the contingency. Allocation may also be necessary for organizations that prefer contingency be split between appropriations. In addition, allocation may be needed for budget submissions when the organization does not make allowance for the separate display of contingency amounts. Allocation is generally performed before the risk-adjusted estimate is phased and converted to budget dollars.

Allocating contingency is not straightforward. There are several methods for allocating contingency across WBS elements. Two common methodologies are discussed below. Analysts must ensure that contingency is assigned to WBS elements commensurate with the risk of that element, and that the sum of the risk-adjusted WBS elements equals the total risk-adjusted estimate. Each WBS element has contributed differently to the overall S curve in the Monte Carlo simulation. That is, each WBS element has its own probability distribution, with some elements more likely to underrun or overrun, and some elements positively or negatively correlated with others. Thus, contingency cannot simply be allocated equally across all cost elements, nor can it be allocated proportionally based on the contribution of each element to the total cost. Rather, contingency must be allocated according to the magnitude and variance of each WBS element’s individual probability distribution.

It is important to note that the allocation of contingency to WBS elements in this manner does not represent a commitment to fund the WBS elements. Contingency funds should be retained by management until specific needs are realized. It is likely that contingency funds will not be spent on each WBS element according to the estimated allocation.

Allocation is a modeling exercise to support budget submissions, verify the prioritized risk list, and to inform the risk management process.[39]

Allocation Methods

Analysts that need to allocate contingency to lower-level WBS elements must ensure the allocation meets two conditions: risk-adjusted lower level elements must sum to their parents, and elements that have more risk and uncertainty should have higher amounts of contingency. The difficulty meeting the first condition arises from the fact that because each WBS element's cost distribution is different, lower-level WBS elements at a specified percentile will not sum to the parent's WBS percentile value. For example, the sum of level three WBS elements at the 80th percentile will be greater than their level 2 and level 1 parents' 80th percentile value; conversely, the sum of all level three WBS elements at the 20th percentile will be less than their level 2 and level 1 parents' 20th percentile value.

Cost analysts have proposed several methods of allocating contingency to address these conditions. Two popular methods used are allocating by standard deviation and allocating by need.

> Allocation by standard deviation: Analysts may allocate contingency by adjusting the cost estimate to account for the difference in contingency between the sum of the children and the parent at a specified percentile. Analysts select the costs of children elements and the parent element at the same percentile, and calculate the difference between the sum of the children and the parent. The difference is then allocated back through the children elements proportional to the magnitude of the element's standard deviation. Therefore, more contingency is allocated to elements that have wider cost distributions and the risk-adjusted children elements sum to the parent.

> Allocation by need: Other experts have proposed that the variance of a cost element is a poor proxy for the risk associated with an element. Instead, they suggest that the analysis should take into account the probability of the element overrunning its point estimate, or its "need." Need is represented by the difference between the cost element's most likely estimate and the estimate at the specified percentile, and is adjusted by the correlation

[39]Experts have noted other issues with the assumption that contingency will be spent according to the forecasted allocations. For example, many risks when realized affect multiple WBS elements. In these cases, pre-allocating contingency funds to one element will underfund contingency for the other affected elements.

between lower-level elements. Contingency is allocated to lower-level elements proportional to the total need.

Other allocation methods are available in cost analysis publications, which vary in complexity and applicability. While mathematical complexity may result in more theoretically precise results, there may be a trade-off with the cost estimating team's ability to defend the methodology to stakeholders and key decision makers.

Phasing

Contingency—either as an allocated portion of a WBS element, or a total amount that is left unallocated—may be phased, or spread, across future years of the program's life cycle. Common methods for phasing contingency are spreading costs proportionally, through SME input, or through analogy to a similar program.

A simple approach to phasing is to spread the contingency proportionally across future years according to the phasing of the WBS element. However, proportional phasing assumes that contingency will be needed at the same rate that costs are incurred, which may not be realistic.

A common method for phasing contingency is to distribute it through future years according to the likelihood of risks being realized. For example, SMEs may assume that all risk associated with a WBS element would be realized prior to the fourth year of development, with the bulk of risk likely occurring in the third year. Cost analysts could therefore distribute half of the available contingency across years 1 and 2 of development, and assign the remaining contingency to year 3. Because this phasing method relies on the input of SMEs, it is often difficult to validate.

A third method of phasing is to spread the contingency by analogy to historical programs. For example, if the program being estimated is early in development, analysts may examine the rate of contingency expended during similar development programs. Phasing distributions modeled from historical data may serve as the basis for this phasing. As more information is known about the program, less abstract methods can be substituted for phasing. As the program moves into production, for example, the production schedule for that specific program can be the primary basis for phasing risk dollars, rather than historical programs.

Finally, cost risk software can automatically phase contingency. When using these software programs, analysts must understand the underlying assumptions used by the software and ensure that the final results are realistic and defensible.

Converting

Contingency is calculated on the total cost estimate and is therefore typically in base-year dollars. Once phased, the cost estimate must be converted into budget dollars by applying inflation indexes. Converting risk-adjusted estimates to budget year dollars is no different than converting point estimates. See step 7, chapter 10, for more information on creating budget year dollars.

Updating and Documenting a Risk and Uncertainty Analysis

The S curve from a cost risk and uncertainty analysis only quantifies the imperfectly understood risks identified at the time of the analysis. Threats and opportunities that are not known or otherwise not identified when the risk analysis is initially performed will not be quantified. Prudent organizations recognize that uncertainties and risks can become better defined as the program advances and conduct periodic re-evaluations of the risk register.

The initial risk and uncertainty analysis, and each subsequent update, should be fully documented to include the risk data, sources of risk data, and techniques used to validate the risk data. The methodologies used to perform the simulation should be detailed, including correlation and the derivation of probability distributions. In addition, outputs such as the cumulative probability distribution of the total cost estimate should be included, along with a discussion of contingency.

A risk and uncertainty analysis should be performed periodically as the cost estimate is updated to reflect progress and changes to risks. As the program progresses, risks retire or change in potential severity, and new risks that were not previously identified may appear. The time between analysis updates will vary according to program duration, complexity, risk, and the availability of management resources. Preferably, risk analysis is performed before key program decision points to ensure decision-makers have updated information throughout the life of the program. The analysis might be performed more regularly, for instance, to support annual budget request submissions so that adequate contingency can be included in the budget baseline. Alternatively, the analysis results can be used to determine the level of confidence associated with different potential budget levels. If the risk and uncertainty analysis is not updated periodically, the following cannot be determined: the likelihood of completing the program within budget, the amount of contingency needed to provide an acceptable level of confidence in the required budget, and the risks most likely to impact the program cost.

An updated risk analysis is particularly important to support the internal independent assessment process if the program is re-baselined or if significant changes are made to the risk register. Updating the program cost estimate is discussed in chapter 15 and re-baselining is discussed in chapter 20.

Survey of Step 9

Process Tasks

- Conduct a risk and uncertainty analysis that includes the following steps:
  - Model probability distributions based on data availability, reliability, and variability.
  - Account for correlation between cost elements.
  - Use a Monte Carlo simulation model (or other modeling technique) to develop a distribution of total possible costs and an S-curve showing alternative cost estimate probabilities.
  - Identify the cumulative probability associated with the point estimate.
  - Identify contingency for achieving the desired confidence level.
  - Allocate the risk-adjusted cost estimate to WBS elements, if necessary.
  - Phase and convert the risk-adjusted estimate into budget year dollars.
  - Perform a risk and uncertainty analysis periodically as the cost estimate is updated to reflect progress and changes to risks.

Best Practices

A risk and uncertainty analysis is conducted that quantifies the imperfectly understood risks and identifies the effects of changing key cost driver assumptions and factors.

- Probability distributions are modeled based on data availability, reliability, and variability.
- Correlation between cost elements is captured.
- A Monte Carlo simulation model (or other modeling technique) is used to develop a distribution of total possible costs and an S curve showing alternative cost estimate probabilities.

- The cumulative probability associated with the point estimate is identified.
- Contingency is identified for achieving the desired confidence level.
- The risk-adjusted cost estimate is allocated to WBS elements, as necessary.
- The risk-adjusted cost estimate is phased and converted to budget year dollars.
- A risk and uncertainty analysis is performed periodically as the cost estimate is updated to reflect progress and changes to risks.

Likely Effects If Criteria Are Not Fully Met

- Without a risk and uncertainty analysis, the program estimate will not reflect the degree of uncertainty, and a level of confidence cannot be given about the estimate. Unless a range of costs is provided, decision-makers will lack information on cost, schedule, and technical risks, and will not have insight into the likelihood of executing the program within the cost estimate.
- Lacking risk and uncertainty analysis, management cannot determine a defensible level of contingency that is necessary to cover increased costs resulting from unexpected design complexity, incomplete requirements, technology uncertainty, and other uncertainties.
- If risks are not accounted for and analyzed, cost estimators may underestimate or overestimate program costs.
- Unless a risk and uncertainty analysis is conducted and a program's potential range of costs is assessed, management will lack information on whether the program fits within the overall risk range of the agency's portfolio.
- If the risk and uncertainty analysis has been poorly executed or is based upon low-quality data, management may get a false sense of security that all risks have been accounted for and that the analysis is based on sound data. When this happens, program decisions will be based on bad information.
- If cost estimators only focus on the risks that most concern the program office or contractor, rather than a broad range of potential risks, program decisions may be based on poor quality information.
- If correlation is ignored, the risk and uncertainty analysis will likely understate the spread of the probability distribution about the total cost, resulting in a false sense of confidence in the estimate.

- Without an S curve, decision-makers will lack insight of what the likelihoods of different funding alternatives imply about program success. Furthermore, management will be less likely to proactively monitor a program's costs because it does not know the likelihood of incurring overruns.
- Without an understanding of which input variables have a significant effect on a program's final costs, management cannot efficiently devote resources to acquire better knowledge about those inputs to respond to their risks.
- If the risk and uncertainty analysis is not updated periodically, the following cannot be determined: the likelihood of completing the program within budget, the amount of contingency needed to provide an acceptable level of confidence in the required budget, and the risks most likely to impact the program cost.

Chapter 13: Step 10: Document 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 reliable. It also supports reconciling differences with an independent cost estimate by 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 lack of thorough documentation can raise questions about an estimate's reliability because the documentation does not demonstrate the development of the underlying cost elements. Case study 19 shows the effect of incomplete documentation on Veterans Affairs cost estimates.

Case Study 19: Documentation Guidance, from *VA Construction*, GAO-18-479

The Department of Veterans Affairs (VA) relied on the Veterans Health Administration's (VHA) Minor Construction and non-recurring maintenance (NRM) programs to maintain and improve its 1,240 medical facilities at a cost of over $1 billion in fiscal year 2018. However, in recent years, GAO and the VA's Inspector General had identified weaknesses in these programs. GAO was asked to assess VHA's management of its Minor Construction and NRM programs.

A reliable cost estimate is critical to the success of any construction program. Such an estimate provides the basis for informed decision making, realistic budget formulation and program resourcing, and accountability for results. For example, VA relies on these estimates to make annual funding decisions for various facilities. Additionally, because these estimates inform VA's overall annual budget requests, Congress relies on them to make annual appropriations decisions.

The GAO *Cost Estimating and Assessment Guide* identifies 12 steps that, when incorporated into an agency's cost-estimating guidance, should result in reliable and valid cost estimates that management can use to make informed decisions. GAO found that VHA's guidance for medical center engineering staff and contractors on how to prepare cost estimates for minor construction program projects—specifically VHA's Minor Construction Handbook, VA's *Manual for Preparation of Cost Estimates and Related Documents*, and the Veterans Affairs *Medical Center Unit Cost Guide By Project Type*—did not fully incorporate these 12 steps, raising the possibility of unreliable cost estimates affecting decisions on how many such projects the agency can fund at one time.

For example, according to the *Cost Guide*, documentation provides total recall of the estimate's details so that the estimate can be replicated by someone other than those who prepared it. Documentation 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. VHA's guidance required that supporting documents be submitted once a project is approved. However, it did not require all detail to be shown, including parameters, assumptions, descriptions, methods, and the calculations used to develop the estimate. By revising the cost-estimating guidance to address the 12 steps in GAO's *Cost Estimating and Assessment Guide*, such as considering each project's scope and complexity, VHA would have greater assurance that its cost estimates for minor construction and NRM projects are reliable.

GAO, *VA Construction: Management of Minor Construction and Non-Recurring Maintenance Programs Could Be Improved*, GAO-18-479 (Washington, D.C.: July 31, 2018).

Additionally, 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, documentation should describe the cost estimating process, data sources, and methods, and should be detailed enough to allow analysts 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 and stakeholders.

Cost estimators should document all the steps used to develop the estimate. As a best practice, the cost estimate documentation should also address how the estimate satisfies the guidance used to govern the creation, maintenance, structure, and status of the cost estimate. Table 15 describes the various sections of proper cost estimate documentation and what they should include.

Table 15: Cost Estimate Documentation Elements

Document section	Description
Cover page and table of contents	• Names the cost estimators, the organization they belong to, and the like • Gives the program's name, date, and milestones • Lists the document's contents, including supporting appendixes
Executive summary	• 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 life cycle cost estimate (LCCE) in constant and current year dollars, broken out by major work breakdown structure (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 independent cost estimate (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 recommendations and compares them to the funding profile
Introduction	• Gives the team composition—names, organizational affiliations, who was responsible for developing the estimate • Gives a program overview, how cost was estimated, and the date associated with the estimate • Addresses the estimate's purpose, need, and whether it is an initial estimate or an 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
System description	• 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	• Details the program schedule, including master schedule and deliverables • Describes the acquisition strategy • Describes ground rules and assumptions, such as inflation rates

Document section	Description
Estimating method and data by WBS cost element	• 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 cost estimating relationships (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 • Documents the inflation indexes used to convert dollars between constant years and budget years
Sensitivity analysis	• Describes the effect of changing key cost drivers and assumptions independently • Identifies the major cost drivers that should be closely monitored
Risk and uncertainty analysis	• 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 • Discusses risk distributions and correlation between WBS elements • The basis for contingency and how it was calculated is fully documented
Management approval	• Includes information, such as 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 a comparison to the current budget to identify any funding shortfalls • Presents the estimate's limitations and strengths • Includes management approval memoranda, recommendations for change, and feedback
Updates reflecting actual costs and changes	• Reflects changes in technical or program assumptions or new program phases or milestones • Replaces estimates with actual costs 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: GAO. | GAO-20-195G

Note: “Management” will vary depending on organizational structures and program complexity, but typically refers to the requester of funds. For example, the program manager, program executive officer, or acquisition authority is responsible for approving the cost estimate.

While documentation of the cost estimate is typically in the form of a written document, the documentation can be completed in other ways. For example, some organizations rely on cost models that automatically develop documentation, while others use detailed spreadsheets with notes and hyperlinks to other documents. It is important to consider 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, cost estimate documentation should 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.

Survey of Step 10

Process Tasks

- Document all steps performed 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 how the source data were normalized.

- Describe in detail the estimating methodology and rationale used to derive each WBS element's cost.
- Describe the results of the risk, uncertainty, and sensitivity analyses and whether any contingency was identified.
- Document how the estimate compares to the funding profile.
- Track how the current estimate compares to previous estimates.

Best Practices

The documentation shows the source data used, the reliability of the data, and the estimating methodology used to derive each element's cost.

- Data are adequate for easily updating the estimate to reflect actual costs or program changes so that they can be used for future estimates.
- The documentation identifies what methods were used such as analogy, expert opinion, engineering build up, parametric, or extrapolation from actual cost data.
- The supporting data have been documented. For example, sources, content, time, and units are documented, along with an assessment of the accuracy of the data and reliability and circumstances affecting the data.
- The documentation describes how the data were normalized, and the documentation includes the inflation indexes that were used.
- The inflation indexes used to convert constant year dollars to budget year dollars are documented.

The documentation describes how the estimate was developed so that a cost analyst unfamiliar with the program could understand what was done and replicate it.

- The documentation describes the estimate with narrative and cost tables and contains an executive summary, introduction, and descriptions of methods, with data broken out by WBS cost elements, sensitivity analysis, risk and uncertainty analysis, and updates that reflect actual costs and changes.
- The documentation addresses the guidance used to govern the creation, maintenance, structure, and status of the cost estimate.
- The documentation completely describes the risk and uncertainty analysis. For example, the documentation discusses contingency and

how it was derived, the cumulative probability of the point estimate, correlation, and the derivation of risk distributions.

- The documentation includes access to an electronic copy of the cost model, and both the documentation and the cost model are stored so that authorized personnel can easily find and use them for other cost estimates.

The documentation discusses the technical baseline description and the data in the technical baseline are consistent with the cost estimate.

- The technical data and assumptions in the cost estimate documentation are consistent with the technical baseline description.

Likely Effects if Criteria Are Not Fully Met

- Without good documentation, management and oversight will not be convinced that the estimate is credible; supporting data will not be available for creating a historical database; questions about the approach or data used to create the estimate cannot be answered; lessons learned and a history for tracking why costs changed will not be recorded; and the scope of the analysis will not be defined.
- Without adequate documentation, an analyst unfamiliar with the program will not be able to replicate the estimate because they will not be provided enough information to recreate it step by step.
- Unless the estimate is fully documented, it will not support an effective independent review or reconciliation with an independent cost estimate, hindering the understanding of any differences and the ability of decision-makers to make informed decisions.
- Unless thoroughly documented, the cost estimate may not be defensible. That is, the documentation may not present a convincing argument of an estimate’s validity or help answer decision-makers’ and oversight groups’ probing questions.

Chapter 14: Step 11: Present the Estimate to Management

A cost estimate is not considered complete until management has approved it. Because many cost estimates are developed to support a budget request or make a decision between competing alternatives, it is vital that management is presented with information on how the estimate was developed, including risks associated with the underlying assumptions, data, and methods. Therefore, the cost estimator should present management with enough detail to easily defend the estimate by showing how it is complete and high in quality. Cost estimators should present the documented life cycle cost estimate (LCCE) to management along with an explanation of the program's technical and program baseline.

The information in a cost estimate presentation should succinctly illustrate the main cost drivers and the final cost estimate, and should match the information in the cost estimate documentation. Presented information should include program and technical data specific to the program, along with displays of budget implications, contractor staffing levels, and industrial base considerations, to name a few. Management should be presented with cost estimate information on each program phase—development, production, operations and maintenance, and disposal. Management should also be presented with any concerns or challenges with the estimate, including whether adequate time and resources were available to develop the estimate.

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 information presented to management should be clear and complete, making it easy for those unfamiliar with the estimate to gauge its level of competence. A best practice is to present the cost estimate in a consistent format that facilitates management's understanding of the completeness and the quality of the cost estimate.

Management should be presented with sufficient information to enable it to understand how the estimate was developed. These items should be included in the information presented to management:

- Date and intended audience
- A top-level outline
- The estimate's purpose, including why it was developed and what approval is needed

- A brief program overview, including scope, physical and performance characteristics, and acquisition strategy to enable management to understand the program’s technical foundation and objectives
- Estimating ground rules and assumptions
- Life cycle cost estimate, including time-phased costs and constant year dollars
- Changes from any previous estimates
- A discussion of WBS elements, including: (1) a breakout of element costs and their percentage of the total cost estimate to help identify key cost drivers; (2) the estimating method for each WBS element; and (3) data sources and historical data
- Sensitivity analysis, including an interpretation of cost drivers and results
- Discussion of risk and uncertainty analysis, including: (1) cost drivers and top risk areas; (2) the corresponding S curve, the level of confidence in the point estimate, and contingency associated with select confidence levels; and (3) how risk and uncertainty distributions were defined
- Comparison to an independent cost estimate with a discussion of differences and the results of reconciliation
- A comparison of the life cycle cost estimate to the program budget, expressed in budget year dollars, including contingency based on the risk and uncertainty analysis and any budget shortfall and its effect
- Concerns or challenges with the estimate
- Conclusions and recommendations

This approach allows management to gain confidence in the estimating process and, thus, the estimate itself. Without this information, management will not have confidence that the estimate is complete and high in quality. Cost estimators should ask management whether it accepts the cost estimate and management’s desired level of confidence. Acceptance, along with any feedback from management, should be acted on and documented in the cost estimate documentation package.[40]

[40]“Management” will vary depending on organizational structures and program complexity, but typically refers to the requester of funds. For example, the program manager, program executive officer, or acquisition authority is responsible for approving the cost estimate.

Survey of Step 11

Process Tasks

- Present the documented life cycle cost estimate to management. Include in the presentation information on how the life cycle cost estimate was developed, including:
  - The estimate's purpose;
  - An explanation of the program's technical and program baseline;
  - Estimating ground rules and assumptions;
  - A discussion of WBS elements, their costs, data and data sources;
  - Sensitivity analysis, risk and uncertainty analysis, contingency, and the confidence level of the estimate;
  - Changes from previous estimates;
  - Comparison to an independent cost estimate;
  - A comparison of the LCCE to the funding profile;
  - Any concerns or challenges with the estimate.
- Request acceptance of the estimate from management.

  Act on and document feedback.

Best Practices

The documentation provides evidence that the cost estimate was reviewed and accepted by management.

- Management was presented with a clear explanation of the cost estimate so as to convey its level of competence.
- The following was included in the information presented to management:
  - an overview of the program's technical foundation;
  - life cycle costs presented in time-phased and constant year dollars;
  - a discussion of changes from any previous estimates;
  - a discussion of ground rules and assumptions;
  - a description of the estimating method and data sources for each WBS element;

- the results of sensitivity analysis and identification of cost drivers;
    - the results of risk and uncertainty analysis, including S curve cumulative probabilities and risk distributions;
    - a comparison of the point estimate to an independent cost estimate with explanations for any differences;
    - a comparison of the life cycle costs and contingency to the funding profile with a discussion of any shortfall and its effect;
    - conclusions and recommendations; and
    - discussion of any other concerns or challenges.

    There is documentation showing management's acceptance of the cost estimate, including recommendations for changes, feedback, and the amount of contingency to reach management's desired level of confidence.

Likely Effects if Criteria Are Not Fully Met

- If management is not presented with sufficient information about how the estimate was constructed—including the specific details about the program's technical characteristics, assumptions, data, cost estimating methodologies, sensitivity, and risk and uncertainty—management will not have confidence that the estimate is complete and high in quality.

Chapter 15: Step 12: Update the Estimate

Programs should be monitored continually 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 more accurate estimate, but also gives opportunities 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 those mistakes on future estimates. Finally, actual cost, technical, and historical schedule data should be archived in a database for use in supporting new estimates.

Effective program and cost control requires ongoing revisions to the cost estimate, budget, and projected estimates at completion. Developing a cost estimate should not be a one-time event but, rather, a recurrent process. Most programs, especially those in development, do not remain static; they tend to change in the natural evolution of a program. 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 continually represents the new reality.

Update the Program Cost Estimate with Actual Costs

Regardless of whether changes to the program result from a major contract modification or other factors, the cost estimate should be regularly updated to reflect all changes. The estimate should also be kept current as the program passes through new phases or milestones. Not only is this a sound business practice, it is also a requirement outlined in OMB's Capital Programming Guide.[41] 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 current 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

[41]Office of Management and Budget, *Capital Programming Guide: Supplement to Circular A-11, Part 7, Preparation, Submission, and Execution of the Budget* (Washington, D.C.: December 2019), 70.

recorded against the old estimate baseline. Several key activities are associated with updating the cost estimate, including:

- 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;
- updating estimates with EVM estimates at completion (EACs) and independent EACs, if applicable;
- 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 such as source lines of code sizing, effort, schedule, risk items, and the like so they can be used for estimating future programs; and
- assessing and recording lessons learned as the program progresses to inform the next version of the estimate.

After these activities are completed, the estimator should document the results in detail, including reasons for all changes. This critical step allows others to track the estimates and to identify when, how much, and why the program cost is 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. Case study 20 shows the impact of not updating a cost estimate after major program changes.

Case Study 20: Updating Estimates, from *Space Launch System*, GAO-15-596

The Space Launch System (SLS) is National Aeronautics and Space Administration's (NASA) first heavy-lift launch vehicle for human space exploration in over 40 years. For development efforts related to the first flight of SLS, NASA established its cost and schedule commitments at $9.7 billion and November 2018. The program, however, had continued to pursue more aggressive internal goals for cost and schedule.

GAO concluded that the cost and schedule estimates for the SLS program substantially complied with five of six relevant best practices, but could not be deemed fully reliable. In particular, the program had not updated its cost and schedule estimates, rendering them less reliable as program management and oversight tools. Since the estimate was created, the program had substantial funding increases but had also realized both expected and unexpected risks that were forcing the program to delay its internal goal for launch readiness. The program's cost estimate, however, did not reflect all of these changes or the 2 years of additional contractor performance data that the program had accumulated since the development of the cost estimate. Without regular updates, developed in accordance with best practices—including thorough explanations of how the updates were prepared—cost estimates lose their usefulness as predictors of likely outcomes and as benchmarks for meaningfully tracking progress. Updated cost and schedule estimates would have provided program and agency officials with a more informed basis for decision making and provided the Congress with more accurate information to support the appropriation process.

GAO recommended that to ensure that the SLS cost and schedule estimates better conform with best practices and are useful to support management decisions, the NASA Administrator should direct SLS officials to update the SLS cost and schedule estimates, at least annually, to reflect actual costs and schedule, and record any reasons for variances before preparing their budget requests for the ensuing fiscal year. To the extent practicable, these updates should also incorporate additional best practices, including thoroughly documenting how data were adjusted for use in the update and cross-checking results to ensure they are credible. In July 2018, NASA provided GAO the results of its latest assessment of the SLS's cost and schedule estimates against its Agency Baseline Commitment. NASA explained how data were adjusted for the updated estimate and the reasons for variances between the original estimate and the current estimate.

GAO, *Space Launch System: Management Tools Should Better Track to Cost and Schedule Commitments to Adequately Monitor Increasing R*isk, GAO-15-596 (Washington, D.C.: July 16, 2015).

Survey of Step 12

Process Tasks

- Update the estimate to reflect changes in technical or program assumptions and keep it current as the program passes through new phases or milestones.
- Replace estimates with EVM, EAC, and independent EACs from the integrated EVM system, if applicable.
- 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 changes to the program and how they affect the cost estimate.

Best Practices

The cost estimate is regularly updated to ensure it reflects program changes and actual costs.

- The estimate is updated to reflect changes in technical or program assumptions, and how these changes affect the cost estimate is documented.
- The cost estimates are replaced with actual costs and the sources of the actual costs are documented.

Variances between planned and actual costs are documented, explained, and reviewed.

- The estimate documents variances and any lessons learned for elements whose actual costs or schedules differ from the estimate.

Likely Effects if Criteria Are Not Fully Met

- If the estimate is not updated, it will be difficult to analyze changes in program costs, and collecting cost and technical data to support future estimates will be hindered.
- Unless properly updated on a regular basis, the cost estimate cannot provide decision-makers with accurate information for assessing alternative decisions.
- Without a documented comparison between the current estimate—updated with actual costs—and the old estimate, the cost estimators cannot determine the level of variance between the two estimates. That is, cost estimators cannot determine how well they are estimating and how the program is changing over time.

Chapter 16: Auditing and Validating the Cost Estimate

Chapter 3 describes how the cost estimating best practices can be mapped to an overall process of established methods that result in high-quality cost estimates. By following the 12-step cost estimating process, agencies should be able to produce reliable estimates that can be clearly traced, replicated, and updated to better manage their programs and inform decision-makers of the risks involved.

In this chapter, we expand on the relationship between the four characteristics of high-quality, reliable cost estimates; and the 18 best practices. We also describe how the 12-step cost estimating process, its associated tasks, and best practices can be used by auditors and other evaluators to establish 1) the reliability of a life cycle cost estimate, and 2) the quality of an agency's process, guidance, and regulations for creating and maintaining an estimate.

The Four Characteristics of a Reliable Cost Estimate and their Best Practices

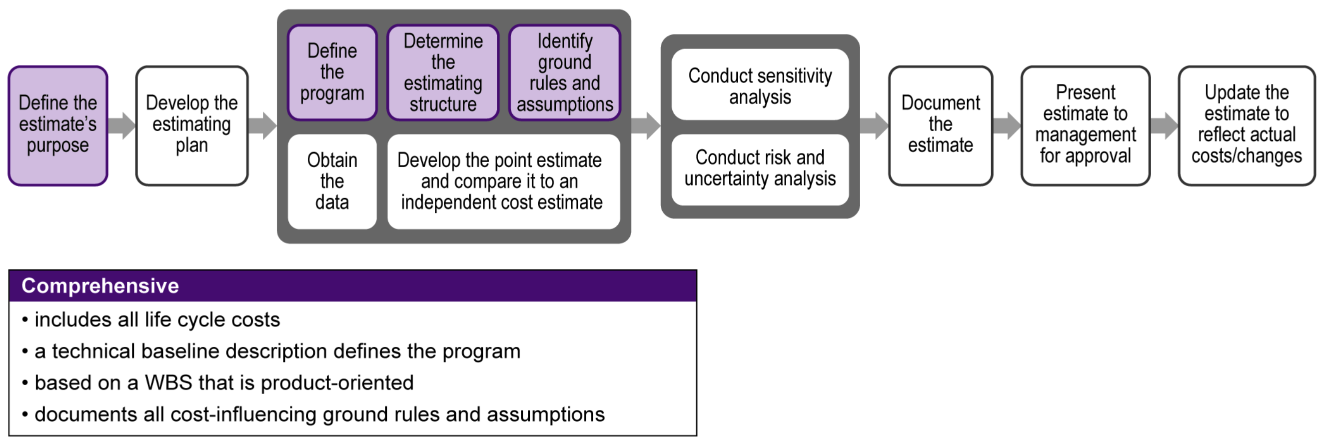
The four characteristics of a high-quality, reliable cost estimate are that it is comprehensive, well documented, accurate, and credible. A comprehensive estimate includes all possible costs, ensures that no costs were omitted or double-counted, and explains and documents key assumptions. A well-documented estimate can easily be repeated or updated and traced to original sources by auditors. An accurate estimate is developed by estimating each cost element using the best methodology from the data collected, adjusted properly for inflation, and contains few, if any, minor mistakes. A credible estimate incorporates results from sensitivity and risk and uncertainty analysis, is reconciled with an independent cost estimate, and is based on results that are cross-checked with alternate methodologies.

Comprehensive

Analysts should ensure that the cost estimate is complete and accounts for all possible costs. Comprehensive cost estimates completely define the program and reflect the current schedule and technical baseline. The reviewer should check that the estimate captures the complete technical scope of the work to be performed using a product-oriented WBS. Cost estimates should be structured with sufficient detail to ensure that cost elements are neither omitted nor double-counted. The reviewer should determine whether all assumptions and exclusions on which the estimate is based are reasonable and clearly identified and explained. Where information is limited and judgments must be made, the cost estimate should document all cost-influencing ground rules and assumptions.

Best Practices Related to a Comprehensive Estimate

Figure 18: Estimating Steps and Best Practices Related to a Comprehensive Estimate



Source: GAO. | GAO-20-195G

The cost estimate includes all life cycle costs.

A life cycle cost estimate should encompass all past, present, and future costs for every aspect of the program, regardless of funding source. The cost estimate should include both government and contractor costs of the program over its full life cycle, from inception of the program through development, production, operations and maintenance, and disposal of the program. Any items excluded from the cost estimate should be documented and justified.

Unless the cost estimate accounts for all costs, the estimate cannot enhance decision making by allowing for design trade off studies to be evaluated on the basis of cost as well as on a technical and performance basis. Without fully accounting for life cycle costs, management will have difficulty successfully planning program resource requirements and making wise decisions.

A detailed discussion of life cycle cost estimates can be found in chapter 2 and chapter 4.

The technical baseline description completely defines the program, reflects the current schedule, and is technically reasonable.

There should be a documented technical baseline description that provides a common definition of the program, including a detailed technical, programmatic, and schedule description of the system, from which cost estimates are derived. The technical baseline should be developed by qualified personnel such as system engineers, approved by management, and should reside in one central location. The technical baseline should include sufficient detail of technical, program, and schedule characteristics based on the best available information known at the time, and this information should be updated as changes occur.

Key to developing a comprehensive 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. Without these data, the cost estimator will not be able to identify the technical and program parameters that support the cost estimate and the quality of the cost estimate will be compromised.

A detailed discussion of a technical baseline can be found in chapter 6, step 3.

The cost estimate is based on a WBS that is product-oriented, traceable to the statement of work, and at an appropriate level of detail to ensure that cost elements are neither omitted nor double-counted.

The WBS should clearly outline the end product and major work of the program. This outline should be traceable to the schedule and, if applicable, the earned value management (EVM) system. In addition to hardware and software elements, the WBS should contain program management and other common elements such as testing, training, and data to ensure that all work is covered. The WBS should be standardized and there should be at least three levels of indenture that break larger products down into progressive levels of detail. Calculations should be performed to ensure that the sum of the lower level elements equal the higher level element. In addition, the WBS needs to be updated as the program becomes better defined and changes occur. There should be a WBS dictionary that defines what is included in each element and how it relates to others in the hierarchy.

A WBS 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. Without a WBS, the program lacks a 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. If a cost estimate does not specifically break out common costs, such as government furnished equipment costs, or does not include an associated WBS dictionary, one cannot ensure that the estimate includes all relevant costs. A standardized WBS is essential to ensure cost data can be collected and shared among programs and organizations, allowing for common cost measures. Without a standard, product-oriented WBS to facilitate the tracking of resource allocations and expenditures, the agency may not have the proper insight to reliably estimate the cost of future similar programs.

A detailed discussion of the WBS can be found in chapter 7, step 4.

The cost estimate documents all cost-influencing ground rules and assumptions.

The cost estimate documentation should include all defined ground rules and assumptions. The rationale and historical data needed to support the assumptions should be Included with the list of ground rules and assumptions. Risks associated with assumptions need to be identified and traced to specific WBS elements, and cost influencing assumptions should be used as inputs to the sensitivity and uncertainty analyses. Examples of potential program threats include budget constraints, delayed program content, dependency on other agencies, and technology maturity. The ground rules and assumptions should be developed by cost estimators with input from the technical community.

Cost estimates are typically based on incomplete or uncertain information and therefore need to be bound by the constraints that make estimating possible. These constraints are usually made in the form of ground rules and assumptions. However, because these assumptions are best guesses, the risks associated with any of these assumptions changing need to be identified and assessed. Many assumptions profoundly influence cost; the subsequent rejection of even a single assumption by management could invalidate many aspects of the cost estimate. Unless ground rules and assumptions are clearly documented, the cost estimate will not provide a basis for areas of potential risk to be identified and treated. Furthermore, the estimate will not be able to be reconstructed when the original estimators are no longer available.

A detailed discussion of ground rules and assumptions can be found in chapter 8, step 5.

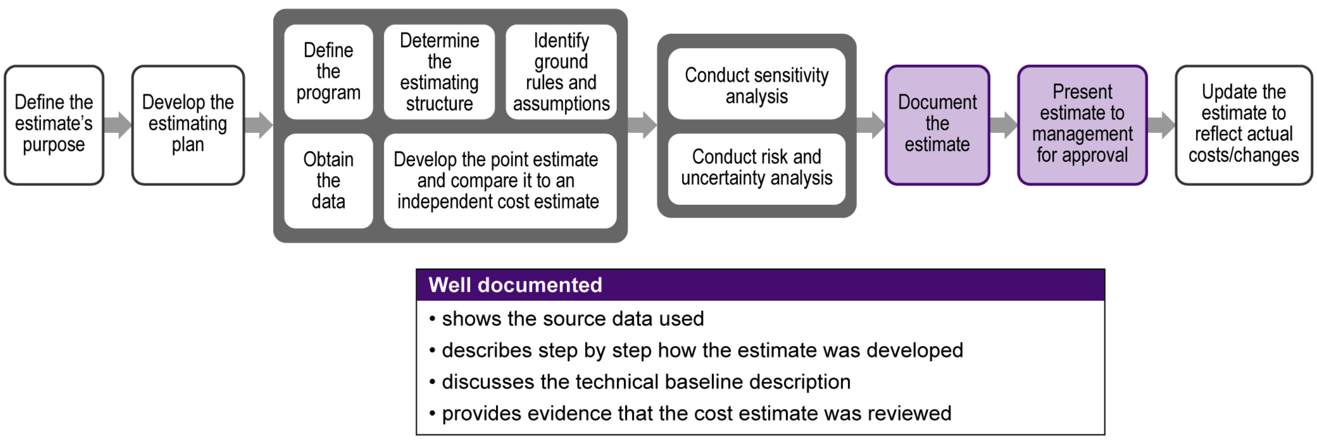
Well-documented

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. Thorough documentation also increases an estimate’s credibility and supports an organization’s decision-makers. 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 for every WBS cost element. Estimating methods used to develop each WBS cost element, including any cost estimating relationships, should be thoroughly documented so that their derivation can be traced to all sources.

Best Practices Related to a Well-Documented Estimate

Figure 19: Estimating Steps and Best Practices Related to a Well-Documented Estimate



Source: GAO. | GAO-20-195G

The documentation should show the source data used, the reliability of the data, and the estimating methodology used to derive each element's cost.

The documentation should identify what methods were used such as analogy, expert opinion, engineering build up, parametric, or extrapolation from actual cost data. The supporting data are documented as well. For example, sources, content, time, and units are documented, along with an assessment of the accuracy of the data and reliability and circumstances affecting the data. It includes descriptions of how the data were normalized. Inflation indexes used to convert constant year dollars to budget year dollars are documented.

Data are the foundation of every cost estimate. The quality of the data affects the estimate's overall reliability. Depending on the data quality, an estimate can range anywhere from a mere guess to a highly defensible cost position. Without sufficient background knowledge about the source and reliability of the data, the cost estimator cannot know with any confidence whether the data collected can be used directly or need to be modified. Because data can be gathered from a variety of sources, they are often in many different forms and need to be adjusted before being used. As a result, data normalization is often necessary so that the data are consistent and allow for valid comparisons and projections to occur.

For more information on data and documentation, see chapter 9, step 6 and chapter 13, step 10.

The documentation describes how the estimate was developed so that a cost analyst unfamiliar with the program could understand what was done and replicate it.

The data contained in the documentation should be adequate for easily updating the estimate to reflect actual costs or program changes so that they can be used for future estimates. The estimate documentation should include narrative and cost tables, and contain an executive summary and an introduction. A description of methods and related data should be broken out by WBS cost elements. In addition, sensitivity analysis, risk and uncertainty analysis, and updates that reflect actual costs and changes should be included. The documentation should completely describe the risk and uncertainty analysis. For example, the documentation discusses contingency and how it was derived, the cumulative probability of the point estimate, correlation, and the derivation of risk distributions. The documentation needs to include access to an electronic copy of the cost model, and both the documentation and the cost model are stored so that authorized personnel can easily find and use them for other cost estimates. Finally, analysts should ensure that guidance was used to govern the creation, maintenance, structure, and status of the cost estimate.

Without good documentation, management and oversight will not be convinced that the estimate is credible; supporting data will not be available for creating a historical database; questions about the approach or data used to create the estimate cannot be answered; lessons learned and a history for tracking why costs changed cannot be recorded; and the scope of the analysis cannot be thoroughly defined. Furthermore, without adequate documentation, analysts unfamiliar with the program will not be able to replicate the estimate because they will not understand the logic behind it.

For more information on data and documentation, see chapter 9, step 6 and chapter 13, step 10.

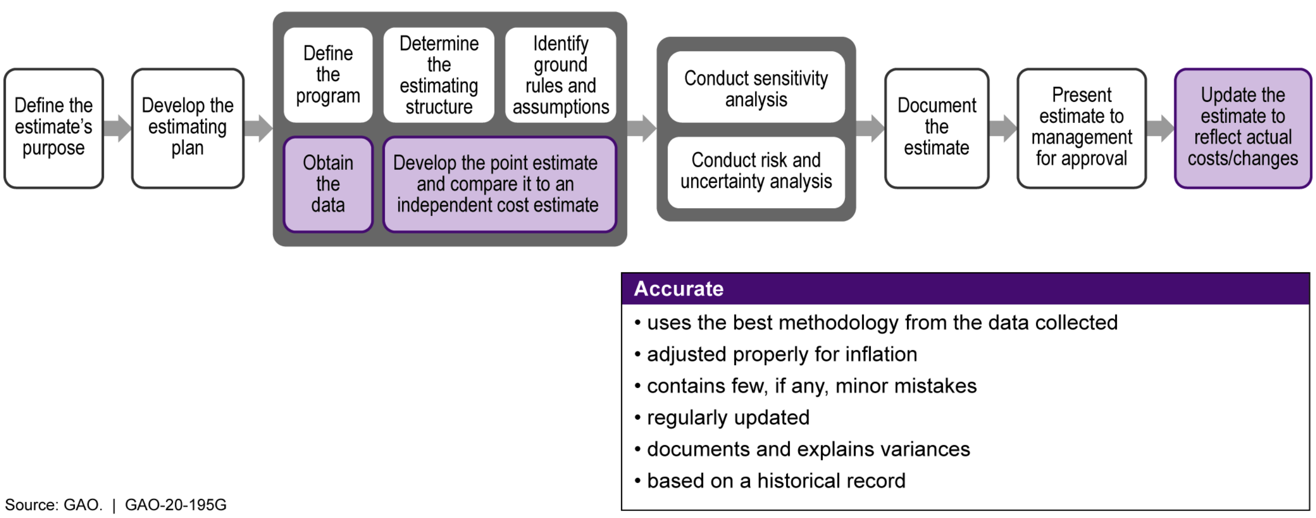
The documentation discusses the technical baseline description and the data in the technical baseline are consistent with the cost estimate.	The technical data and assumptions in the cost estimate documentation are consistent with the technical baseline description. Because the technical baseline is intended to serve as the basis for developing a cost estimate, it should be discussed in the cost estimate documentation. Without a technical baseline, the cost estimate will not be based on a comprehensive program description and will lack specific information regarding technical and program risks. For more information on technical baseline descriptions and documentation, see chapter 6, step 3 and chapter 13, step 10.
The documentation provides evidence that the cost estimate is reviewed and accepted by management.	The documentation should provide evidence that management was presented with a clear explanation of the cost estimate so as to convey its level of competence. For instance, management should be presented with an overview of the program's technical foundation, time-phased dollars of the life cycle cost estimate, ground rules and assumptions, the estimating method and data sources for each WBS cost element. The cost estimating team should also convey the results of sensitivity analysis and cost drivers; the results of risk and uncertainty analysis including S curve cumulative probabilities and risk distributions; and the point estimate compared to an independent cost estimate along with any differences. A comparison to the current budget, conclusions and recommendations, and any other concerns or challenges that need to be addressed should also be presented. Management's acceptance of the cost estimate, including recommendations for changes, feedback, and the level of contingency decided upon to reach a desired level of confidence, should be documented. A cost estimate is not considered valid until management has approved it. Thus, it is imperative that management understands how the estimate was developed, including the risks associated with the underlying data and methods. Providing a briefing or documentation package to management about how the estimate was constructed—including the specific details about the program's technical characteristics, assumptions, cost estimating methodologies, data sources, sensitivity, and risk and uncertainty—is necessary for management to gain confidence that the estimate is accurate, complete, and high in quality. For more information on management approval and documentation, see chapter 13, step 10 and chapter 14, step 11.

Accurate

Validating that a cost estimate is accurate requires thoroughly understanding and investigating how the cost model was constructed. For example, all WBS cost elements should be checked to verify that calculations are accurate and account for all costs, including indirect costs. Moreover, appropriate inflation rates should be used so that costs are expressed consistently and accurately. Checking spreadsheet formulas, databases, and cost model data inputs is imperative to validate cost model accuracy. Besides the basic checks for accuracy, the estimating technique used for each cost element should be reviewed. In addition, cost estimators should update the cost estimate regularly to reflect significant changes in the program—such as when schedules or other assumptions change—and actual costs, so that it is always reflecting current status. During the update process, variances between planned and actual costs should be documented, explained, and reviewed.

Best Practices Related to an Accurate Estimate

Figure 20: Estimating Steps and Best Practices Related to an Accurate Estimate



Source: GAO. | GAO-20-195G

The cost model was developed by estimating each WBS element using the best methodology from the data collected.

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. For example, if analogy is used, adjustments should be reasonable and based on program information, physical and performance characteristics, and the like. If the build-up method is used, the work scope should be well-defined, the WBS sufficiently detailed, a detailed and accurate materials and parts list available, specific quantities available, and an auditable source for labor rates provided. If the parametric method is used, the data set should be homogeneous and of a sufficient size for developing the cost estimating relationship (CER). Parametric models should be calibrated and validated using historical data. If CERs are used, statistics should be reasonable and documented, and the inputs are within the valid dataset range. If learning curves are used, they should represent manual, complex, and repetitive labor effort; production breaks are incorporated if production is not continuous. Finally, expert opinion is used sparingly and the estimates account for the possibility that bias influenced the results.

Understanding the methodology used to calculate each WBS element is essential to ensuring that the appropriate method was chosen and applied correctly. Each selected cost estimating method has strengths and weaknesses depending on, in part, where the program is in its life cycle and the availability of data. A program estimate's credibility will suffer because the rationales of the methodology or the calculations underlying the cost elements are not accurate or based on sound estimating practices.

For more information on selecting a cost methodology, see chapter 10, step 7.

The estimate has been adjusted properly for inflation.

The cost data should be adjusted for inflation so that they can be described in like terms and to ensure that comparisons and projections are valid. The final estimate should be converted to budget year dollars.

Adjusting for inflation is an important step in cost estimating because in the development of an estimate, cost data must be expressed in like terms. If the inflation index used is not correct, the resulting estimate could overstate or understate the cost of the program. It is imperative that inflation assumptions be well documented and that the cost estimator always performs uncertainty and sensitivity analysis to study the effects of changes on the assumed inflation rates. Moreover, without access to the estimate details, analysts cannot verify that appropriate rates were used to adjust costs for inflation so that they are expressed consistently.

For more information on inflation adjustments, see chapter 9, step 6.

The cost estimate contains few, if any, minor mistakes.

The cost estimate should be mathematically sound. In other words, it should not contain mistakes, such as numbers that do not sum properly or costs that do not match between documents, among others. The program should employ a quality control process to ensure the cost estimates contains few, if any, minor mistakes.

Validating that a cost estimate is accurate requires thoroughly understanding and investigating how the cost model was constructed. Cost models with limited details complicate the ability to determine if all WBS cost estimate calculations are accurate and account for all costs.

For more information on mathematically sound cost estimates, see chapter 10, step 7.

The cost estimate is regularly updated to ensure it reflects program changes and actual costs.

The estimate should be updated to reflect changes in technical or programmatic assumptions, and how these changes affect the cost estimate should be documented. Estimates for cost elements should be replaced with actual costs from valid sources as they become available.

If the estimate is not updated, it will be difficult to analyze changes in program costs, and collecting cost and technical data to support future estimates will be hindered. The cost estimate should be updated when the technical baseline changes to maintain credibility. Unless properly updated on a regular basis, the cost estimate cannot provide decision-makers with accurate information.

For more information on updating the estimate, see chapter 6, step 3 and chapter 15, step 12.

Variances between planned and actual costs are documented, explained, and reviewed.

The estimate should document any variances for elements whose actual costs or schedules differ from the estimate. Any lessons learned from the variances should be documented.

Without a documented comparison between the current estimate, updated with actual costs, and the baseline estimate, the cost estimator cannot determine how well they are estimating and how the program is changing over time.

For more information on updating the estimate, see chapter 15, step 12.

The estimate is based on a historical record of cost estimating and actual experiences from other comparable programs.

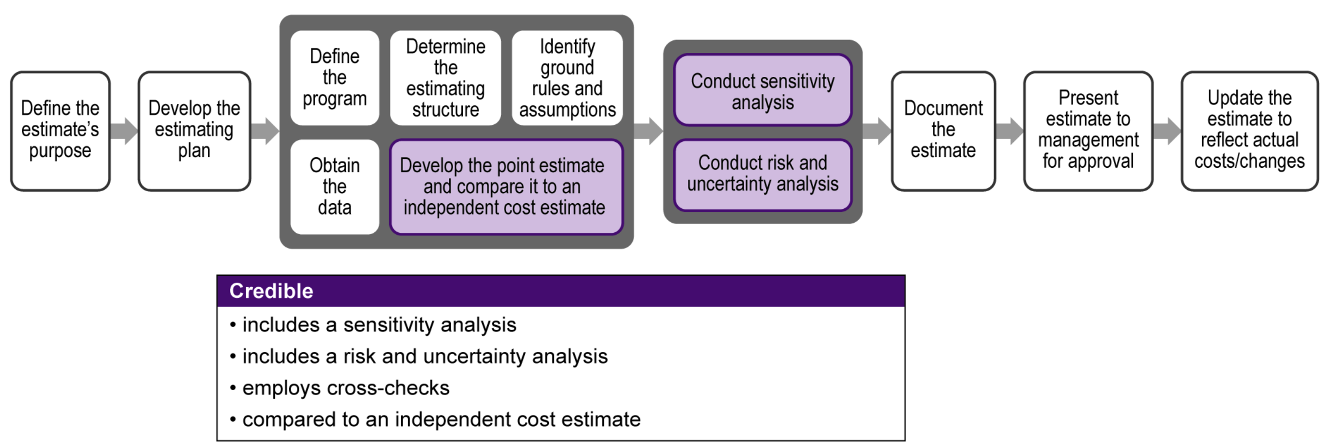
The estimate is based on reliable and historical data and the data are applicable to the program. There is enough knowledge about the data source to determine if the data can be used to estimate accurate costs for the new program. If EVM data are available, they should be derived from an EVM system validated against the EIA-748 guidelines.

Accurate cost estimates are rooted in historical data. These data provide insight into actual costs of similar programs, including any cost growth from the original baseline estimate. Historical data can be used to challenge optimistic assumptions and bring more realism to the estimate. Thus, collecting valid and useful historical data is a key step in developing a sound cost estimate.

For more information on basing the estimate on actual data from comparable programs, see chapter 9, step 6.

Credible

Figure 21: Estimating Steps and Best Practices Related to a Credible Estimate



Source: GAO. | GAO-20-195G

Because uncertainty cannot be avoided, it is necessary for cost estimators to identify the cost elements that represent the most risk and, if possible, quantify the risk. Credible cost estimates clearly identify limitations resulting from uncertainty or bias surrounding the data or assumptions. Major assumptions are varied and alternative outcomes recomputed to determine how sensitive outcomes are to changes in the 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. Along with a sensitivity analysis, a risk and uncertainty analysis adds to the credibility of the cost estimate because it identifies, among other things, the level of confidence associated with achieving the cost estimate. Another way to strengthen the credibility of the cost estimate is to perform cross-checks on cost estimating methodologies. That is, cost analysts should apply different methods to estimate high-value cost elements and determine if they produce similar results. Finally, an independent cost estimate (ICE) is considered one of the best and most reliable validation methods. An ICE provides an independent view of expected program costs that tests the program office's estimate for reasonableness.

The cost estimate included a sensitivity analysis that identifies a range of possible costs based on varying major assumptions, parameters, and data inputs.

As a best practice, a sensitivity analysis should be included in all cost estimates because it examines the effects of changing assumptions and ground rules. Key cost drivers and ground rules and assumptions should be identified as factors, particularly those supporting cost elements that represent the highest percentage of cost. The total cost should be re-estimated by varying each factor. Results are documented and outcomes evaluated for those factors most sensitive to change.

Without conducting a sensitivity analysis to determine how the cost estimate is affected by a change in a single factor, the cost estimator will not fully understand which variable most affects the cost estimate. Simply varying factors by applying a subjective plus or minus percentage that does not have a valid basis does not constitute a valid sensitivity analysis. For management to make informed decisions, there should be a clear link between the technical baseline parameters, assumptions, and cost model inputs examined by cost estimators in the sensitivity analysis. Carefully assessing the underlying risks and supporting data, and documenting the sources of variation is necessary for a sensitivity analysis to inform decisions. An agency that fails to conduct sensitivity analyses to identify the effects of uncertainties associated with different assumptions increases the risk that decisions will be made without a clear understanding of these impacts on costs.

For more information on sensitivity analysis, see chapter 11, step 8.

A risk and uncertainty analysis was conducted that quantified the imperfectly understood risks and identified the effects of changing key cost driver assumptions and factors.

For management to make informed decisions, the program estimate must reflect the degree of uncertainty so that a level of confidence can be given about the estimate. Cost analysts should conduct a risk and uncertainty analysis that models a probability distribution for each cost element's uncertainty based on data availability, reliability, and variability; accounts for correlation between cost elements; uses an uncertainty modeling technique such as Monte Carlo simulation to develop a distribution of total possible costs and an S curve to show alternative cost estimate probabilities; associates the point estimate with a cumulative probability; recommends contingency for achieving a desired confidence level; allocates, phases, and converts the risk-adjusted cost estimate to budget year dollars for budgeting as necessary.

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. Without risk and uncertainty analyses, the estimate will lose credibility. Management will not be able to make good decisions because the estimate will lack the level of confidence associated with achieving the cost estimate. An estimate without risk and uncertainty analysis is unrealistic because it does not assess the variability in the cost estimate from such effects as schedules slipping, missions changing, and proposed solutions not meeting users' needs. Lacking risk and uncertainty analysis, management cannot determine a defensible level of contingency that is necessary to cover increased costs resulting from unexpected design complexity, incomplete requirements, technology uncertainty, and other uncertainties.

For more information on risk and uncertainty analysis, see chapter 12, step 9.

Major cost elements were cross-checked to see if results were similar.

Major cost elements should be cross-checked with results from alternative methodologies to determine if results are similar.

One way to reinforce the credibility of the cost estimate is to see whether applying a different method produces similar results. Unless an estimate employs cross-checks, the estimate will have less credibility because stakeholders will have no assurance that alternative estimating methodologies produce similar results.

For more information on using alternative methodologies to cross-check results, see chapter 10, step 7.

An independent cost estimate (ICE) was conducted by a group outside the acquiring organization to determine whether other estimating methods produce similar results.

An ICE should be performed by an organization outside of the program office's influence. The depth of the ICE should be sufficient to allow for reconciliation between the ICE and the program office estimate, and differences between the two should be documented and justified. The ICE should be based on the same technical baseline and ground rules as the program office estimate.

Without an ICE, decisions-makers will lack certain insights into a program's potential costs because ICEs frequently use different methods and are less burdened with organizational bias. Moreover, ICEs typically incorporate adequate risk and, therefore, tend to be more conservative by forecasting higher costs than the program office. A program estimate that has not been reconciled with an ICE has an increased risk of proceeding underfunded because an ICE provides an objective and unbiased assessment of whether the program estimate can be achieved.

For more information on comparing the cost estimate to an independent cost estimate, see chapter 10, step 7.

Assessing the Reliability of a Cost Estimate

In this chapter, the cost estimating best practices and the four characteristics of a high-quality cost estimate are presented as criteria—that is, the required or desired state or expectation with respect to a program or operation. Auditors can use these criteria to assess the reliability of a cost estimate and determine the thoroughness of an organization's cost estimating guidance.[42] In addition, non-audit organizations can use the best practices and four characteristics to validate the quality of a program's cost estimate.

Cost Estimate Audit Criteria

Auditors should identify criteria. Criteria provide a context for evaluating evidence and understanding the findings, conclusions, and recommendations included in an audit report. According to Government Auditing Standards, criteria represent the laws, regulations, contracts, grant agreements, standards, specific requirements, measures, expected performance, defined business practices, and benchmarks against which performance is compared or evaluated.[43]

---

[42]From an auditing perspective, reliability means that data are reasonably complete and accurate, meet the intended purposes, and are not subject to inappropriate alteration. For more information, see GAO, *Assessing the Reliability of Computer-Processed Data*, GAO-09-365G, (Washington, D.C.: July 2009).

[43]GAO, *Government Auditing Standards*, GAO-18-568G (Washington, D.C.: July 2018).

Auditors should use criteria that are relevant to the audit objectives and permit consistent assessments of the subject matter. By using the process task lists and best practices described in this Guide, auditors and others charged with determining the quality of a cost estimate can:

- assess the reliability of a cost estimate,
- evaluate the extent to which an organization's processes and procedures address best practices, and
- independently validate a cost estimate.

Auditors write statements of quality of cost estimates by determining the extent to which the estimate reflects each best practice. Best practice evaluations are then summarized at the characteristic level to determine the extent to which the estimate meets the four characteristics. For example, a cost estimate that completely addresses the components of a sensitivity analysis, a risk and uncertainty analysis, includes methodology cross-checks, and is compared to an independent cost estimate can be considered a credible cost estimate. A cost estimate that fully reflects the comprehensive, well-documented, accurate, and credible characteristics is considered a reliable cost estimate.

Case study 21 provides an example of the extent to which an agency's cost estimate met the four characteristics of a reliable cost estimate.

Case Study 21: Unreliable Cost Estimates, from *Ford-Class Aircraft Carrier*, GAO-17-575

The Navy is investing over $43 billion to develop three Ford-Class nuclear-powered aircraft carriers. This class of ships is intended to feature an array of cutting-edge technologies to improve combat capabilities and create operational efficiencies by increasing the rate of aircraft launches and reducing the number of personnel needed to operate the ship. The Navy expects to achieve these improvements while simultaneously reducing acquisition and life cycle costs. However, this expectation has not been borne out. Costs to construct the lead ship Gerald R. Ford (CVN 78) increased from $10.5 billion to $12.9 billion (nearly 23 percent), and promised levels of capability have been reduced. GAO assessed the extent to which the CVN 79 follow-on ship's cost estimate was reliable and provided a reasonable basis for meeting the cost cap given known cost risks from the performance of the lead ship.

GAO's review of the CVN-79 cost estimate found that the $11.4 billion the Navy budgeted to construct the ship was likely insufficient. The CVN 79 estimate was substantially comprehensive in that it included all life cycle costs, mostly defined the program, and had a product oriented work breakdown structure. However, GAO found several weaknesses in the other best practices that indicate the $11.4 billion was not a realistic program estimate. In particular, GAO found that the estimate was only partially well documented and lacked analysis to support the derived cost savings from CVN 78. The cost estimate documentation also did not describe the estimating methodology and there was limited documentation to support the cost model inputs. The estimate was partially accurate because of its optimistic assessment regarding the labor hours needed to construct the ship and because the estimators did not use timely data to ensure that the cost estimate reflected the costs most likely to be incurred. Finally, the estimate was partially credible because it did not sufficiently account for program risks. As a result, the cost estimate did not provide a reliable basis for important program decision making, such as developing annual budgets, making requirement trade-offs, and gauging shipbuilder progress, among other things.

GAO, *Ford-Class Aircraft Carrier: Follow-On Ships Need More Frequent and Accurate Cost Estimates to Avoid Pitfalls of Lead Ship*, GAO-17-575 (Washington, D.C.: June 13, 2017).

Relevance of Cost Estimating Criteria

As detailed in appendix I, in developing this Guide, we researched legislation, regulations, policy, and guidance for the most pertinent criteria to cost estimating and EVM. We intend this Guide to serve as a starting point for auditors to identify criteria. For each new engagement, 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 and the criteria may no longer conform to sound management principles or reflect current conditions. In such cases, auditors need to select or develop criteria that are appropriate for the engagement's objectives. Table 16 lists salient legislation and regulations as sources of criteria related to cost estimating and EVM.

Table 16: Select Cost Estimating and EVM Criteria for Federal Agencies: Laws and Regulations

Year	Title	Applicable agency	Notes
2009	Weapon Systems Acquisition Reform Act of 2009, as amended	DOD	Limits weapon system cost overruns and strengthen oversight and accountability. It established four offices within DOD: Systems Engineering; Developmental Test and Evaluation; Cost Assessment and Program Evaluation; and Performance Assessments; and Root Cause Analyses. The Act also requires DOD to ensure that the acquisition strategy for major defense acquisition programs includes measures to ensure competition or the option of competition throughout the program life cycle.
1982	Unit Cost Reports ("Nunn-McCurdy"); 10 U.S.C. § 2433	DOD	Establishes the requirement for DOD to prepare unit cost reports on major defense acquisition programs or designated subprograms, if a program exceeds cost growth thresholds specified in the law. This is commonly referred to as a Nunn-McCurdy breach, which DOD is required to report to Congress and, if applicable submit a certification to Congress in order to continue the program, in accordance with 10 U.S.C. 2433a.
1994	The Federal Acquisition Streamlining Act of 1994, § 5051(a), 41 U.S.C. § 3103	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	Clinger-Cohen Act of 1996, 40 U.S.C. §§ 11101–11704	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	Federal Acquisition Regulation (FAR), Major Systems Acquisition, 48 C.F.R. part 32, subpart 34, 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).

Year	Title	Applicable agency	Notes
2008	Defense Federal Acquisition Regulation; Earned Value Management Systems, 73 Fed. Reg. 21,846 (April 23, 2008), codified in pertinent part at 48 C.F.R. §§ 234-201 to 234-203, and §§§ 252.234-7001 - 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.
2010	Government Performance and Results Act (GPRA) Modernization Act of 2010, Pub. L. No. 111-325, 124 Stat. 3866 (Jan. 4, 2011)	All	Significantly enhances the Government Performance and Results Act (GPRA) of 1993, Pub L. No. 103-62, 107 Stat. 285 (Aug. 3, 1993). 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.
2017	American Innovation and Competitiveness Act 42, Pub. L. No. 114-329, 130 Stat. 2969, 2989 (Jan. 6, 2017), codified in pertinent part at U.S.C. § 1862s-2(a)(2)(D)	National Science Foundation	When engaging in oversight of a major multi-user research facility project, the Director of the National Science Foundation is required to ensure that policies for estimating and managing costs and schedules are consistent with the best practices described in the GAO Cost Estimating and Assessment Guide, among other guidance.

Source: GAO. | GAO-20-195G

Assessing the Extent to Which Cost Estimating Best Practices Are Met

Auditors should collect data produced from both a program's cost estimate and, if applicable, its EVM system. They can collect these data via questionnaires, structured interviews, direct observations, or computations, among other methods. Appendix IV is a sample data collection instrument with reasons why auditors need the information.

After auditors have collected the data, they must evaluate the data for integrity and quality. For cost estimates, auditors must confirm that, at a minimum, internal quality control checks show that the data are reliable and valid. To do this, they must have source data and must evaluate the rationale for each cost element. Examples of these techniques include verifying that:

- the parameters (or input data) used to create the estimate are valid and applicable;
- labor costs include a time-phased breakdown of labor hours and rates, if applicable;
- the calculations for each cost element are correct and the results make sense;

- the program cost estimate is an accurate total of sub-element costs; and
- inflation adjustments are properly made to account for differences in the price of goods and services over time.

Auditors should clarify issues about data and methodology with agency cost estimators. For example, auditors may 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 normalized the data to remove their effects. According to experts in the cost community, program inefficiencies should not be removed from historical data because the development of most complex systems usually encounters problems. The experts stress that removing data associated with past problems introduces unnecessary risk. This topic is discussed in greater detail in chapter 9.

With regard to EVM, auditors should request a copy of the system compliance or certification letter that shows the contractor's ability to satisfy the 32 EVM guidelines. The 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 EVM system quality and robustness. Auditors should also request a copy of the integrated baseline review (IBR) results (discussed in chapter 19) to see what risks and treatment plans were identified. Auditors should request copies of internal management documents or reports that use EVM data to ensure that EVM is being used for management, not only 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.

Assessing the Thoroughness of an Organization's Estimating Guidance

As GAO has previously reported, a lack of formal cost estimating guidance at agencies has led, in certain circumstances, to cost estimates of poor quality. This guidance serves as a mechanism for providing a standard cost-estimating process to agency officials and contractors. Cost estimating guidance also establishes roles and responsibilities for those preparing, reviewing, and updating all types of cost estimates. The 12-step cost estimating process and the process task lists that follow each chapter in this Guide can be used by agencies and other organizations to ensure that their cost estimating guidance, policies, and directives fully reflect industry and government standards for high-quality cost estimating. Table 17 summarizes the 12 steps and their associated tasks.

Table 17: The Twelve Steps and their Associated Tasks

Step	Process Task
1. Define the estimate's purpose	• Cleary define the estimate's purpose. • Determine the estimate's overall scope. • Determine the required level of detail for the estimate, which should be consistent with the level of detail available for the program.
2. Develop the estimating plan	• Ensure the cost estimating team's composition is commensurate with the assignment. • Develop a written study plan that describes the cost estimating approach and includes a schedule to complete the cost estimate. • Ensure the team has access to the necessary subject matter experts. • Ensure the team has adequate time to develop a high-quality estimate, including the time needed to conduct site visits and collect data.

3. Define the program	• In a technical baseline document or group of documents, identify
	  • The program's purpose and its system and performance characteristics;
	  • All system configurations;
	  • Any technology implications;
	  • The program acquisition schedule and acquisition strategy;
	  • The relationship to other existing systems, including predecessor or similar legacy systems;
	  • Support (e.g., manpower, training) and risk items;
	  • System quantities for development, test, and production; and
	  • Deployment and maintenance plans.

4. Determine the estimating structure	• Define a work breakdown structure (WBS) that is standardized and product-oriented. • Ensure the cost estimate WBS matches the schedule and earned value management WBS, if applicable. • Describe each WBS element in a WBS dictionary. • Update the WBS as the program becomes better defined to reflect changes as they occur.

Step	Process Task
5. Identify ground rules and assumptions	• Document all cost-influencing ground rules and assumptions. • Document the rationale and historical data that support the ground rules and assumptions. • Include input from the technical community when developing ground rules and assumptions. • Document risks associated with assumptions and trace to specific WBS elements.
6. Obtain the 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, 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.
7. Develop the point estimate	• Develop the cost model, estimating each WBS element, using the best methodology from the data collected 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.
8. Conduct sensitivity analysis	• Identify assumptions and parameters, including key cost drivers, as factors for sensitivity testing. • Test the sensitivity of cost elements to changes in identified factors. • Document the results, including those factors that are most sensitive to change.

Step	Process Task

9. Conduct risk and uncertainty analysis	• Conduct a risk and uncertainty analysis that includes the following steps:
	  • Model probability distributions based on data availability, reliability, and variability.
	  • Account for correlation between cost elements.
	  • Use a Monte Carlo simulation model (or other modeling technique) to develop a distribution of total possible costs and an S-curve showing alternative cost estimate probabilities.
	  • Identify the cumulative probability associated with the point estimate.
	  • Identify contingency for achieving the desired confidence level.
	  • Allocate the risk-adjusted cost estimate to WBS elements, if necessary.
	  • Phase and convert the risk-adjusted estimate into budget year dollars.
	  • Perform a risk and uncertainty analysis periodically as the cost estimate is updated to reflect progress and changes to risks.

10. Document the estimate	• Document all steps performed 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 how the source data were normalized. • Describe in detail the estimating methodology and rationale used to derive each WBS element's cost. • Describe the results of the risk, uncertainty, and sensitivity analyses and whether any contingency was identified. • Document how the estimate compares to the funding profile. • Track how the current estimate compares to previous estimates.
11. Present the estimate to management for approval	• Present the documented life cycle cost estimate to management • Request acceptance of the estimate from management. • Act on and document feedback.
12. Update the estimate to reflect actual costs and changes	• Update the estimate to reflect changes in technical or program assumptions and keep it current as the program passes through new phases or milestones. • Replace estimates with EVM, EAC, and independent EACs from the integrated EVM system, if applicable. • 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 changes to the program and how they affect the cost estimate.

Source: GAO. | GAO-20-195G

Case study 22 provides an example of the extent to which an agency's cost estimating guidance incorporates best practices.

Case Study 22: Incomplete Cost Estimating Guidance, from *Project and Program Management,* GAO-15-29

The National Nuclear Security Administration (NNSA)—a semiautonomous agency within the Department of Energy (DOE)—is responsible for managing the nation's nuclear security missions. These missions include maintaining the safety, security, and effectiveness of the U.S. nuclear weapons stockpile and reducing the threat posed by nuclear proliferation. To examine the extent to which DOE and NNSA cost estimating requirements and guidance for its projects and programs reflect best practices for developing and reviewing cost estimates, GAO reviewed DOE and NNSA requirements and guidance related to cost estimating for projects and programs and compared them with the best practices identified in our 2009 *Cost Estimating and Assessment Guide.*

DOE and NNSA cost estimating requirements and guidance for projects generally did not reflect best practices for developing cost estimates. DOE's 2010 project management order required the use of only one of the 12 cost estimating best practice steps. Specifically, the order required an ICE be prepared at critical decision point 2 (approve project performance baseline) and critical decision point 3 (approve start of construction) for projects with an estimated cost of $100 million or greater. However, the order did not require any of the other 11 best practice steps, such as conducting a risk and uncertainty analysis, identifying ground rules and assumptions, documenting the estimate, developing a point estimate, or determining the estimating structure. According to the DOE officials responsible for developing DOE's project management order, DOE had chosen to not require all cost estimating best practices in the order and instead included suggested approaches for developing cost estimates in the DOE cost estimating guide that accompanied the order. However, because neither DOE nor NNSA required the use of most cost estimating best practices for its projects, it was unlikely that NNSA and its contractors would consistently develop reliable cost estimates.

GAO recommended that, to enhance NNSA's ability to develop reliable cost estimates for its projects and for its programs that have project-like characteristics, the Secretary of Energy DOE, among other things: (1) revise DOE's project management order to require that DOE, NNSA, and its contractors develop cost estimates in accordance with the 12 cost estimating best practices, and (2) revise DOE's cost estimating guide so that it fully reflects the 12 cost estimating best practices. In June 2015, based in part upon GAO's work, the Secretary of Energy issued a memo to enhance and clarify departmental policy related to project management. The memo outlined changes that recent GAO reports had noted as areas for improvement. Specifically, the memo required that the DOE project management order, the cost estimating guide, and the Department of Energy Acquisition Regulations be revised consistent with the cost estimating best practices. The memo further specified that these and other provisions of the memo were to be made effective immediately and implemented as required project management procedures. This action satisfied this recommendation.

GAO, *Project and Program Management: DOE Needs to Revise Requirements and Guidance for Cost Estimating and Related Reviews*, GAO-15-29 (Washington, D.C.: November 25, 2014).

Chapter 17: Earned Value Management

In this chapter, we review the importance of obtaining the best perspective on a program and its inherent risks by linking cost estimating to earned value management (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 and risks to management with sufficient lead time to respond. We discuss implementing EVM and summarize benefits and obstacles, and the EVM guidelines. In addition, the 13 activities that encompass the EVM process are discussed. Further discussion is included on how to use EVM to manage program costs through execution as well as updating the EVM system and the cost estimate.

What EVM Is

EVM 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.

As a key management concept, EVM provides improved oversight of acquisition programs. 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. 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.

How EVM Works

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 program is underrunning its estimated costs. However, an earned value analysis reveals that the program 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 program 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, earned value provides the missing information necessary for understanding the health of a program and provides an objective view of program status. 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.

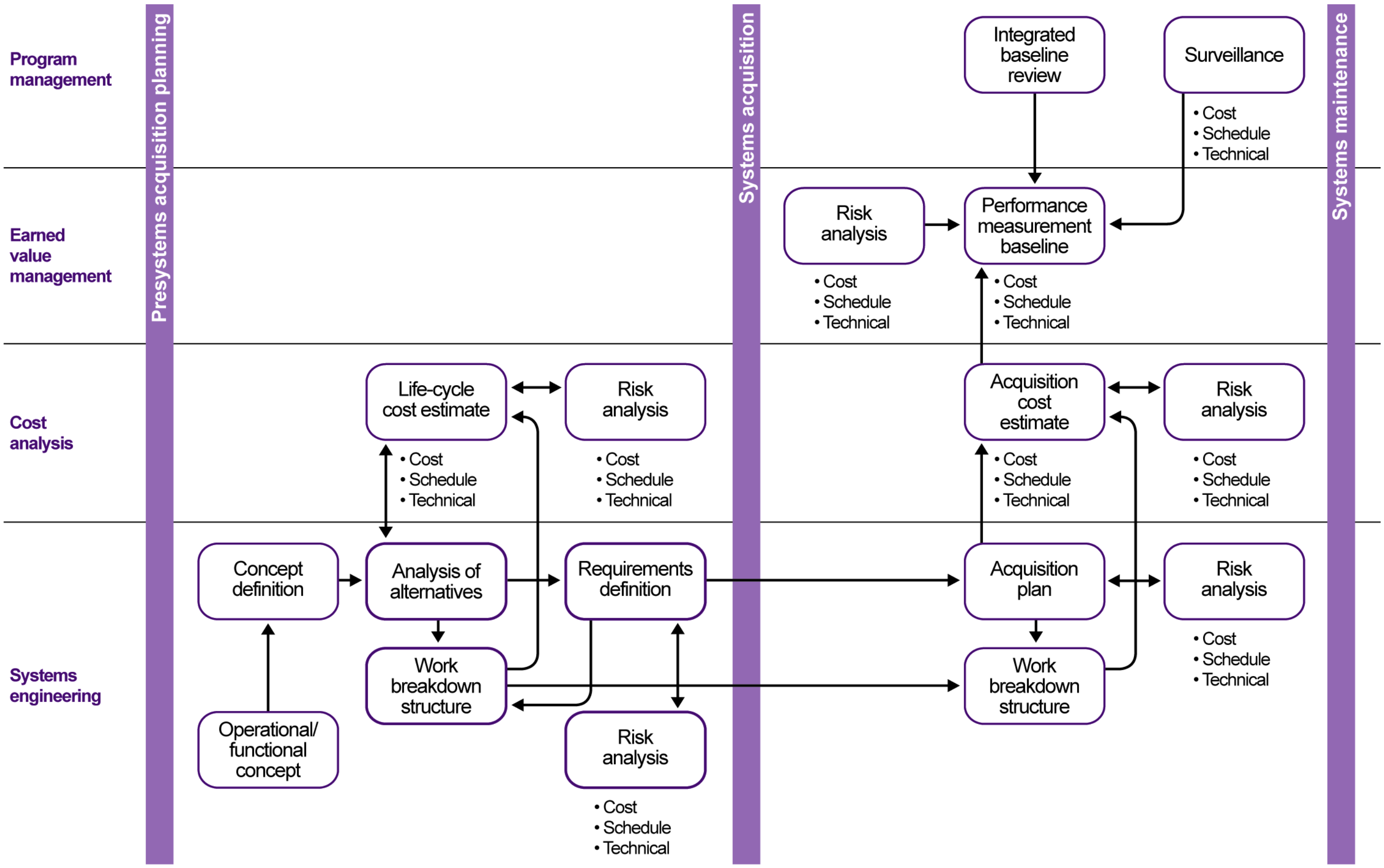
Without knowing the planned cost of completed work and work in progress (that is, earned value), true program status cannot be determined. Moreover, because EVM provides data in consistent units (usually labor hours or dollars), the progress of vastly different work efforts can be combined. For example, 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.

Using the value of completed work for estimating the cost and time needed to complete a program will 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.

Implementing EVM

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) provide the customer with timely and accurate data for determining contract status by product. An effective EVM system comprises management processes for integrating program planning and execution across cost, schedule, and technical disciplines. Figure 22 shows the flow of activity between key functions such as cost estimating, system development oversight, and risk management.

Figure 22: Integrating Cost Estimation, Systems Development Oversight, and Risk Management



Source: Copyright © 2007, National Defense Industrial Association (NDIA), Program Management Systems Committee, *Earned Value Management Systems Application Guide*. | GAO-20-195G

As the lower left of figure 22 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, the cost analysis team conducts a risk analysis examining cost, schedule, and technical impacts. 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 analysis continue in conjunction with the development of the program's EVM performance measurement baseline.[44] This baseline is necessary for defining the time-phased budget plan from which actual program performance is measured. If the baseline is not based on a reliable cost estimate or does not reflect the approved work, the program is at risk for cost overruns, missed deadlines, and shortfalls in performance. Additionally, management will have difficulty successfully planning resources and making informed decisions. After the performance measurement baseline has been established, the program manager and contractor participate in an Integrated Baseline Review (IBR) to ensure mutual understanding of all the risks. This review also validates that the program baseline realistically portrays all authorized work according to the schedule.

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, including all risk handling activities. 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.

Implementing EVM at the Program Level

Implementing EVM at the program level rather than solely at 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

[44]The system acquisition phase includes both contract and government organization efforts. If government staffing is selected, the effort should be managed in the same way as contract work. This means that government effort is 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.

programs. [45] 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's *Capital Programming Guide* addresses the use of EVM as an important part of program management and decision making.[46] 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 can 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 managers adequately plan for the receipt of material, for example 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 communicated.

A Baseline for Risk Management

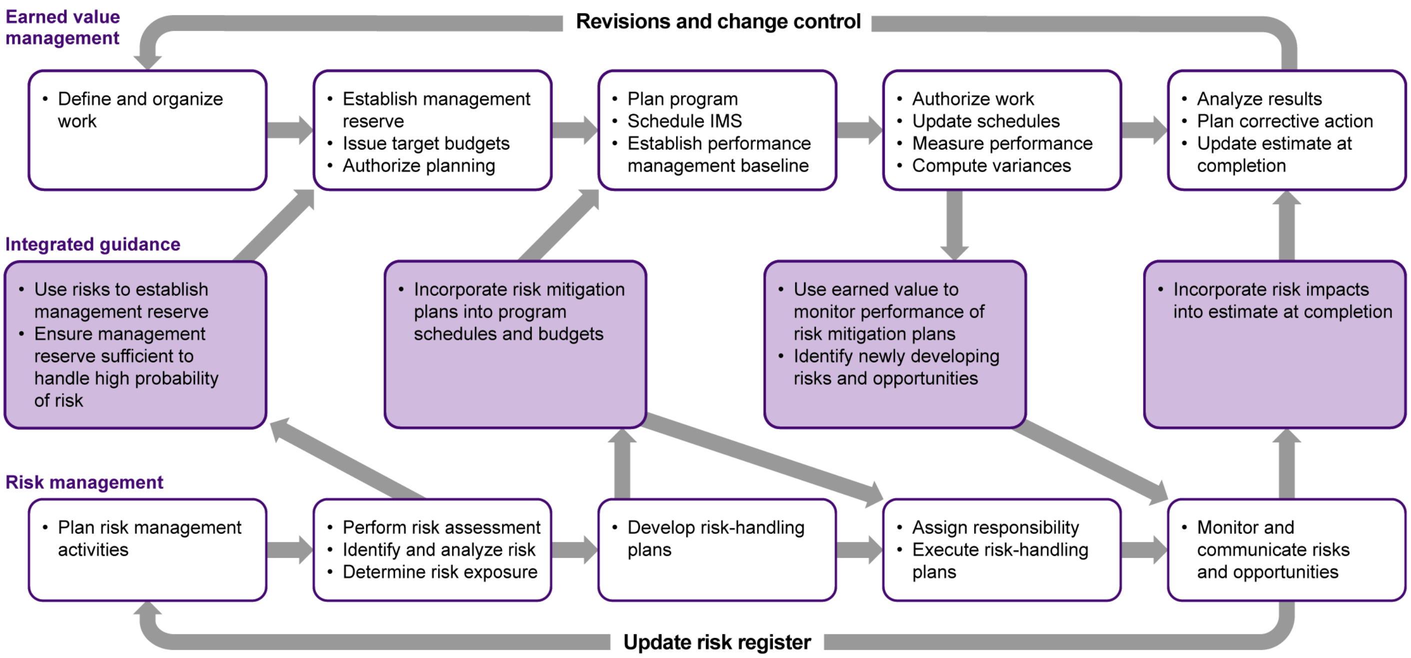
Using generally accepted risk management techniques, a program manager can decide how much management reserve budget to set aside to cover risks that were unknown at the program's start. As the program develops according to the baseline plan, metrics from the EVM system

[45] 41 U.S.C. § 3103. A similar requirement applied to the Department of Defense but was later amended to remove the 90 percent measure. 10 U.S.C. § 2220. DOD has its own major program performance oversight requirements in chapters 144 (Major Defense Acquisition Programs) of title 10 of the U.S. Code. Regarding information technology programs, agencies are required 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. 40 U.S.C. § 11317.

[46] Office of Management and Budget, *Capital Programming Guide: Supplement to Circular A-11, Part 7, Preparation, Submission, and Execution of the Budget* (Washington, D.C.: December 2019).

can be analyzed to identify risks that have been realized, as well as those that are emerging. By integrating EVM data and risk management practices, program managers can develop estimates-at-completion (EACs) for all management levels. In figure 23, EVM is integrated with risk management for a comprehensive program view.

Figure 23: Integrating Earned Value Management and Risk Management



Source: Copyright © 2018, National Defense Industrial Association (NDIA), Integrated Program Management Division, *Earned Value Management Systems Application Guide*. All rights reserved. | GAO-20-195G

Often, organizational barriers can complicate integrating the EVM and risk management processes. 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 a program faces. Doing so will promote a more thorough understanding of program risks and improve the program's response to the risks. Additionally, when the program addresses risk in the formulation of the program EVM baseline, there is a greater likelihood of program success.

Cost Estimation and EVM in System Development Oversight

Cost estimating efforts and EVM analysis should be integrated; however, government cost estimating and EVM are often conducted by different groups that rarely interact during system development. Once the cost estimate has been developed and approved, cost estimators typically move on to the next program, often without 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. Likewise, EVM analysts are usually not familiar with a program's technical baseline document, GR&As, and cost estimate data or methodology. As such, they generally start monitoring programs with incomplete knowledge of the risks associated with the underlying cost estimate.

As a result, program managers do not benefit from integrating these efforts. Limited integration can mean that:

- cost estimators may update the program estimate without fully understanding what the earned value data represent,
- 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 identified risks translate into the program's performance measurement baseline.

Therefore, it is considered a best practice to link cost estimating with 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. As a result, both groups of analysts can scope changes and present risks to management in time to address them. Analysts can compare program status 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.

Key Benefits of Implementing EVM

Table 18 describes some of the key benefits that can be derived from successfully implementing an EVM system.

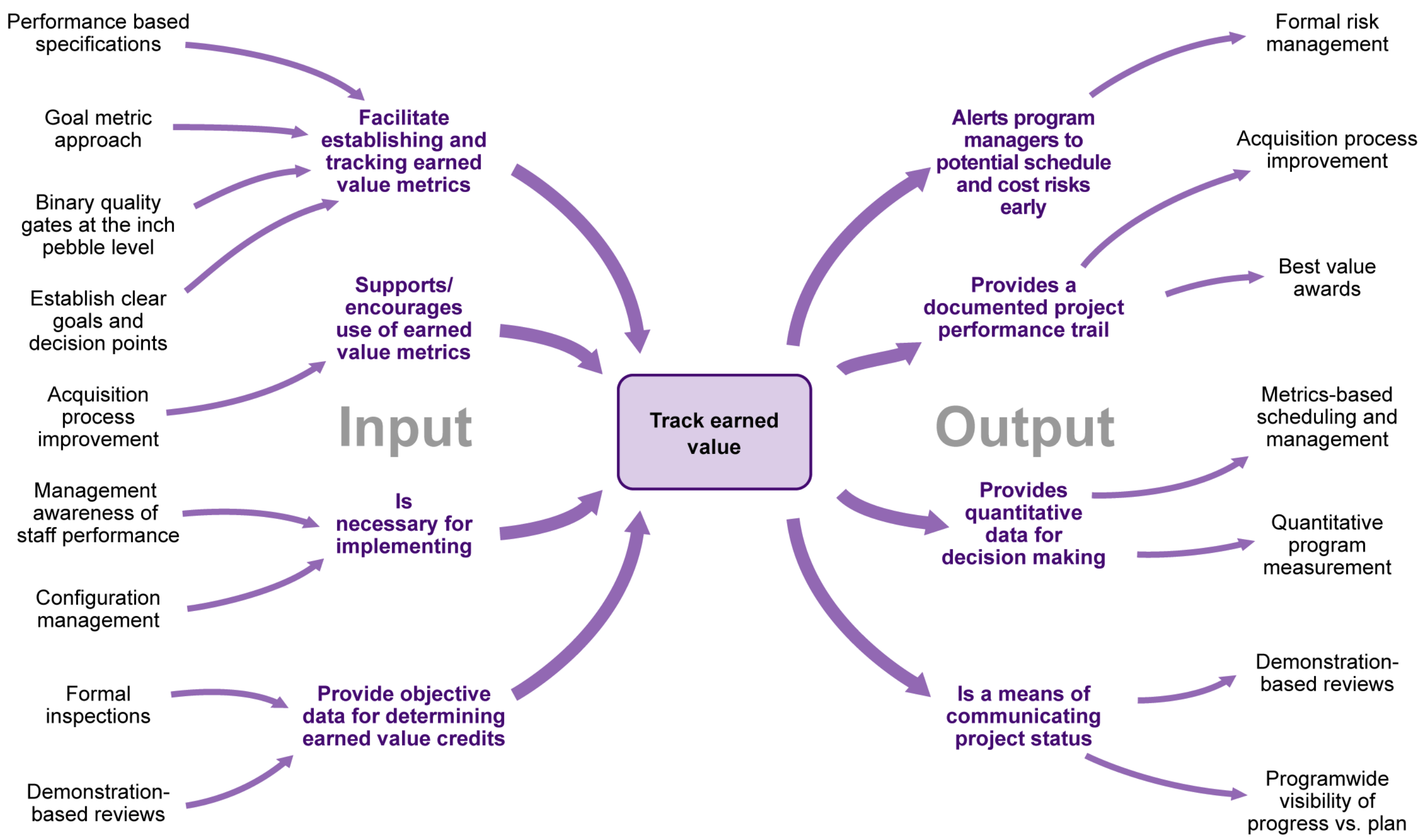
Table 18: Key Benefits of Implementing EVM

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.
Improves insight into program performance	• Enhanced insight into program performance results from the upfront planning, scheduling, and control EVM requires; this is important because the window of opportunity for correcting program problems occurs early in a program. • 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. Thus, programs operating within an EVM system can 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. Because EVM allows 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) should result in a database useful for comparative analysis, giving managers insight into how their programs perform compared to historical program data. • Data may also be used 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, and ICEAA. | GAO-20-195G

Figure 24 shows the expected inputs and outputs associated with tracking earned value.

Figure 24: Inputs and Outputs for Tracking Earned Value



Sources: DOD and GAO. | GAO-20-195G

Other Benefits of EVM

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.

Management Reporting Tool

EVM measures program status with objective methods 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. Programs should use a networked schedule that highlights the program's critical path.[47] The earned value is measured in terms of the planned cost of work actually completed. This added feature of including earned value allows for objective measurements of program status that other reporting systems cannot provide.

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, enabling 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.[48]

Obstacles to EVM

Obstacles, real or imagined, stop many programs and organizations from implementing EVM. Table 19 describes 11 common concerns about EVM implementation and discusses the basis of each one.

[47]For information on reliable integrated master schedules, see GAO, *Schedule Assessment Guide: Best Practices for Project Schedules*, GAO-16-89G (Washington, D.C.: December 2015).

[48]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 is underrunning 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.

Table 19: Eleven 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, including efforts such as performing an initial assessment, developing an implementation plan, creating compliance documentation, implementing hardware and software, establishing good cost, scheduling, and reporting systems, conducting training, and doing certification preparation. • Many companies already have some elements in place and can get certified with less effort. Even so, most of the time this is a significant investment that can translate instead into several hundred thousand dollars. Something as simple as a spreadsheet workbook with worksheets for the plan and time-stamped snapshots of status to date can serve as an effective EVM function for smaller projects. • On the other hand, companies that do establish a good EVM system realize better program management decision making and have fewer cost and schedule overruns and potentially greater repeat business. It is hard to measure what those gains amount to, but some experts have noted that the return on investment is reasonable. The smaller the company, the more difficult EVM is to implement because upfront costs may be prohibitive with their need to maintain adequate cash flow to manage the business. • Another perspective is that although an EVM system is expensive to implement, not having one may cost an organization future work because of the inability to compete with others that have a system in place. 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, taking into account the long-term effects and consequences of the implementation decision.
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 program 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 program is desirable. In some cases, for every large and high visibility program there are 10 to 20 small programs. Failure of these small programs to execute on time or within costs is as unacceptable as on large projects even though the relative impact is smaller. Several small programs can add up to a substantial loss of money and can result in the loss of larger projects or future awards if a pattern of overruns is evident. • EVM can be tailored and ingrained into the culture to ensure that program 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 risk management plans to address issues. • On the corporate side, losing money is not an acceptable option, even if the program's visibility is lower. Poor performance on a smaller program can damage a company's reputation just as much as poor performance on a large, highly visible program. Although 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 a good, practical program management tool.

Concern	Basis for concern
3. EVM practices go above and beyond basic program management practices.	• Our experts noted program managers who claim that they have been successfully managing their projects for years without EVM. Yet, when pressed to say how they ensure that cost and schedule goals are met, and how they manage their baselines along with changes, they inevitably resort to EVM by other means. • The biggest difference for successful program managers is the formality and rigor of EVM. Our experts noted that program 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 program management practices is the uniformity of data and formatting of information that makes it possible to draw comparisons against other like projects. Successful program 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 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. In many companies, this would hinder the company with respect to problem identification and corrective actions, and limit management and executive visibility into projects. • The rigor and discipline of a formal EVM system can 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 program, schedule, or EVM data, but understand enough about EVM to know how to interpret the data and evaluate the processes (planning, budgeting, executing, controlling, change control) because of this disciplined structure. • EVM practices go beyond the basics and have greater rigor and formality. This ensures uniform practices that are auditable (or verifiable) 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 and guidance.
4. EVM is merely a government reporting requirement.	• One 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 program to make sure taxpayer money is being used judiciously. • While it makes for program visibility for the government, it is primarily intended as a systematic approach to help manage a program. Reports are only as good as the data and the processes that support them; EVM serves more as a set of mandated government program management tools with reporting as a by-product.
5. Reports are a key product of EVM.	• 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 byproduct 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 program. It is a program management “process tool set” that helps ensure 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 anticipated and discussed by senior management.

Concern	Basis for concern
6. EVM is a financial management tool.	• EVM is best viewed as an enhancement to traditional financial management. EVM requirements came about largely to reduce the high percentage of cost and schedule overruns that ended up delivering to the government a product that was technically inferior. • 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 versus 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.	• Some metrics produced by an EVM system are backward looking and show performance to date, both cumulative and by period. They can help identify past trends that can be used to predict costs and schedule performance, along with the final cost of a program. • 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 program.
8. Variances EVM reveals are bad and should always be avoided.	• Variances are expected because programs rarely perform exactly to plan. Variances are neither good nor bad but simply a measure of how much actual performance has varied from the plan. • Variance thresholds quantify an acceptable range of deviation. Variances that exceed a threshold 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 program was planned, how well changes to the baseline plan are being implemented, how much planned and unplanned change has occurred since inception, and how well the program is being executed.
9. No one cares about EVM data.	• If line managers and the program manager ignore EVM data, they may not achieve cost and schedule goals. EVM data help them make the necessary midcourse adjustments based on timely and accurate program status data.
10. EVM does not help with managing a program.	• As noted in the previous nine items—especially 3, 7, 8, and 9—when managing a program, it is important to identify and manage resources to ensure that over- or under-allocations do not exist. EVM helps identify these conditions. • It helps identify and manage program risks and funding requirements to ensure that funding shortfalls do not surprise the program manager.
11. My program is using Agile software development and we do not need EVM to manage the program.	• Agile development emphasizes working software over detailed documentation, but a program still needs to develop data to report program status and performance metrics. • Many software-intensive programs also have other elements, such as hardware and program support, which also need to be tracked with performance metrics and should be managed with EVM.

Source: GAO. | GAO-20-195G

To overcome some of these obstacles and have an effective EVM system, strong leadership from the top is necessary to create a shared vision of success that brings together areas often stove-piped by organizational boundaries. Senior management should set an expectation that reliable and high-quality data are key to managing a successful program. Senior management should also show an active interest in program status so that their staff knows that they are accountable and that results matter. Accordingly, stakeholders need to take an interest in and empower those doing the work, and ensure that corporate practices are in place that allow them to accurately gauge 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.

Additionally, agencies should set forth policies that clearly define and require disciplined program management practices for EVM planning and execution. 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 policies 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. Program managers and staff need to be able to interpret and validate EVM data to effectively manage deliverables, costs, and schedules. In addition, oversight personnel and decision-makers 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.

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) jointly established a national standard for EVM systems in 1998.The most recent EVMS standard, EIA-748-D, was revised in January 2019.

OMB imposed the use of EVM for all major capital acquisitions in accordance with OMB Circular A-11 in 2006. OMB states in its 2019 *Capital Programming Guide* that all major acquisitions with development effort are to require that contractors use an EVM system that meets the EIA-748 guidelines.[49]

[49]See Office of Management and Budget, *Capital Programming Guide,* I.5.5.4, “Planning for Acquisition Management.” (Washington, D.C.: December 2019). The OMB requirements are also reflected in the FAR at 48 C.F.R. subpart 34.2.

The EVM guidelines 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 been adopted by industry, major U.S. government agencies, and government agencies in foreign countries including 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 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 EIA-748 guidelines. Several other guides are available to help agencies implement EVM systems, and they are listed in table 20.

Table 20: EVM Implementation Guides

Guide	Applicable agency	Description
DOD, OSD (AT&L), *The Program Manager's Guide to the Integrated Baseline Review Process* (Washington, D.C.: 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) Integrated Program Management Division (IPMD) *Surveillance Guide* (Arlington, VA.: November 2018).	All	Defines a standard industry approach for monitoring whether an EVM system satisfies the processes and procedures outlined in the EIA-748 guidelines
NDIA, National Defense Industrial Association (NDIA) Integrated Program Management Division (IPMD) *Earned Value Management Systems* EIA-748-D Intent Guide (Arlington, VA: August 2018).	All	Defines in detail the management value, intent, and objective evidence for all 32 guidelines. Contractors use it to assess initial compliance and perform implementation surveillance
NDIA, National Defense Industrial Association (NDIA) Integrated Program Management Division (IPMD, *Earned Value Management System Acceptance Guide* (Arlington, VA: September 2019).	All	Provides guidance and a standard framework to prepare an organization to successfully demonstrate compliance with EIA-748 guidelines
NDIA, National Defense Industrial Association (NDIA) Integrated Program Management Division (IPMD) *Earned Value Management Systems Application Guide* (Arlington, VA: May 2018).	All	Defines a standard approach for all organizations implementing an EVM system through all phases of acquisition
DOD, OUSD AT&L (PARCA), *Earned Value Management System Interpretation Guide* (Washington, D.C.: February 2015).	DOD	Provides the basis to be used for the Department of Defense to assess EVM compliance with the EIA-748 guidelines

Guide	Applicable agency	Description
DOE, *Earned Value Management System* (EVMS), DOE G 413.3-10A (Washington, D.C.: March 2012).	DOE	Provides approaches for implementing the EVMS requirements of DOE 413.3B in compliance with EIA-748 guidelines
Federal Aviation Administration, *Earned Value Management Guide* (Washington, D.C.: March 2012).	FAA	Provides implementation guidance for EVM systems use on FAA programs and contracts
Federal Aviation Administration, *Earned Value Management System Acceptance Guide* (Washington, D.C.: March 2012).	FAA	Provides guidance for the review, validation and formal acceptance of EVM systems for use on FAA programs
Federal Aviation Administration, *Program Performance Surveillance Guide* (Washington, D.C.: March 2012).	FAA	Provides procedures for conducting program performance surveillance of FAA programs

Source: GAO. | GAO-20-195G

Chapter 18: Earned Value Management: Process

As we noted in the previous chapter, earned value management (EVM) data allow management to track deviations from a program's plan for prompt understanding of problems. Proactive management of program performance increases the likelihood that a program will achieve its goals on time and within the expected cost. In this chapter, we discuss the EVM process, including the development of the program management baseline, tracking of program progress, and analyzing EVM data to manage performance and predict results.

EVM Process

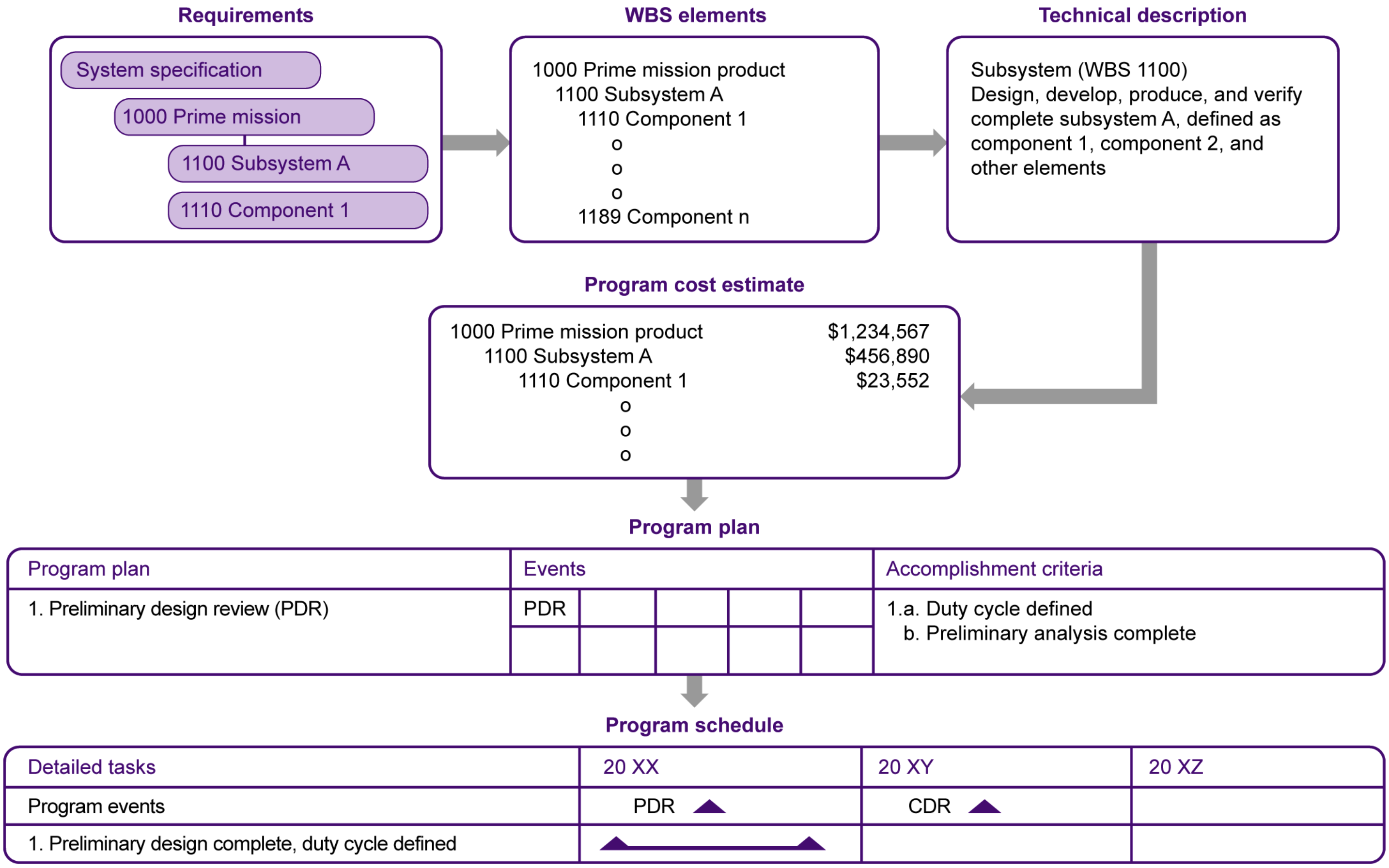
The EVM process can be broken down into thirteen fundamental activities, outlined and described in this section:

1. define the scope of effort with a WBS;
2. identify who in the organization will perform the work;
3. schedule the work to a timeline;
4. estimate resources and authorize budgets;
5. determine objective measures 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 performance measurement baseline (PMB) plan;
9. forecast estimates-at-completion (EACs) using EVM;
10. conduct an integrated cost-schedule risk analysis;
11. compare EACs from EVM (9) with EAC from risk analysis (10);
12. take management action to respond to risks; and
13. update the performance measurement baseline as changes occur.

1: Define the Scope of Effort with a WBS

The WBS is a critical component of EVM that defines the work to be performed. It should be the basis of the cost estimate and the program schedule. In the schedule, activities traceable to 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. Figure 25 shows a breakdown of the overall program plan.

Figure 25: Work Breakdown Structure Integration of Cost, Schedule, and Technical Information



Source: Copyright © 2018, National Defense Industrial Association (NDIA), Integrated Program Management Division, *Earned Value Management Systems Application Guide*. | GAO-20-195G

Note: CDR = critical design review.

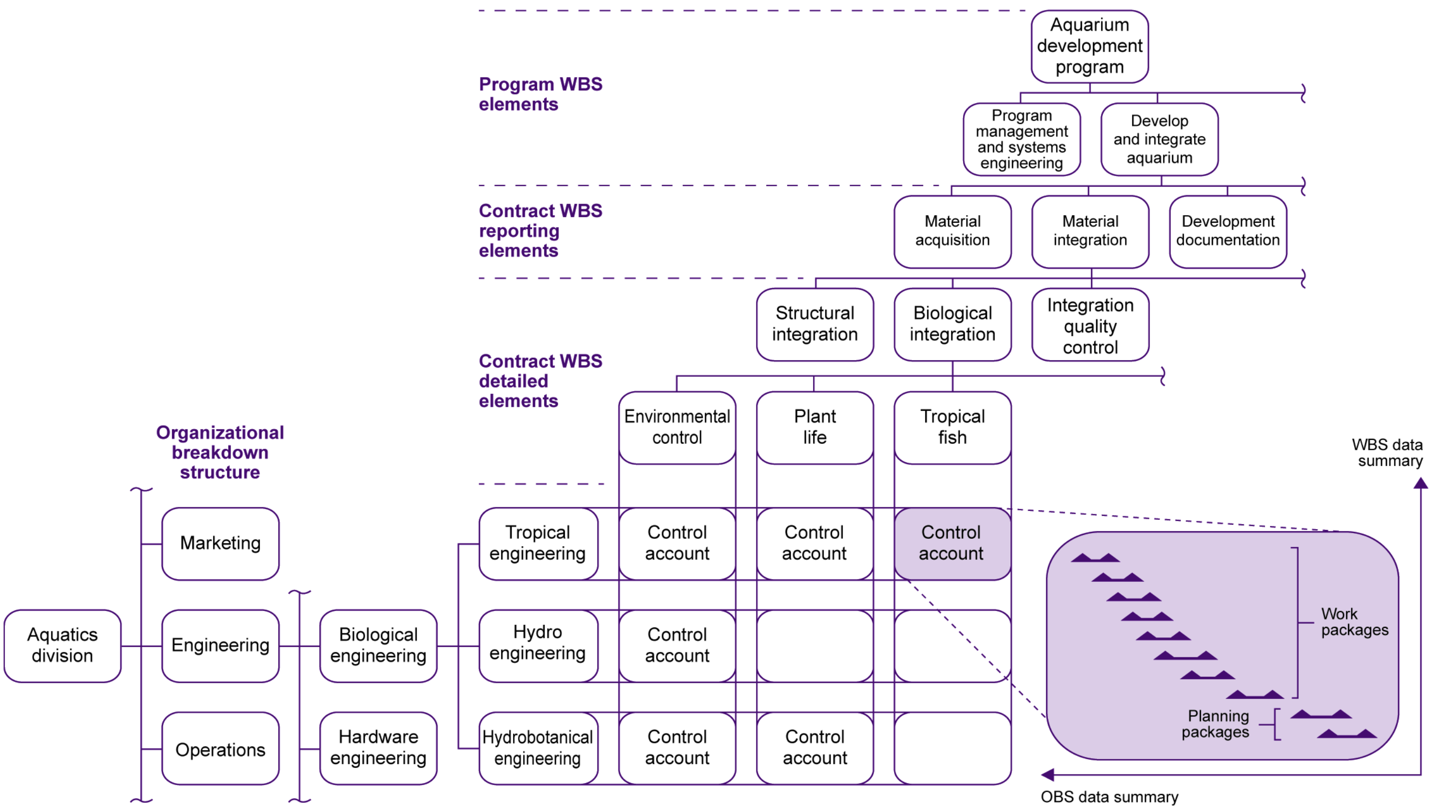
The hierarchical WBS ensures that the entire statement of work accounts for the detailed technical tasks and facilitates communication between the customer and supplier on cost, schedule, technical information, and the progress of the work. It is important that the WBS is comprehensive enough to represent the entire program at a level of detail sufficient to manage the size, complexity, and risk associated with the program. Furthermore, there should be only one WBS for each program. It should match the WBS used for the cost estimate and schedule so that actual costs can be fed back into the estimate and schedule. While costs are usually tracked at lower levels of the WBS, what is reported in an EVM system is usually summarized at a higher level. Because of its hierarchical structure, the WBS can be expanded to different degrees of detail so that problems can be identified and tracked at various levels.

2: Identify Who in the Organization Will Perform the Work

Once the WBS has been established, the next step is to assign someone to do the work. An organizational breakdown structure (OBS) is used to show who is assigned each task. To ensure that someone is accountable for every WBS element and its associated tasks, it is useful to determine levels of accountability, or control accounts, at the points of intersection between the OBS 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 26 shows how control accounts are determined. The WBS is shown at the top, including program elements, contract reporting elements, and detailed elements. The left-hand side of the figure shows the OBS. The control accounts lie in the center of the figure, where the WBS and OBS 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 control account has a control account manager who is assigned responsibility for managing and completing the work.

Figure 26: Identifying Responsibility for Managing Work at the Control Account



Source: ICEAA (International Cost Estimating and Analysis). Cost Estimating Body of Knowledge. Vienna, Va.: 2013. | GAO-20-195G

Note: WBS = work breakdown structure.

A control account manager is responsible for managing, tracking, and reporting earned value data 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 in duration—are defined by who authorizes the task and how the work will be measured and tracked. Work packages reflect near-term effort and require specific effort to meet control account objectives. Planning packages represent far-term work and are 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 in a process called “rolling wave” planning. Rolling wave planning is described later in the chapter.

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 included as a separate work package. Doing this accounts for a reasonable amount of rework while preserving the ability to track variances. Using this approach, programs should include rework in the budget baseline because they acknowledge effort that is bound to involve revision, such as design.

3: Schedule the Work to a Timeline

Developing a schedule provides a time sequence for the program’s activities. A program schedule also provides the vehicle for developing a time-phased budget baseline. The typical method of scheduling is the critical path method, implemented in standard scheduling software packages. The critical path method is used to derive the critical activities—that is, activities that cannot be delayed without delaying the end date of the program.[50]

Because some costs, such as labor, supervision, rented equipment and facilities, and other program elements typically cost more when 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 the schedule is of high quality, it shows the logical relationships between program activities, and includes activity resource requirements and realistic durations. 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. A detailed schedule can be used to identify where problems are or could potentially be. Moreover, as changes occur within a program, if the schedule is kept up to date (well-statused), it will aid in analyzing how the changes affect the program.

A 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. We

[50]GAO, *Schedule Assessment Guide: Best Practices for Project Schedules*, GAO-16-89G (Washington, D.C.: December 2015), 6.

have identified the following ten best practices associated with a high-quality and reliable schedule:

- Capturing all activities. The schedule should reflect all activities as defined in the program's work breakdown structure (WBS), which defines in detail the work necessary to accomplish a program's objectives, including activities both the owner and contractors are to perform.
- Sequencing all activities. The schedule should be planned so that critical program dates can be met. To do this, activities must be logically sequenced and linked—that is, listed in the order in which they are to be carried out and connected to other activities to show schedule dependencies. In particular, a predecessor activity must start or finish before its successor. Date constraints and lags should be minimized and justified. This helps ensure that the interdependence of activities that collectively lead to the completion of activities or milestones can be established and used to guide work and measure progress.
- Assigning resources to all activities. The schedule should reflect the resources (labor, materials, travel, facilities, equipment, and the like) needed to do the work, whether they will be available when needed, and any constraints on funding or time.
- Establishing the duration of all activities. The schedule should realistically reflect how long each activity will take. When the duration of each activity is determined, the same rationale, historical data, and assumptions used for cost estimating should be used. Durations should be reasonably short and meaningful, and should allow for discrete progress measurement. Schedules that contain planning and summary planning packages as activities will normally reflect longer durations until broken into work packages or specific activities.
- Verifying that the schedule can be traced horizontally and vertically. The schedule should be horizontally traceable, meaning that it should link products and outcomes associated with other sequenced activities. Such links are commonly referred to as "hand-offs" and serve to verify that activities are arranged in the right order for achieving aggregated products or outcomes. The schedule should also be vertically traceable—that is, data are consistent between different levels of a schedule. When schedules are vertically traceable, lower-level schedules are clearly consistent with upper-level schedule milestones, allowing for total schedule integrity and enabling different teams to work to the same schedule expectations.

- Confirming that the critical path is valid. The schedule should identify the program's critical path—the path of longest duration through the sequence of activities. Establishing a valid critical path is necessary for examining the effects of any activity's slipping along this path. The program's critical path determines the program's earliest completion date and focuses the team's energy and management's attention on the activities that will lead to the program's success.
- Ensuring reasonable total float. The schedule should identify reasonable total float (or slack)—the amount of time a predecessor activity can slip before the delay affects the program's estimated finish date—so that the schedule's flexibility can be determined. The length of delay that can be accommodated without the finish date slipping depends on the number of date constraints within the schedule and the degree of uncertainty in the duration estimates, among other factors, but the activity's total float provides a reasonable estimate of this value. As a general rule, activities along the critical path have the least total float. Unreasonably high total float on an activity or path indicates that schedule logic might be missing or invalid.
- Conducting a schedule risk analysis. A schedule risk analysis starts with a good critical path method schedule. Data about program schedule risks are incorporated into a statistical simulation to predict the level of confidence in meeting a program's completion date; to determine the contingency, or reserve of time, needed for a level of confidence; and to identify high-priority risks. Programs should include the results of the schedule risk analysis in constructing an executable baseline schedule.
- Updating the schedule using actual progress and logic. Progress updates and logic provide a realistic forecast of start and completion dates for program activities. Maintaining the integrity of the schedule logic is necessary for the schedule to reflect the true status of the program. To ensure that the schedule is properly updated, people responsible for the updating should be trained in critical path method scheduling.
- Maintaining a baseline schedule. A baseline schedule is the basis for managing the program scope, the time period for accomplishing it, and the required resources. The baseline schedule is designated the target schedule and is subjected to a configuration management control process. Program performance is measured, monitored, and reported against the baseline schedule. The schedule should be continually monitored so as to reveal when forecasted completion dates differ from baseline dates and whether schedule variances affect downstream work. A corresponding basis document explains

the overall approach to the program, defines custom fields in the schedule file, details ground rules and assumptions used in developing the schedule, and justifies constraints, lags, long activity durations, and any other unique features of the schedule.

For further discussion of these scheduling best practices, see GAO's *Schedule Assessment Guide*.[51]

4: Estimate Resources and Authorize Budgets

Budgets should be authorized as part of the EVM process, as well as the resources needed to do the work. In activity 3, we discussed how the schedule is resource loaded. Resources 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. This feeds directly into the EVM process and should tie back to the cost estimate methodology.

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 allocate budget to mitigate problems and control programs. However, it can be applied only to in-scope work and cannot be used to offset or minimize existing cost variances.

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. Two key issues associated with management reserve are how much should be provided to the program and how it should be controlled. 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. One way to derive 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). Risk and uncertainty analysis should be used to specify the probability that work will be

[51]GAO, *Schedule Assessment Guide: Best Practices for Project Schedules*, GAO-16-89G (Washington, D.C.: December 2015).

performed within budget. The likelihood of meeting the budget can then be increased by establishing sufficient management reserve budget.

Controlling management reserve is also important. 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.

5: Determine Objective Measures 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 21 describes several acceptable, frequently used methods for determining earned value performance.

Table 21: Typical Methods for Measuring Earned Value Performance

Method	Description
Fixed formula (0/100, 50/50, 25/75, etc.)	A specified percentage of the earned value is assigned to the start milestone of the work package. The remaining earned value is assigned when the work is complete. Used for smaller work packages planned to start and end within two reporting periods. The 0/100 technique should only be used on work packages planned to start and end within one reporting period. This technique is commonly used for receipt of materials.
Percent complete	Performance is measured by an estimate of the percentage of work completed. This should be based on objective and quantifiable work completion. The percent complete for each work package is the cumulative value of the work accomplished to date divided by the total budget for the work package.
Weighted milestone	This method divides the work package into measurable segments, each ending with an observable milestone. A weighted value is assigned to the completion of each milestone. This method is more suitable for longer duration work packages that have intermediate and tangible results. For the most effective use, the method requires at least one interim milestone for each reporting period.
Physical measurement	Measurement can include any units that can be explicitly related to the completion of work. Examples may include length of cable laid, quantity of concrete poured, or the quantity of similar units.

Source: Project Management Institute, Inc. *Practice Standard for Earned Value Management*, Second Edition, 2011. | GAO-20-195G

No single method for measuring earned value status is perfect for every program. Several WBS elements may use different methods. It is important that the method be the most objective approach for measuring true progress.

Two other methods used to measure earned value include level of effort and apportioned effort. Both are subjective, however, and should only be used when no other method discussed in the table above is applicable. Level of effort reflects earned value for activities that are merely related to the passage of time and have no physical products or defined deliverables. One example is program management. Level of effort should be used sparingly; programs that report a high amount of 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 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.

Apportioned effort is work that by itself is not readily divisible into short-span work packages but is related in direct proportion to an activity or activities with discrete measured effort. Apportioned effort work packages can be as discretely defined as individual work packages, but apportioned effort tasks are unique because they are closely dependent on another distinct work package. Examples include quality control responsibilities associated with pipefitting or pouring concrete. These quality control activities should span their dependent activities and their earned value should be based on the related activities' earned value.

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

Status date

	Tasks	Week 1	Week 2	Week 3	Week 4	Performance: Task budget	Task % complete	Earned value
1	Set steel columns and beams					$125	100%	$125
2	Install first floor joists and decking					$250	100%	$250
3	Frame first floor walls; install wall sheathing					$720	25%	$180
4	Install roof trusses					$240	0%	$0
5	Install roof decking					$280	0%	$0
6	Inspect rough-in framing					$100	0%	$0
7	Framing complete					$10	0%	$0
8								
9	Total project					$1,725		$555

Scheduled milestones/activities

Completed milestones/activities

Source: GAO. | GAO-20-195G

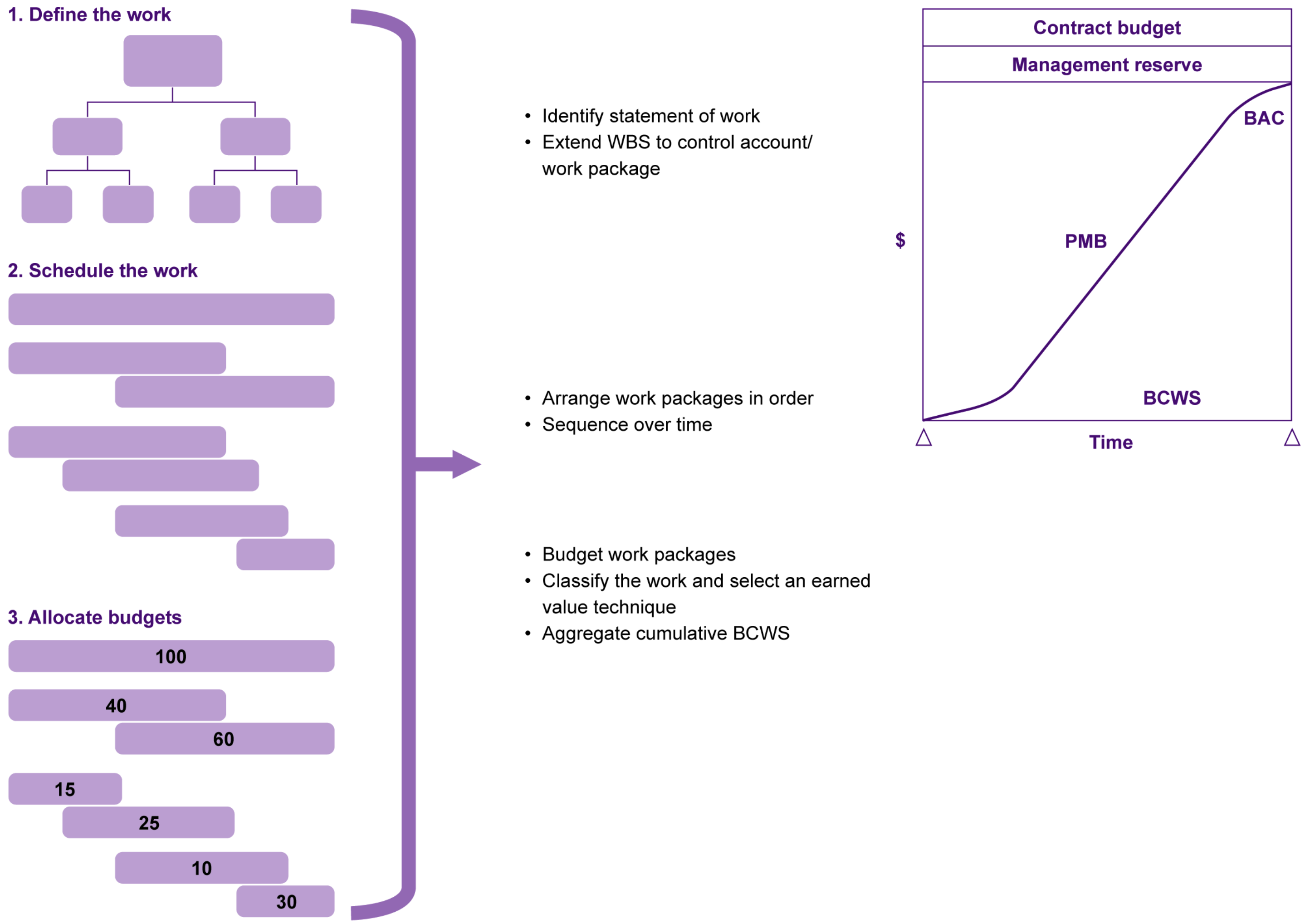
Figure 27 displays how planned effort is compared with work accomplished. It also shows how earned value represents the budgeted value of the work completed and directly relates to the percentage complete of each activity.

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 provides management with a better view of program risks and better information for understanding what resources are needed to complete the program.

6: 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 sequence, based on finite resources, with budgets representing those resources spread over time. The performance measurement baseline is 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 the performance measurement baseline integrates cost, schedule, and technical effort into a single baseline.

Figure 28: The Genesis of the Performance Measurement Baseline



Source: Copyright © 2005 MCR, LLC, "Using Earned Value Data." All rights reserved. | GAO-20-195G

Note: BCWS = budgeted cost for work scheduled; BAC = budget at complete; PMB = performance measurement baseline; WBS = work breakdown structure.

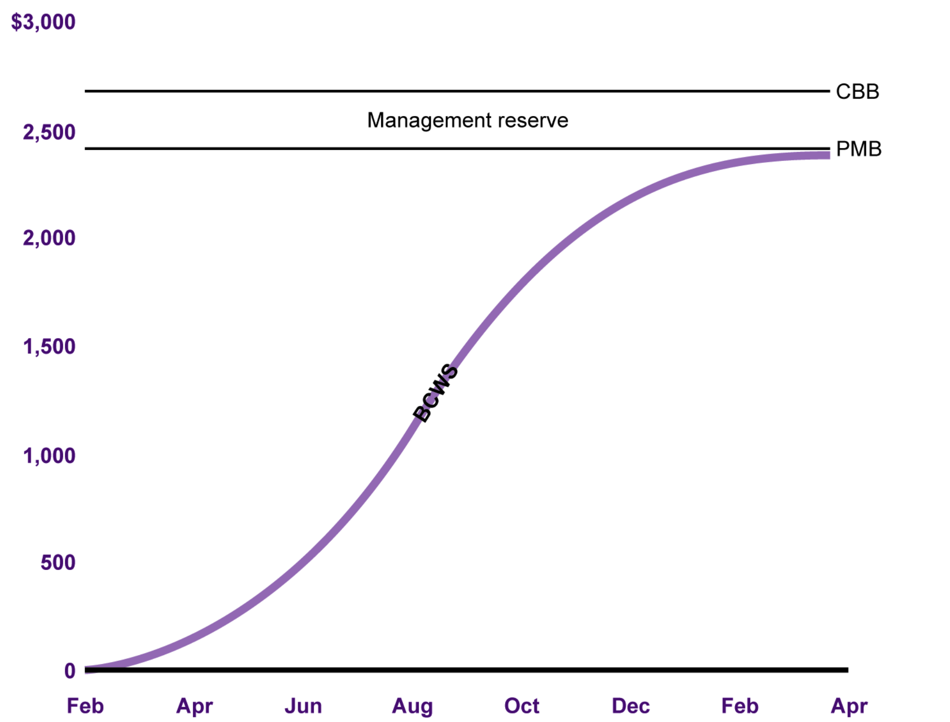
The performance measurement baseline includes all budgets for resources associated with completing the program, including direct and indirect labor, material, and other direct costs associated with the authorized work.

The performance measurement baseline includes any undistributed budget. Undistributed budget is used as a short-term holding account for new work; it is distributed to a control account once the work is planned in detail. To 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 include management reserve or any fee and thus does not equal the program contract value. Because the budget for management reserve is accounted for outside the performance measurement baseline, it cannot be associated with any particular effort. Once a risk is realized and recovery actions identified, then the management reserve is distributed to the appropriate control account. The management reserve and performance measurement baseline values together make up the contract budget base which in turn represents the total cost of the work. Fee is added to the contract budget base to reflect the total contract price.

Figure 29 depicts a typical time-phased cumulative performance measurement baseline that follows the shape of an S curve. It portrays 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.

Figure 29: The Time-Phased Cumulative Performance Measurement Baseline



Source: ICEAA (International Cost Estimating and Analysis). Cost Estimating Body of Knowledge. Vienna, Va.: 2013. | GAO-20-195G

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:

- 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, putting the program at risk of severe overrun in later phases.
- The performance measurement baseline can become a rubber baseline—that is, a continual shift of the baseline budget to match actual expenditures in order to mask cost variances. This results in deceptive baselines by covering up variances early in the program, delaying insight until they are difficult, if not impossible, to mitigate.
- The performance measurement baseline can become outdated if changes are not incorporated quickly. As a result, variances do not

reflect reality, which hampers management in realizing the benefits of EVM.

7: Execute the Work Plan and Record All Costs

For this activity, 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, material costs should be accurately charged to control accounts using recognized and acceptable techniques to keep variances due to accounting accrual issues to a minimum.

8: Analyze EVM Performance Data and Record Variances from the Performance Measurement Baseline Plan

Because all programs 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. Cost and schedule variances should be examined periodically with management's focus on variances with the most risk to the program. This means that EVM data should be regularly reviewed if they are to be of any use. In addition, management must identify solutions for problems early if there is any hope of averting degradation of program performance.

9: Forecast Estimates at Completion Using EVM

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; however, some organizations will also conduct periodic bottom-up estimating.

10: Conduct an Integrated Cost-Schedule Risk Analysis

A schedule can be used, in combination with risk analysis data (often including traditional 3-point estimates of duration or the impact of risk drivers) and Monte Carlo simulation software, to estimate schedule risk and the EAC. Risk analysis uses data that represent the probability that risks will occur and estimates of the risks' impact on the schedule and cost. Although historical data can be used, much of the risk analysis data is derived from interviews and workshops.

Using the results of the schedule risk analysis, the cost elements that relate to time uncertainty (labor, management, and rented facilities) can be linked directly to the uncertainty in the schedule. The schedule risk analysis provides quantification of risk and uncertainty related to time-dependent cost elements in addition to an estimate of when the program may finish and the identification of key risk drivers. These results can be exported to a spreadsheet where cost models and estimates are often developed and stored. The cost risk and uncertainty 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 because it converts time to a cost estimate by using labor and associated rates along with any material costs.

The GAO *Schedule Assessment Guide* has more details on performing a schedule risk analysis.[52]

11: Compare EACs from EVM with EAC from Risk Analysis

This activity demonstrates the integration of EVM and risk management processes. 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 comparison is valuable because it is performed on EACs created with quite different approaches. If different approaches produce results that are in general agreement, their EAC forecasts are probably sound. If not, one or the other method (or both) should be reviewed for changes and revisions.

12: Take Management Action to Respond to Risk

Management should integrate the results of information from activities 8 through 11 with the program's risk management plan to respond to emerging and existing risks. Management should focus on responses 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.

13: Update the Performance Measurement Baseline as Changes Occur

While the 32 EIA-748 guidelines are for the overarching goal of maintaining the integrity of the baseline and the resulting performance measurement data, changes are likely throughout the life of the program. 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 changes 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 the changes into the

[52]GAO, *Schedule Assessment Guide: Best Practices for Project Schedules*, GAO-16-89G (Washington, D.C.: December 2015).

performance measurement baseline. A detailed record of the changes made to the performance measurement baseline makes it easy to trace them to the program. This also lessens the burden on program personnel when compiling information for internal and external program audits, EVM system 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.

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, such 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.

Because 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.

Case study 23 highlights a program in which a performance measurement baseline was not representative of a program's external commitments.

Case Study 23: Performance Measurement Baseline Data, from *Space Launch System*, GAO-15-596

The Space Launch System (SLS) is National Aeronautics and Space Administration's (NASA) first heavy-lift launch vehicle for human space exploration in over 40 years. For development efforts related to the first flight of SLS, NASA established its cost and schedule commitments at $9.7 billion and November 2018. The program, however, had continued to pursue more aggressive internal goals for cost and schedule.

NASA was using contractor earned value management (EVM) data as an additional means to monitor costs for SLS, but the EVM data remained incomplete and provided limited insight into progress toward the program's external committed cost and schedule baselines. Program officials indicated that the SLS contractor performance measurement baselines—which established the program scope, schedule, and budget targets to measure progress against—were based on the program's more aggressive internal goal for launch readiness for EM-1 in December 2017 and not its external committed date of November 2018.

Both contractor and program-level EVM data were only reported relative to the December 2017 date, according to program officials. The potential impact of cost and schedule growth relative to the program's external committed cost and schedule baseline of November 2018 was neither reported nor readily apparent, and rendered the EVM data less useful in support of management decisions and external oversight. Major NASA programs are required by statute to report annually to certain congressional committees on changes that occurred over the prior year to the programs' committed cost and schedule baselines, among other things. As this report reflects cost and schedule overruns that have already occurred, it does not serve as a mechanism to regularly and systematically track progress against committed baselines so that decision-makers have visibility into program progress and can take proactive steps as necessary before cost growth or schedule delays are realized.

By pursuing internal launch readiness dates that were unrealistic, the program left itself and others in a knowledge void wherein progress relative to the agency's commitments was difficult to ascertain. As the EVM system only tracked progress toward the program's internal goals, the program lacked a mechanism to track progress to its external cost and schedule baseline commitments. Without such a tracking tool, stakeholders lacked early insight into potential overruns and delays.

GAO, *Space Launch System: Management Tools Should Better Track to Cost and Schedule Commitments to Adequately Monitor Increasing Risk*, GAO-15-596 (Washington, D.C.: July 16, 2015).

Chapter 19: Earned Value Management: Execution

In the previous chapter, we discussed the 13 fundamental steps in the EVM process and the EVM best practices. Next, we will expand upon some of the steps and provide more detail on executing EVM. First, we cover the validation of the performance measurement baseline through the conduct of the integrated baseline review. Second, we discuss contract performance reports, how to use them to analyze EVM performance data, and describe the monthly analysis that should be performed. Next, we cover the projection of future performance through the calculation and use of estimates-at-complete. We describe the presentation of EVM analysis to management, and the continual updating of the program cost estimate to reflect actual data and reasons for any variances until the program is completed.

Validating the Performance Measurement Baseline and Integrated Baseline Reviews

Just as EVM supports risk management by identifying problems when there is still time to act, so an integrated baseline review (IBR) helps program managers fully understand the detailed plan to accomplish program objectives and identify risks so they can be included in the risk register and closely monitored. The goal of the IBR is to verify, prior to or soon after contract award, if the performance measurement baseline is realistic. The IBR should assist in aiding the contractor and government in mutually understanding program scope, schedule, and risks, and verify that the baseline's budget and schedule are adequate for performing 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 in an unrealistic baseline for performance measurement.

Conducting an IBR increases 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.

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 requires agencies to conduct IBRs prior to award or as soon as possible after award, and whenever there is a major modification to a program. OMB states the purposes of the IBR are to:

- Track, manage, and report risk associated with the program;
- Develop the risk management requirements; and
- Identify new risks associated with the program and develop necessary mitigation/contingency strategies.

Experts agree that it is a best practice for the government and prime contractor to partner in conducting an IBR on every major subcontract in conjunction with the prime contract IBR. This practice is especially important because subcontracts can make up a substantial portion of the prime contract. The increasing roles and responsibilities assumed by subcontractors in these contracts make the accuracy of subcontractor EVM data that much more significant.

Review of the Performance Measurement Baseline

The performance measurement baseline (PMB) represents the time-phased budget plan against which program performance is measured for the life of the contract. 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.

The IBR examines the performance measurement baseline to determine 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 is realistic. 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?

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 and near-critical 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. More information on how to perform an IBR is found in appendix IX.

After the PMB is validated, 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 the PMB is not validated, there should be less confidence in the accuracy and soundness of monthly EVM reporting.

Management Processes

After the PMB is completed and validated, the focus should be on the ongoing ability of management processes to record actual program performance and detect program risks. A 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 processes should occur:

- 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, classify, and quantify 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 such as scheduling, developing estimates to complete, and EVM analysis, so that risks may be monitored and detected throughout the life of the program.

Contract Performance Reports

Once the IBR is completed and the PMB is validated, EVM data can be collected and used to assess performance and project costs at completion. EVM data are typically summarized in a standardized contract performance report (CPR). A CPR is the primary source for program cost and schedule status and provides the information needed for effective program control. A CPR provides cost and schedule variances, comparing actual performance against the plan, which can be further examined to understand the causes and the degree of impact on the program. Management can use this information 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.

Periodically reviewing CPR data helps track program progress, risks, and plans for activities. Because 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.

Management should use the EVM data captured by the CPR to:

- integrate cost and schedule performance data with technical performance measures,
- identify the magnitude and impact of actual and potential problem areas causing significant cost and schedule variances, and
- provide valid and timely program status to senior management.

As a management report, the CPR provides a timely, reliable summary of EVM data to assess current and projected contract performance. The primary value of the CPR 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 these to 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.

There are five parts, or formats, to a CPR.[53] Each format should be tailored to ensure that information essential to management on cost and schedule is collected from contractors. The data reported in each format should be consistent with each other.

- 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

[53]DOD's Integrated Program Management Report (IPMR) DI-MGMT-81861A replaces the standard CPR. It includes a format 6, which is the integrated master schedule and a format 7 which is an electronic history and forecast file that provides information intended to supplement format 5. Other agencies, such as DOE, may also use the IPMR format.

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. It need not be obtained, for example, when a contractor does not manage along organizational 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 look forward and should be correlated with the cost estimate.
- Format 4 forecasts the staffing levels by functional category required to complete the contract, and is an essential component to evaluating the EAC. This format—also forward looking—allows the analyst to correlate the forecasted 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 is conducted on the CPR's format 1 and format 5. Format 1 is used to examine lower-level control account status to determine lower-level variances. Format 5 contains descriptions of causes for variances in format 1.

Table 22 describes some of the major data elements in format 1.

Table 22: 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. This is the definitized contract target cost for an incentive-type contract[a] Changes to the estimated cost consist only of estimated amounts for changes in the contract scope of work.
Estimated cost of authorized, unpriced work	The work that has been authorized in writing but for which the contract price has not been definitized. Excludes fee or profit.
Budget at completion (BAC)	The sum of the estimated budgets for all cost elements. At lower-levels, such as a control account or WBS element, it represents the budgeted cost for the individual element.

Data element	Description
Estimated cost at completion (EAC)	The latest revised estimate of cost at completion including estimated overruns and underruns for all authorized work. It is calculated by adding the forecasted cost of work remaining (budgeted cost for work remaining) to actual costs using an appropriate forecasting method. Contractors are typically required to provide three EACs – a best case, a worst case, and a most likely case.
Variance at completion	Variance at completion is the difference between the BAC and EAC. Program variance at completion is the sum of variance at completion for all cost elements.
Performance data[b]	
Budgeted cost for work scheduled (BCWS)	The sum of the budgets for all work packages and planning packages scheduled to be accomplished within a given time period.
Budgeted cost for work performed (BCWP)	The sum of the budgets for completed work and completed portions of ongoing work within a given time period.
Actual cost of work performed (ACWP)	The costs actually incurred and recorded in the earned value management system for accomplishing the work performed within a given time period.
Cost variance	The difference between BCWP and ACWP. Cost variance measures work accomplishment compare with actual costs. A positive number is favorable an d indicates that work was completed under budget. A negative number indicates that more money was spent to complete a task than was budgeted for the task.
Schedule variance	The difference between BCWP and BCWS. It measures work accomplishment compared with the work planned. A positive number indicates that planned work was completed ahead of schedule and a negative number indicates that the work was not completed as planned.[c]
Budgeted cost for work remaining	The planned work that still needs to be completed. It is the difference between the BCWP and the BAC.

Source: DOD. | GAO-20-195G

[a]Definitized cost or price = contract cost or contract price that has been negotiated.

[b]Some texts on earned value management use different terms for earned value parameters. We use BCWS (budgeted cost of work scheduled), ACWP (actual cost of work performed), and BCWP (budgeted cost of work performed.) Others use PV (planned value), AC (actual cost), and EV (earned value), respectively.

[c]Schedule variance in EVM analysis is expressed in dollar units, not time. Using EVM data, schedule variance reflects the fact that scheduled work has a budget; that is, work takes time to complete and requires resources such as money. Schedule variance should be assessed for whether the delay is occurring on the critical path.

Management can detect problems using the measures in format 1 at the control account level. The sooner a problem is detected, the easier it is to avoid or reduce its effects. However, it is also critical to know what is causing the problem. The purpose of format 5 of the CPR is to provide necessary insight into problems. Format 5 focuses on the corrections needed to avoid future cost overruns and schedule delays or the changes to cost and schedule forecasts when corrective action is not possible. In addition, format 5 describes the causes of variances and future risks and challenges. To provide good insight into problems, format 5 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.

Format 5 should also discuss in detail each cost or schedule variance, including its nature and causes, its effect on immediate tasks and the total program, corrective actions taken or planned, the associated WBS number, and whether it is driven primarily by labor or material.

In summary, the format 5 variance report should provide enough information for management to understand the reasons for variances and the contractor's response to them. It is critical for good information to be available on variances if EVM data are to have any value. If format 5 does not contain good information, then the EVM data will not be as useful as a management tool, as case study 24 illustrates.

Case Study 24: Cost Performance Reports, from Defense Acquisitions, GAO-05-183

The U.S. Navy invests significantly to maintain technological superiority of its warships. In 2005 alone, $7.6 billion was devoted to new ship construction in six ship classes—96 percent of which was allocated to four classes: Arleigh Burke class destroyer, Nimitz class aircraft carrier, San Antonio class amphibious transport dock ship, and the Virginia class submarine. For the eight ships GAO assessed, the Congress had appropriated funds to cover a $2.1 billion increase in the ships' budgets. GAO's analysis indicated that total cost growth on these ships could reach $3.1 billion or even more if shipyards did not maintain current efficiency and meet schedules.

While DOD guidance allows some flexibility in program oversight, GAO found that reporting on contractor performance was inadequate to alert the Navy to potential cost growth for the eight case study ships. With the significant risk of cost growth in shipbuilding programs, it is important that program managers receive timely and complete cost performance reports from the contractors. However, earned value management—a tool that provides both program managers and the contractor insight into technical, cost, and schedule progress on their contracts—was not used effectively. Cost variance analysis sections of the reports were not useful in some cases because they only described problems at a high level and did not address root causes or what the contractor plans were to mitigate them.

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.

GAO recommended that, to improve management of shipbuilding programs and promote early recognition of cost issues, the Secretary of Defense should direct the Secretary of the Navy to require shipbuilders to prepare variance analysis reports that identify root causes of reported variances, associated mitigation efforts, and future cost impacts. The Undersecretary of Defense for Acquisition, Technology, and Logistics directed components of the Department of Defense (DOD), including the Navy, to conduct a comprehensive review of earned value management system policies and practices in order to help improve the quality of cost and schedule reporting and surveillance in DOD programs. This review was intended to address recent audit findings and other identified deficiencies, such as the quality of variance analysis reports.

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

The level of detail for format 5 is typically determined by specific variance analysis thresholds which, if exceeded, require 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 effects on program performance are transparent.

Periodic 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 lessened. Some labor intensive programs review the data weekly, using labor hours as the measurement unit, to 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. As we have noted in previous chapters, 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 can 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. CPR data can answer the following questions:

- How much work should have been completed by now—that is, what is the budgeted cost for work scheduled (BCWS)?
- How much work has been done—that is, what is the earned value or budgeted cost for work performed (BCWP)?
- How much has the completed work cost—that is, what is the actual cost of work performed (ACWP)?

- What is the planned total program cost—that is, what is the budget at completion (BAC)?
- What is the program expected to cost, given what has been accomplished—that is, what is the estimated cost at completion (EAC)?

Analyzing the past performance captured in the CPR can provide 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. This information should be provided to managers and stakeholders on a regular basis, such as in program briefings, and be traceable back to the CPR formats. 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.

Figure 30 is an example of a 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 30: Monthly Program Assessment Using Earned Value

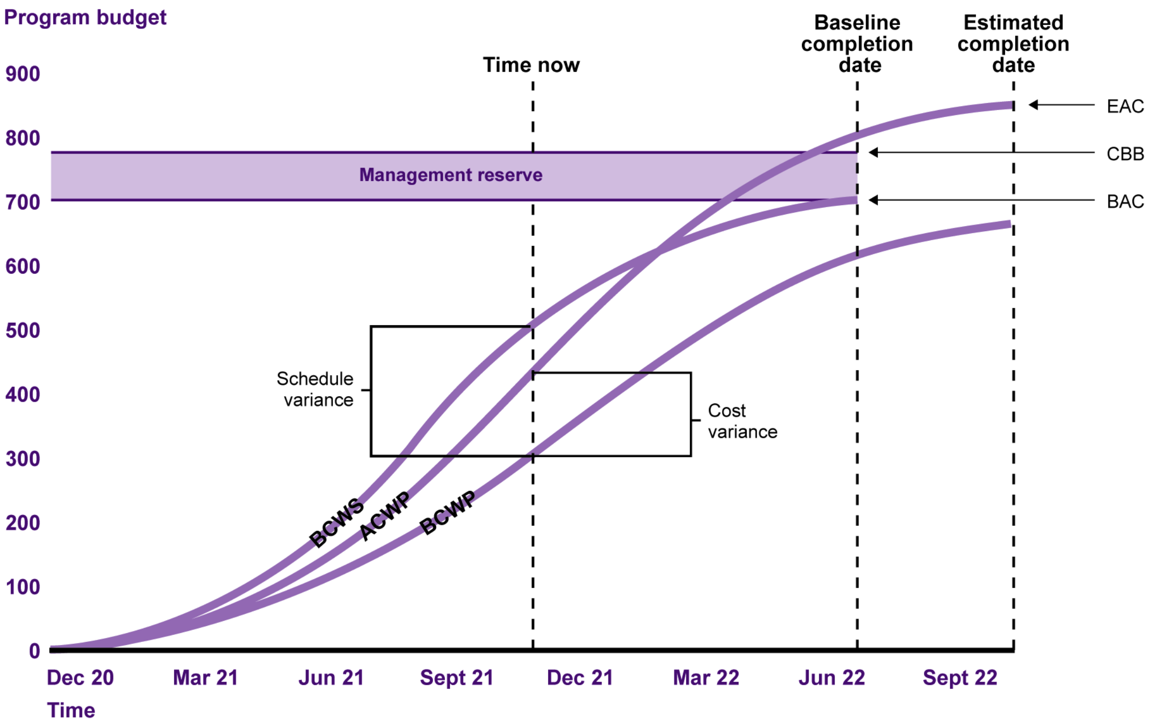
Task description	J	F	M	A	M	J	J	A	S	O	N	D	Budgeted	% Complete	Earned
Concrete	3,000	5,000	2,000										$10,000	100%	$10,000
Framing		5,000	10,000	5,000									20,000	60	12,000
Roofing			1,000	8,000	6,000								15,000	30	5,000
Electrical					10,000	15,000	15,000						40,000		
Plumbing							6,000	12,000	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 (BCWP)	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: DOD. | GAO-20-195G

According to the data in figure 30, 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. At the end of April, $39,000 worth of concrete, framing, and roofing work was planned to be completed. By comparing the total amount of work expected to be complete to the work that was actually accomplished—$27,000—one can determine that $12,000 worth of work is behind schedule. Likewise, by comparing the amount of work that was accomplished ($27,000) to the amount of money that was spent to accomplish it ($33,000), one can see that the work cost $6,000 more than planned.

Cumulative EVM data can be graphed for an overall program view, as in figure 31.

Figure 31: Overall Program View of Earned Value Management Data



Source: GAO. | GAO-20-195G

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 31 shows that in October, the program is both behind schedule and overrunning cost. Cost variance is the difference between completed work (BCWP) and its cost (ACWP); schedule variance is 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.

From this performance information, various estimates at completion can be calculated. The EAC shows projected performance and expected costs at completion. 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.

Analyze Performance

Analyze the Data

The basic steps for analyzing EVM data are

1. Analyze performance:
- validate the data,
- 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 because each step builds on findings from the previous one. Developing independent EACs without first validating the EVM data is not recommended. 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 so that all information is known before making independent projections of costs at completion.

Validate the Data

It is important to make sure that the CPR data make sense and do not contain anomalies that would make them invalid. If existing errors are not detected, then the data will be skewed, resulting in erroneous metrics and poor decision making. To determine if the data are valid, analysts should check 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 far greater or less than the planned value;
- inconsistency between EAC and BAC—for example, no BAC but an EAC or a BAC with no EAC;
- ACWP exceeds EAC; and
- BCWP or BCWS exceed BAC.

If the CPR data contain anomalies, the performance measurement data may be inaccurate. 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. Or, it could mean that an accounting error occurred in a previous reporting period that is now being reconciled. Another reason could be work that was behind schedule is finally being done; in this case there would be BCWP without BCWS because the work is occurring later than planned. Case study 25 highlights CPR data with these anomalies.

Case Study 25: Data Anomalies, from *James Webb Space Telescope*, GAO-16-112

Based on analysis of James Webb Space Telescope (JWST) contractor EVM data over 17 months, GAO found that some of the data used to conduct the analyses were unreliable. First, GAO found that both Northrop Grumman and Harris were reporting optimistic EACs that did not align with their historical EVM performance and fell outside the low end of our independent EAC range. Second, GAO found various anomalies in contractor EVM data for both contractors that they had not identified throughout the 17-month period we examined. The anomalies included unexplained entries for negative values of work performed (meaning that work was unaccomplished or taken away rather than accomplished during the reporting period), work tasks performed but not scheduled, or actual costs incurred with no work performed. For Northrop Grumman, many were relatively small in value ranging from a few thousand to tens of thousands of dollars. These anomalies are problematic because they distort the EVM data, which affects the projection of realistic EACs. GAO found that these anomalies occurred consistently within the data over a 17-month period, which brought into question the reliability of the EAC analysis built upon this information. NASA did not provide explanations into the anomalies for either contractor. While the contractors were able to provide explanations for the anomalies upon request, their explanations or corrections were not always documented within EVM records. Some of the reasons the contractors cited that were not in the EVM records included tasks completed later than planned, schedule recovered on behind schedule tasks, and replanning of customer-driven tasks. Without reconciling and documenting data anomalies, and utilizing reliable data for the risk-adjusted EAC, the JWST project did not have a reliable method to assess its cost reserve status going forward. This meant that some of the cost information the project officials used to inform their decision making may have failed to indicate true program performance, and as result, project management may not have had a solid basis for decision making.

GAO recommended that to resolve contractor data reliability issues and ensure that the project obtained reliable data to inform its analyses and overall cost position, the NASA Administrator direct JWST project officials to require the contractors to identify, explain, and document all anomalies in contractor-delivered monthly earned value management reports. In February 2016, NASA issued letters to the contractors requiring them to explain all anomalies in the contractor earned value management reports.

GAO, *James Webb Space Telescope: Project on Track but May Benefit from Improved Contractor Data to Better Understand Costs*, GAO-16-112 (Washington, D.C.: December 17, 2015).

In addition to checking the data for anomalies, the analyst should verify that the CPR data are consistent across formats. For example, the analyst should review whether the data reported on the bottom line of format 1 matches the data on the bottom line of format 2. The analyst should also assess whether program cost is consistent with the authorized budget.

Determine Variances

Cost and schedule variances 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 negatively, 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.

Probe Schedule Variances for Activities on the Critical Path

Analysts should determine whether schedule variances are from activities on the critical path. If they are, then the program will be delayed, resulting 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 determine whether 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 because 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.

A reliable network schedule that is kept current is a critical tool for monitoring program performance. Carefully monitoring the contractor’s network schedule will allow for determining when forecasted completion dates differ from the planned dates. Activities may be re-sequenced or resources realigned to reduce the schedule delay. It is also important to determine whether schedule variances are affecting downstream work. For example, a schedule variance may compress the durations of remaining activities or cause “stacking” of activities toward the end of the program, to the point at which success may no longer be realistic. If this happens, then an overtarget 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 total float, as well as the number of activities with lags, date constraints, or lack of progress should be examined each month.[54] Some indicators of poor schedule health:

- Excess total float usually indicates that the schedule logic is flawed, broken, or absent. Large total float values should be checked to determine if they are real or a consequence of incomplete scheduling.
- Date constraints typically are substitutes for logic and can mean that the schedule is not well planned.
- Lags are typically 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 force activities to start or finish on a specified date.
- 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 accuracy.

In addition to monitoring tasks on the critical path, close attention should be paid to near-critical tasks, as these may alert management to potential schedule problems. If an activity is not on the critical path but is experiencing a schedule variance, it 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 activities to slip, then its effect is much more significant.

A negative schedule variance eventually disappears when the full scope of work is completed because at this point the amount of work accomplished is equal to the amount of work planned. However, 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, because as schedule

[54]Total float is the amount of time an activity can be delayed or extended before delay affects the program's finish date. A lag is used in a schedule to denote the passing of time between two activities. Lags cannot represent work and cannot be assigned resources. Date constraints can be placed on an activity's start or finish date to override network logic. They can limit the movement of an activity to the past or future or both. See GAO. *Schedule Assessment Guide: Best Practices for Project Schedules*, GAO-16-89G. (Washington, D.C.: December 22, 2015) for more information.

increases various costs such as labor, rented tools, and facilities increase. The amount of the estimate due to inflation typically increases also. Additionally, management tends to respond to schedule delays by adding more resources or authorizing overtime.

Develop Historical Performance Data Indexes

Performance indexes are measures of program efficiency that indicate how a program is performing. Performance indexes determine 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. Table 23 provides three performance indexes and describes what each indicates about program status.

Table 23: EVM Performance Indexes

Index	Formula	Indicator
Cost performance index (CPI)	CPI = BCWP / ACWP	The CPI metric is a measure of cost expended for the work completed. A CPI value greater than 1.0 indicates the work accomplished cost less than planned, while a value less than 1.0 indicates the work accomplished cost more than planned.[a]
Schedule performance index (SPI)	SPI = BCWP / BCWS	The SPI metric is a measure of the amount of work accomplished versus the amount of work planned. An SPI value greater than 1.0 indicates more work was accomplished than planned, while an SPI value less than 1.0 indicates less work was accomplished than planned. [a]
To complete performance index (TCPI)	TCPI = BCWR / (EAC – ACWP)[b]	The TCPI is a comparison of the amount of work remaining to the budget remaining. It is the calculated projection of cost efficiency that must be achieved on the remaining work to meet a specified goal, such as BAC or EAC. The performance efficiency need to complete the project is often more than the previous level of performance achieved. The TCPI can be compared to a CPI to test the EAC's reasonableness and used as the basis for discussion of whether the performance required is realistic. [c]

Source: DOD and PMI. | GAO-20-195G

[a]DOD, OUSD A&S (AE/AAP), *Earned Value Management Implementation Guide*, (Washington, D.C.: January 2019).

[b]BCWR = budgeted cost of work remaining, or BAC – BCWP.

[c]Project Management Institute, Inc. *Practice Standard for Earned Value Management*, Second Edition, 2011.

The cost performance index (CPI) and schedule performance index (SPI) can be used independently or together to forecast a range of cost estimates at completion. They also give managers early warning of potential problems that need correcting to avoid adverse results.

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. More analysis is needed to know what is causing an unfavorable condition. Likewise, favorable cost or schedule performance indexes may stem from errors in the EVM system, not necessarily from work taking less time than planned or underrunning its budget. Thus, failure to assess the full meaning behind the indexes runs the risk of basing estimates at completion on unreliable data.

An SPI different from 1.0 warrants more investigation to determine what effort is behind or ahead of schedule. Analysts should 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 should also be an analysis of the available float of activities that are slipping to see if proactive steps should be taken so resources are allocated more efficiently to future activities.

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 overly optimistic. A rule of thumb is that if the TCPI is more than 5 percentage points higher than the CPI, the EAC is too optimistic. For example, if a program’s TCPI is 1.2 and the cumulative CPI is 0.9, it is not expected that the contractor can improve its performance that much through the remainder of the program. To meet the EAC, the contractor must produce $1.20 worth of work for every $1.00 spent. Given the contractor’s actual performance of $0.90 worth of work for every $1.00 spent, it is 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.

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.

In addition to the performance indexes, three other useful calculations for assessing program performance are:

- percent planned = BCWS/BAC,
- percent complete = BCWP/BAC, and
- percent spent = ACWP/BAC.

Taken together, these formulas measure how well a program is performing. For example, if percent planned is much greater than percent complete, the program is significantly behind schedule. Similarly, if percent spent is much greater than percent complete, the program is significantly overrunning its budget.

Graph the Data to Discover Trends

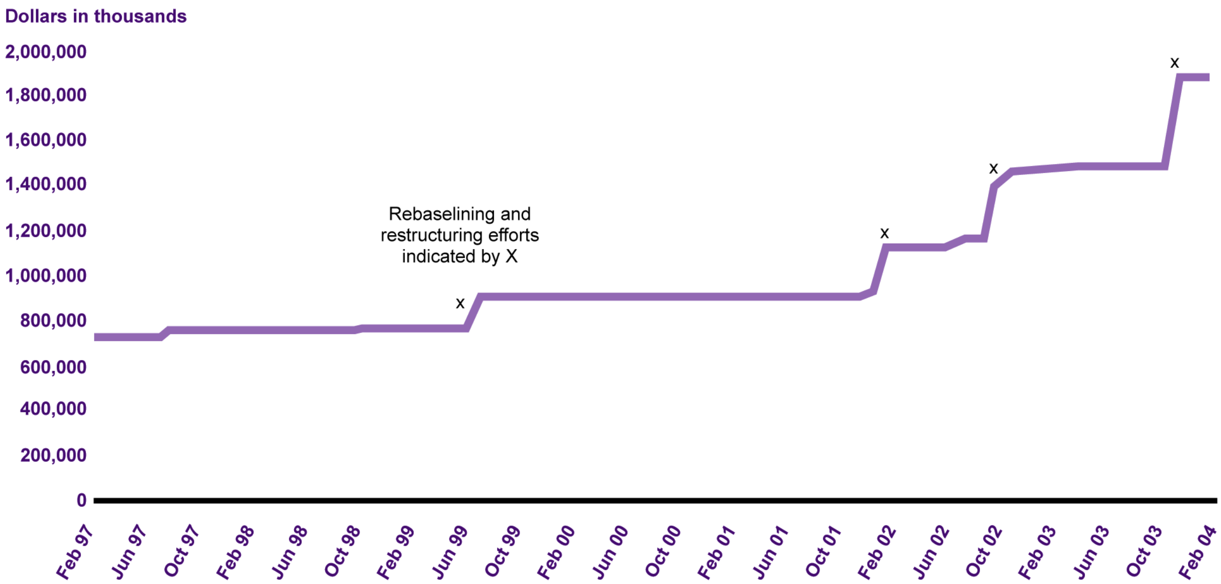
EVM data should be graphed to determine trends. These trends provide valuable information about a program's performance, which is important for accurately predicting costs at completion. Knowing what has caused problems in the past can help determine whether they will continue in the future.

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 provide managers insight into program performance are:

- BAC and contractor EAC over the life of the contract,
- cumulative and current cost variance trends,
- cumulative and current schedule variance trends,
- cumulative and current CPI and SPI,
- current ACWP—also referred to as the monthly burn rate,
- cumulative and current TCPI versus CPI,
- format 3 baseline data,
- projected versus actual staffing levels from format 4, and
- management reserve allocations and rate of expenditure.

Plotting the BAC over the life of the contract will show any contract rebaselines or major contract modifications. BACs that follow a stair-step trend indicate 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 32, BAC for an airborne laser program has been plotted over time to show the effect of major contract modifications and program rebaselines.

Figure 32: Understanding Program Cost Growth by Plotting Budget at Completion Trends



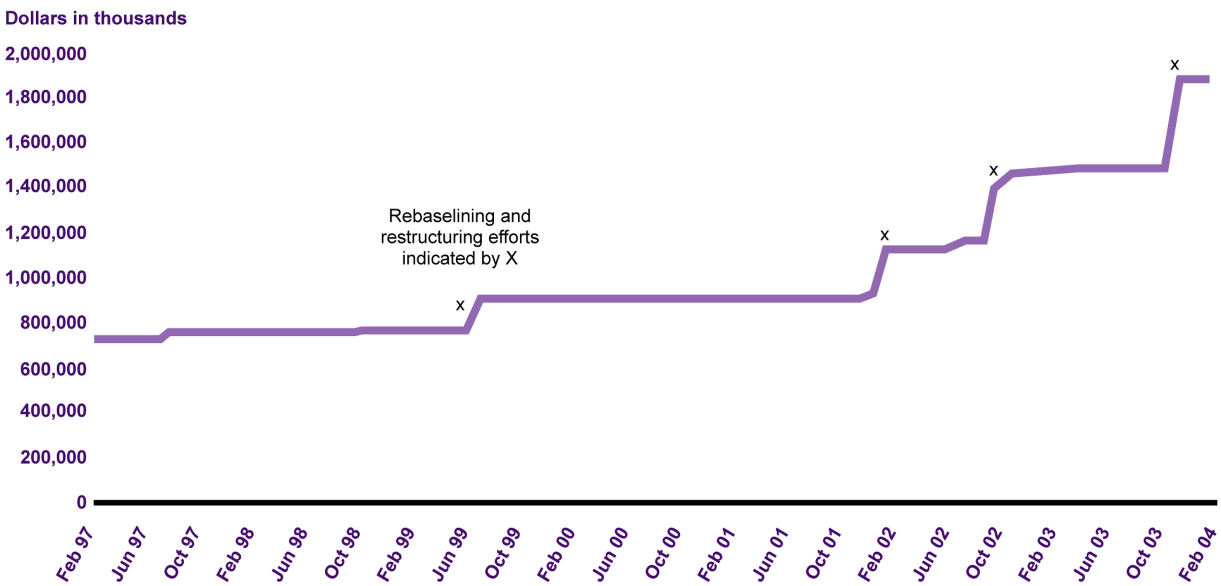
Source: GAO. | GAO-20-195G

Note: The trend examples in figures 32–34, 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), 17–20.

Figure 32 reveals a number of contract modifications, program restructurings, and rebaselines in the airborne laser program which doubled the program cost from 1997 to 2004. The trend data also show instances of major change, making it easy to pinpoint 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 relied 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.

In addition to 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 33 shows trends of increasing cost and schedule variance associated with the airborne laser program.

Figure 33: Understanding Program Performance by Plotting Cost and Schedule Variances



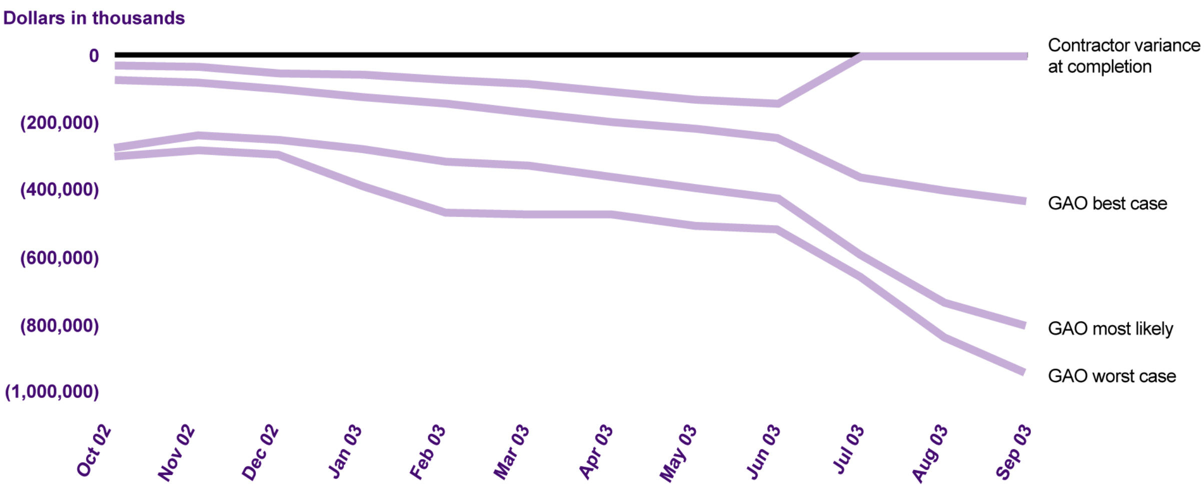
Source: GAO. | GAO-20-195G

Note: The trend examples in figures 32–34, 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), 17–20.

In figure 33, 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, it 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 good way to determine whether the contractor's estimate is reasonable. Figure 34, for example, shows expected cost overruns at contract completion for the airborne laser program.

Figure 34: Understanding Expected Cost Overruns at by Plotting Estimate at Completion



Source: GAO. | GAO-20-195G

Note: The trend examples in figures 32-34, 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), 17–20.

Figure 34 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 33. The program was facing huge technology development problems, which made it unlikely that the contractor could finish the program without additional cost variances. Indeed, 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.

Other trends can offer insight into program performance. To check the reasonableness of a contractor's estimate at completion, analysts can compare the CPI, current and cumulative, with the TCPI to determine if historical trends support the contractor's EAC.

Analysts may plot the ACWP, or monthly burn rate. If the plot shows an increase, the analyst needs to determine whether the growth stems from the work becoming more complex as the program progresses or from overtime being initiated to make up for schedule delays. Analysts can review monthly ACWP and BCWP trends to determine what is being accomplished for the amount spent. In figures 33 and 34, for example, it is evident that the program was paying a larger staff to make a technological breakthrough rather than paying existing staff overtime to meet schedule goals. It is important to know the reasons for variances so that management can make decisions about the best course of action. For the program illustrated in figures 33 and 34, GAO recognized that because 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 determine whether the budget is being revised 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.[55] 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. Management reserve is a budget tool to help manage risks, so analyzing its rate of allocation is important. When management reserve is consumed, any further risk that is realized can only be manifested as unfavorable cost variance. 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 prevent the allocation 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,

[55] A waterfall chart is made up of floating columns that show how an initial value increases and decreases by a series of intermediate values leading to a final value.

risks in the cost estimate should be identified up front and conveyed to the EVM analysts so they can track risks in specific WBS elements.

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. 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 depleted, the analyst should be alert to contractor requests to increase the contract value to avoid variances.

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.

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 expected cost of remaining work. Actual costs spent on completed work are captured by the ACWP. The remaining work is determined by subtracting BCWP from BAC to calculate the budgeted cost of work remaining. To more accurately estimate the cost of remaining work, the EAC should take into account performance to date.

Calculate a Range of EACs and Compare to Available Funding

EVM data can be used to develop a multitude of EACs, and it is a best practice to develop more than one EAC. 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. However, picking the right EAC is challenging because the perception is that bad news about a contract's performance could put a program and its management in jeopardy.

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 efficiency index incorporates the concept 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 (defined in table 24), 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 regression analysis 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 24 summarizes findings from studies describing which EACs make the best predictors, depending on where the program is in relation to its completion.

Table 24: Best Predictive Estimate at Completion (EAC) Efficiency Factors by Program Completion Status

EAC efficiency factor		Percent complete: Early : 0%–40%	Middle : 20%–80%	Late : 60%–100%	Comment
Cost Performance Index (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	
	Cumulative	X	x		Usually produces the highest EAC

EAC efficiency factor		Percent complete: Early : 0%–40%	Middle : 20%–80%	Late : 60%–100%	Comment
CPI x Schedule Performance Index (SPI)	6-month average		x	x	A variation of this formula (CPI6 x SPI), also proven accurate
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 percent of its stable value can be a good predictor of final costs
Weighted		X		x	Weights cost and schedule based on .x(CPI) + .x(SPI); statistically the most accurate, especially when using 50 percent CPI x 50 percent SPI

Source: DOD. | GAO-20-195G

The findings in table 24 are based on extensive research that compared efficiency factors that appeared to best predict program costs. The conclusion was that no single 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 later in program development. 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 to 12 months—especially in the middle of a program when costs are being spent at a greater rate.

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 yield a high 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 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 summing the actual costs to date, the remaining work with a cost growth factor applied, and a cost impact for probable schedule delays. This EAC method also considers risks from the program risk register that may impact remaining cost and schedule, such as test failures or other external factors that have occurred in other past programs. This method 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.

EACs should be created not only at the program level but also at lower levels of the WBS. By doing so, 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 determine 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.

While EVM data are useful for predicting EACs, the contractor should also look at other performance information to develop an 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.

This comprehensive, or bottom-up, EAC should periodically be developed 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 EACs and historical performance indexes.

Determine Whether the Contractor's EAC Is Feasible

Because 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 historical trends, it also tends to include optimistic views of the future.

As noted earlier, 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.

Looking again at the example of the airborne laser program discussed around figures 33–34, 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. 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 that 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's finish date; sufficient slippage in near-critical paths may ultimately have the same result. If the delayed activities will affect the program schedule, then an analysis, generally a schedule risk analysis, should be conducted to determine the most likely completion date. In addition, a schedule risk analysis should be conducted periodically to assess changes to the critical path and explain schedule reserve erosion and mitigation strategies for keeping the program on schedule.[56]

Provide Analysis to Management

The ability to act quickly to resolve program problems depends on having information of their causes early. Management can make better decisions that lead to greater success if it has accurate progress assessments of program status. When problems are identified, they should be captured and managed 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. When this happens, however, management should also be sure to link program outcomes to award-fee objectives.[57] For example, management can evaluate earlier CPRs to determine if they objectively depicted contract status and predicted certain problems. This approach supports performance-based reporting and rewards contractors for managing their contracts effectively and reporting actual conditions, reducing the need for additional oversight.

[56]For a detailed explanation of schedule risk analysis performance, see GAO, *Schedule Assessment Guide*, GAO-16-89G (Washington, D.C.: Dec. 2015).

[57]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. It is important that award fee criteria be selected to properly motivate the contractor to perform well and encourage improved management processes during the award fee period. See the sidebar above for more discussion about use of award fee.

Continue EVM until the Program is Complete

EVM detail planning continues until the program is complete. Rolling wave planning gives the contractor flexibility for planning the effort in detail and allows for incorporating lessons learned. Work may be planned by calendar dates, for example, in 6-month increments; all effort beyond 6 months 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. However, rolling-wave planning based on calendar dates may result in insufficient detail. A best practice is to plan the rolling wave to a design review, test, or other major milestone rather than an arbitrary period, such as 6 months.

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 because EVM data are essential to effective program management and can be used to answer basic program management questions such as those in table 25.

Award Fee Criteria

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, programs should use 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.

In addition, experts agree that award fee periods should be tied to specific contract events like preliminary design review rather than monthly cycles.

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 meet variance thresholds 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.

Source: GAO | GAO-20-195G

Table 25: Basic Program Management Questions That Earned Value Management (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?	Plot cost and schedule variance, CPI, SPI, and the like
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: ICEAA (International Cost Estimating and Analysis). Cost Estimating Body of Knowledge. Vienna, Va.: 2013. | GAO-20-195G

From questions such as those in table 25, 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

Chapter 20: Earned Value Management: Validation, Surveillance, and Over Target Baselines

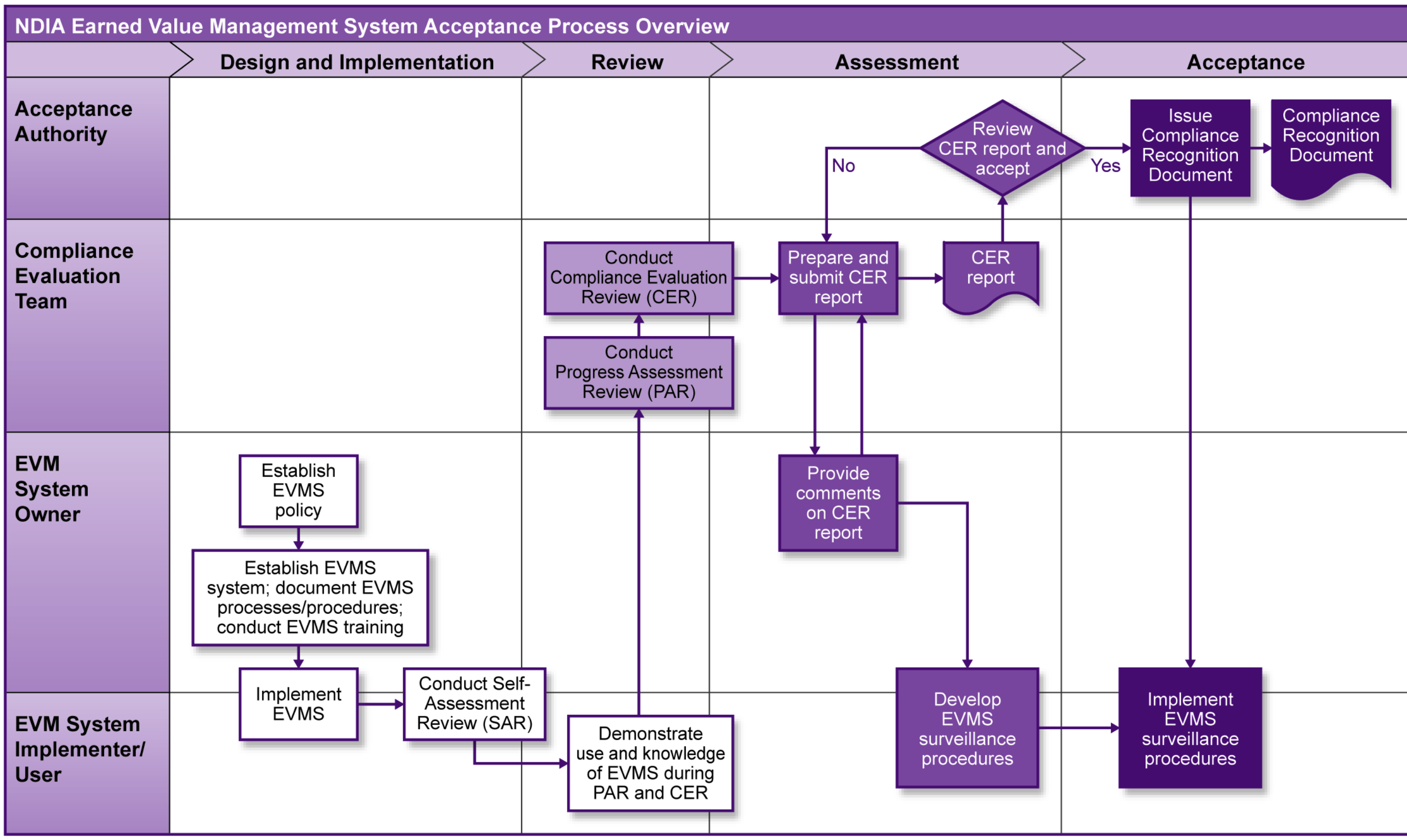
This EVM chapter discusses three remaining important topics: validation of the EVM system, system surveillance, and over target baselines. Having a validated EVM system is the first step to ensuring that the EVM system generates reliable data. The validation process consists of determining how well an EVM system complies with the EIA-748 standards. After a program has started collecting data using a validated EVM system, the program needs to conduct regular surveillance. The purpose of regular surveillance is to maintain the quality of the data, as well as to ensure the system continues to meet the EIA-748 standards. The last topic in this chapter is over target baselines and schedules. At times, cost and schedule baselines may become so unrealistic that they prevent management from discovering problems that can be mitigated. In these cases, changes are made to the cost and schedule baselines to add budget to future work and eliminate historical variances.

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 EIA-748 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 35. 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 a compliant EVM system.[58]

[58]More information on EVM system acceptance is in National Defense Industrial Association (NDIA), Integrated Program Management Division, *Earned Value Management System Acceptance Guide* (Arlington, VA.: March 24, 2013).

Figure 35: The Earned Value Management System Acceptance Process



Source: Copyright © 2013, National Defense Industrial Association (NDIA), Integrated Program Management Division, *Earned Value Management System Acceptance Guide*. | GAO-20-195G

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 implementing the EVM system. Once complete, reviews can begin. These reviews are the Self-Assessment Review (SAR), the Progress Assessment Review (PAR), and the Compliance Evaluation Review (CER). The purpose of these reviews is to assess EVM system compliance with the EIA-748 guidelines and identify areas of non-compliance. The PAR is optional and is conducted after the SAR. It is usually conducted by personnel from the CER team in preparation for a CER.

The CER is an independent review conducted by an individual or organization that:

- has no stake in the EVM system, program, or contract being reviewed;
- 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 EIA-748 guidelines.

The purposes of the CER include:

- ensuring senior management actively participates and accepts ownership of the EVM process;
- verifying that the EVM system is compliant with the EIA-748 guidelines;
- demonstrating the use of the EVM system and EVM system outputs in making management decisions;
- ensuring that the data and reports produced by the EVM system are reliable and capable of being used for planning, risk mitigation, corrective actions, forecasting schedule completion dates, and estimating at completion costs; and
- verifying that the EVM system produces data that is consistent with the program technical, schedule, and cost status.[59]

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.

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 EIA-748 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 (later in this chapter) to ensure that the written system description meets the intent of the 32 guidelines and is actively being followed. An

[59] National Defense industrial Association (NDIA) Integrated Program Management Division (IPMD), *Earned Value Management System Acceptance Guide* (Arlington, VA.: March 24, 2013).

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.

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 EIA-748 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 study 26 showcases programs which used an EVM system that had not been certified as being compliant with the EIA-748 guidelines.

Case Study 26: Certified EVM Systems, from *NASA*, GAO-13-22

The National Aeronautics and Space Administration (NASA) historically has experienced cost growth and schedule slippage in its portfolio of major projects and has taken actions to improve in this area, including adopting the use of EVM. In 2012, GAO was asked to examine, among other things, the extent to which NASA was using EVM to manage its major space flight acquisitions.

We found that 10 major spaceflight projects had not yet fully implemented EVM. As a result, NASA was not taking full advantage of opportunities to use an important tool that could help reduce acquisition risk. We assessed the 10 projects against three fundamental EVM practices that are necessary for maintaining a reliable EVM system and found shortfalls in two of three fundamental practices. Specifically, we found that more than half of the projects did not use an EVM system that was fully certified as compliant with the industry EVM standard.

Four projects had a certified EVM system, three did not, and three had a mixture in which some contractors and subcontractors had certified systems and some did not. When an EVM system is certified, the agency has assurance that the implemented system was validated for compliance with the EIA-748 standard by independent and qualified staff and therefore can be considered to provide reliable and valid data from which to manage a project. The Global Precipitation Measurement, Tracking and Data Relay Satellite System, Landsat Data Continuity Mission, and James Webb Space Telescope were the only projects that provided evidence that the contract performance reports provided came from EVM systems that were certified as compliant with the EIA-748 standard. The Lunar Atmosphere and Dust Environment Explorer, Magnetospheric Multiscale and Radiation Belt Storm Probes projects did not have EVM systems that were certified to be compliant with the EIA-748 standard. Finally, the Jet Propulsion Laboratory, a federally funded research and development center that the California Institute of Technology manages under a contract with NASA, was the only NASA Center with a certified EVM system. The Jet Propulsion Laboratory was responsible for managing the Orbiting Carbon Observatory 2 project. The Mars Atmosphere and Volatile Evolution Mission and Stratospheric Observatory for Infrared Astronomy prime contractors also had certified systems; however, their project offices did not.

GAO, *NASA: Earned Value Management Implementation across Major Spaceflight Projects is Uneven*, GAO-13-22 (Washington, D.C.: November 19, 2012).

Using System Surveillance to Keep the Performance Management Baseline Current

Surveillance is reviewing a contractor’s EVM system as it is applied to one or more programs. Full implementation of EVM includes performing periodic system surveillance reviews to ensure that the EVM system continues to meet the EIA-748 guidelines. Periodic surveillance subjects contractors’ EVM systems to ongoing government oversight. Its purpose is to assess how well a contractor is using its EVM system to manage cost, schedule, and technical performance. For instance, surveillance confirms that 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 EIA-748 guidelines;
- provides timely indications of actual or potential problems by performing spot checks, sample data traces, and random interviews;
- maintains baseline integrity;
- 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. EVM system surveillance ensures that the contractor is following its own corporate processes and procedures and confirms that they continue to satisfy the EIA-748 guidelines.

OMB has recommended the NDIA surveillance guide we listed in table 20 to assist federal agencies in developing and implementing EVM system surveillance practices, which include:[60]

- establishing and maintaining a surveillance organization,
- defining the review scope and selected projects for surveillance reviews,
- establishing the program surveillance review team,
- overseeing surveillance reviews, and
- learning from results of surveillance reviews.

[60]National Defense industrial Association (NDIA), Integrated Program Management Division (IPMD), *Surveillance Guide* (Arlington, VA: November 2018).

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 EIA-748 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.

The Defense Contract Management Agency (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. Agencies may need to 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 because there would be no independent supervision of the system. Further, 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

A 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 guidelines. 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 26 outlines some factors that may warrant program surveillance.

Table 26: Sample Factors in Selecting Projects

Factor	Description
Contract value	The contract value is viewed in relative terms for the organization. The higher the dollar value of the contract, the greater the potential for the program will be selected for a review
Type and phase of contract	The type and phase of a program may provide good indications of risk. Development and notable customer contracts (e.g., Department of Defense (DOD) ACAT I/ACAT II programs) are typically larger with more discrete effort using earned value management (EVM) scheduling and work/budget practices whereas production and operations and maintenance contracts are considered lower in risk due to the repetitive or level of effort nature of the program. High dollar firm fixed price (FFP) contracts primarily hold significant risks to the contractor and may contain EVMS clauses containing reporting requirements on schedule performance. The contract phase may determine the type of program, for example, when transitioning from development to production. Development programs benefit from work definition, budget, and authorization practice reviews, whereas production programs may lend themselves more readily for assessment of manufacturing scheduling and material management and control.
Value and nature of remaining work	The higher the dollar value of the remaining work, the greater the probability a program will be selected for a review. The technical content of remaining work is also reviewed to determine the level of performance risks on the contract.
Experience of organization program office	The program office's experience with implementing and using EVM processes may influence the selection of projects for surveillance. The lack of experience with EVM in the program office's personnel might allow program baseline planning to be accomplished without following documented procedures, thereby increasing the risk of poor applications with unreliable program data. Conversely, program offices that are more experienced with EVM applications and data use are more suited to maintain better data integrity required for program reporting, thus lowering risk.
Internal surveillance	Some program teams engage in internal surveillance. In these instances, the organization may take into account the frequency, quality, and confidence it has in the program team's internal surveillance when determining the frequency and selection of the program for surveillance.
Current or cumulative cost or schedule variances or variances at completion	Projects experiencing difficulty in maintaining cost or schedule control increases the probability the program will be selected for a review. Variances may be indicators of possible issues and may be further investigated within work/budget, scheduling, managerial analysis, or change management practices.
Baseline volatility, resets or changes	The frequency of baseline resets or changes, especially when accompanied by elimination of cumulative cost or schedule variances, may be indicative of a number of situations: poor original baseline planning, a change in work approach, make or buy determinations, or significant schedule/technical changes. Projects reflecting a significant number of baseline resets increases the probability the program will be selected for a review.
Schedule risk analysis confidence level	The program schedule is a foundational element of the EVMS. The lower the confidence in the quality, analysis, or executability of the schedule as well as questionable outcomes resulting from schedule risk assessments increases the probability of selecting the program for review.

Factor	Description
Risk and opportunity assessment	The management and maintenance of the risk and opportunity management process needs to be considered, to include: (1) the quality of the risk and opportunity assessment and the related risk and opportunity handling plans; (2) the extent of risk and opportunity management integration with EVMS, as well as adequate management reserves to address risks and opportunities not included in the PMB. Other factors to consider are the confidence level of the PMB and the program's risk and opportunity trends.
Findings or concerns from prior reviews	Past results may indicate the need for adjusting the frequency of the reviews. Latency in closing previous findings/action items could be a concern and may cause a program to fall out of compliance.
Customer or management interest	The inclusion of subcontractors on the program can influence the selection process. Example considerations: the number of subcontractors, the degree of experience with EVMS, EVMS contractual requirements (e.g., formal EVMS flow-down, integrating the subcontractor into the prime's EVMS, reporting only).
Subcontractor considerations	The degree of customer or management concerns or interest in the program may be a factor influencing the selection process.

Source: ©2018 National Defense Industrial Association (NDIA) Integrated Program Management Division (IPMD), *Surveillance Guide* (Arlington, VA: November 2018). GAO20-195G

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;
- 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 EIA-748 guidelines each year, if a program were almost complete, it would not make sense to focus on work authorization because this process would no longer be relevant.

Developing a Program Surveillance Plan

The surveillance team designated to perform program reviews should consist of 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. 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. The team should allocate sufficient time to complete all these activities. 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 determine if they can describe their compliance with EVM policies, procedures, or processes. The interview enables the surveillance team to gauge the EVM knowledge of the program staff and their awareness of and practice in complying with EVM guidelines. This is especially important because control account managers are the source of much of the information on the program's EVM system. Interviews also 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.

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.

When all the documentation has been reviewed and interviews have been conducted, the surveillance team should provide appropriate feedback to the program team. The surveillance team leader should present all findings and recommendations to the program staff so that any misunderstandings can be clarified and corrected. Specifically, surveillance team members and program personnel should clarify any questions, data requests, and responses to be sure everything is well understood.

Once program personnel have provided their feedback, a preliminary report should be prepared that addresses findings and recommendations. Findings fall into two broad categories: (1) compliance with the accepted EVM system description and (2) consistency with EVM system guidelines. Practices may comply 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 reduced, 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 multi-program database. This information is transformed into specific measures for assessing the overall health of a contractor's EVM system process. These measures should be designed to capture whether the EVM data are readily available, accurate, meaningful, and focused on desirable corrective action. The types of measures 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 identify deviations from documented EVM application processes, and
- process measures that indicate whether the surveillance plan is resolving systemic issues.

To develop consistent measures, individual program results can be summarized by a standard rating system

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 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 historical 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 goals during a rebaseline are 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.[61] This additional budget is believed necessary to finish work that is in process and remaining 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 funding. 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 rarely be necessary. 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 27.

[61]This action is not to be confused with reprogramming in 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), 85.) The overtarget baseline action should also not be confused with replanning. Replanning of actions for remaining work scope is a normal program control process accomplished within the scope, schedule, and cost objectives of the program.

Case Study 27: Maintaining Realistic Baselines, from *Uncertainties Remain Concerning the Airborne Laser's Cost and Military Utility*, GAO-04-643R

From the contract's award in 1996 through 2003, the cost of the Airborne Laser's (ABL) primary 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 than expected. Besides schedule delays, 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 exceed the contractor's July 2003 cost estimate of about $2.1 billion by $431 million to $943 million through the system's first full demonstration.

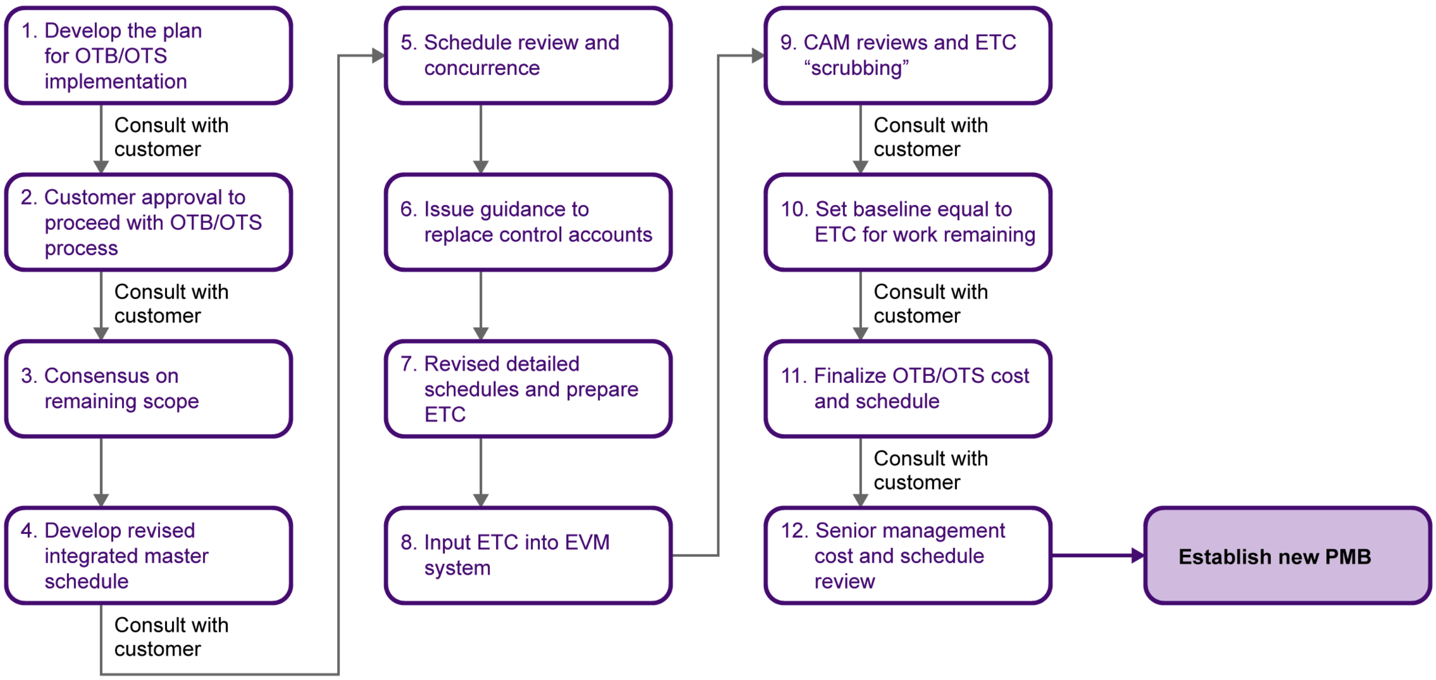
The program had undergone several major restructurings and contract rebaselines from 1996 on, primarily because of unforeseen complexity in manufacturing and integrating critical technology. According to program officials, rapid prototyping resulted in limited subcomponent testing, causing rework and 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 that quantified the confidence to be placed in the estimate.

GAO, *Uncertainties Remain Concerning the Airborne Laser's Cost and Military Utility*, GAO-04-643R (Washington, D.C.: May 17, 2004).

The end result of an overtarget baseline is that its final budget always exceeds the contract budget base. In EVM system terminology, the sum of all budgets (performance measurement baseline, undistributed budget, and management reserve) is known as total allocated budget, and the difference between the total allocated budget and the contract budget base is the overtarget baseline. Figure 36 illustrates the effect an overtarget baseline has on a contract.

Figure 36: The Effect on a Contract of Implementing an Overtarget Budget



Source: DOD. | GAO-20-195G

Like an overtarget budget, an overtarget schedule occurs when the schedule and its associated budgets are spread over time and work gets 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 bottom-up estimate of remaining costs and schedule that accounts for risk and includes management reserve;
- a realistic schedule for the remaining work that has been validated according to the new plan;

- a report on the overtarget budget in the CPR—the government program office and contractor need agreement 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. The program office and the contractor should also consider whether losing valuable historical performance variances and trends is worth the effort and time to reset the baseline. Table 27 identifies common problems and indicators that may be warning signs that a program may need an overtarget budget or schedule.

Table 27: 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 Cost Performance Index and To Complete Performance Index • Early, significant, and frequent allocation of management reserve to the performance measurement baseline for newly identified in-scope effort • Insufficient management reserve for the remaining contract scope • Control account budgets for remaining work that do not represent a reasonable chance of success • Work packages with no remaining budget • Inability to explain the basis for achieving the Estimate at Complete (EAC) • EACs that are too optimistic and do not adequately account for risks

Indicator	Description
Schedule	• High level of concurrent remaining activities • Negative float or significant slips in the critical path • Incomplete or inaccurate critical path • Unrealistic activity durations • Unrealistic logic relationships between activities • Significant number of activities with constrained start or finish dates • Insufficient schedule margin for the remaining contract scope • No horizontal or vertical integration in the schedule • Logic sequence and durations for forecasted work vary significantly from baseline plan
Data accuracy	• EAC less than actual incurred costs for work breakdown structure elements • Evidence of a front-loaded performance management baseline • Lack of corrective action planning or lack of evidence of implementation • Unrealistic cost or schedule projections • Frequent or recurring data errors

Source: DOD. | GAO-20-195G

Contract type is also a key factor to consider when rebaselining a program, because each contract has its own funding implications when an overtarget budget is implemented. Table 28 describes two common types of contracts and considerations for overtarget budget implementation.

Table 28: 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.
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. The customer 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.

Source: GAO analysis of OSD's Over Target Baseline and Over Target Schedule Guide ([Arlington, VA]: December 5, 2012.) | GAO-20-195G

Establishing a revised performance measurement baseline to incorporate significant variances conveys to program management that the amount of risk a program is undertaking has increased. Therefore, in conjunction with evaluating the indicators in table 27, 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 its current performance measurement is still meaningful.

Remaining Schedule

If less than a year is required to complete the remaining work, the benefit of an 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 an overtarget budget and overtarget schedule gives management better control and information. With this analysis, the government program office and contractor ensure that the benefits will outweigh the cost of 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

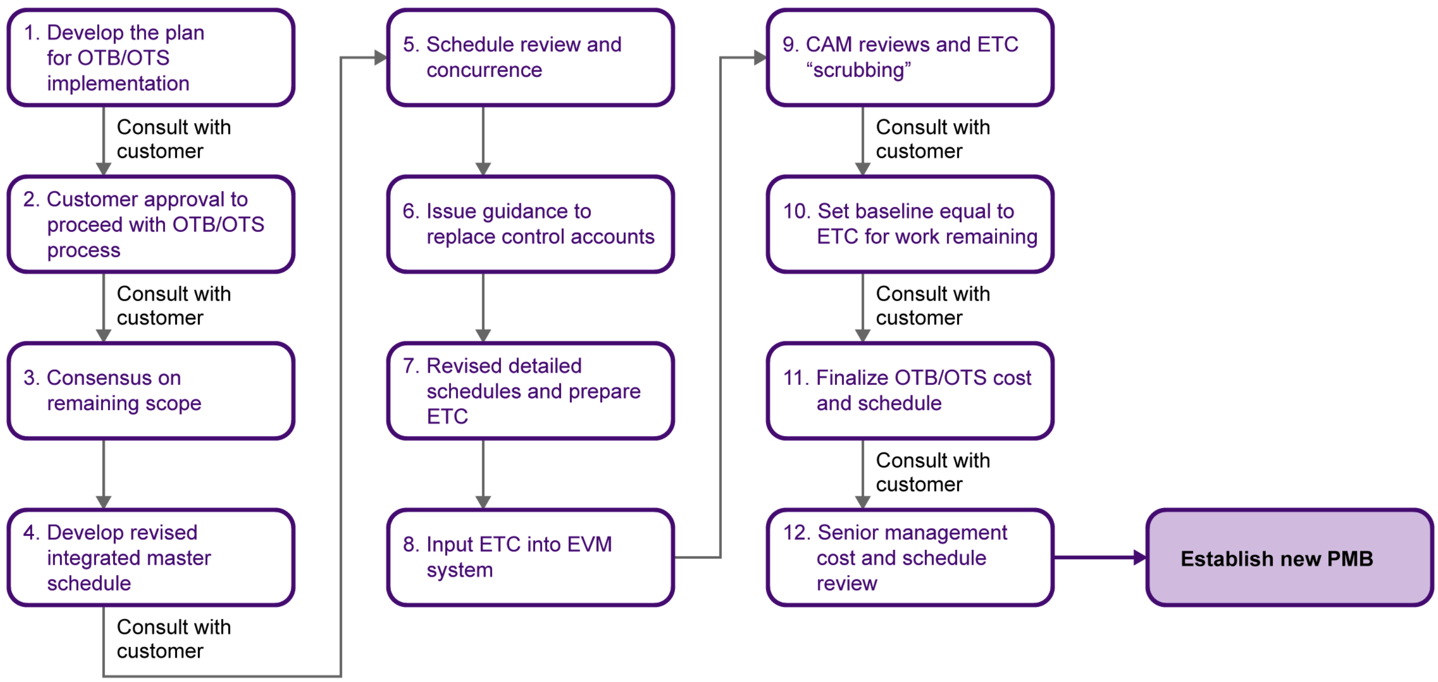
Several overtarget budget requests suggest severe underlying management problems. These should be investigated before implementing a new budget.

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 should develop new work plans that can be reasonably executed. The program manager and supporting business staff should have open lines of communication and a clear review process to ensure that the baseline is reasonable and accurate, and that it reflects known risks.

Thus, the overtarget budget–overtarget schedule implementation process involves multiple steps and processes toward establishing a new performance measurement baseline, illustrated in figure 37.

Figure 37: Steps Typically Associated with Implementing an Overtarget Budget



Source: DOD. | GAO-20-195G

Note: OTB = overtarget budget; OTS = overtarget schedule; ETC – estimate-to-complete; EVM = earned value management; CAM = control account manager; PMB = performance measurement baseline.

The key steps 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, including:

- 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 must an overtarget schedule also be implemented? Conversely, does an overtarget schedule require an overtarget budget or can the revised schedule be managed within the existing budget?
- How feasible 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 a more accurate 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—results in a new performance measurement baseline that reflects the plan of the remaining work and budget. Because existing variances can significantly distort progress toward the new baseline, a single point adjustment is a common and justifiable modification to an overtarget budget. Table 29 describes options for treating historical cost and schedule variances when performing a single point adjustment.

Table 29: Options for Treating Variances in Performing a Single Point Adjustment

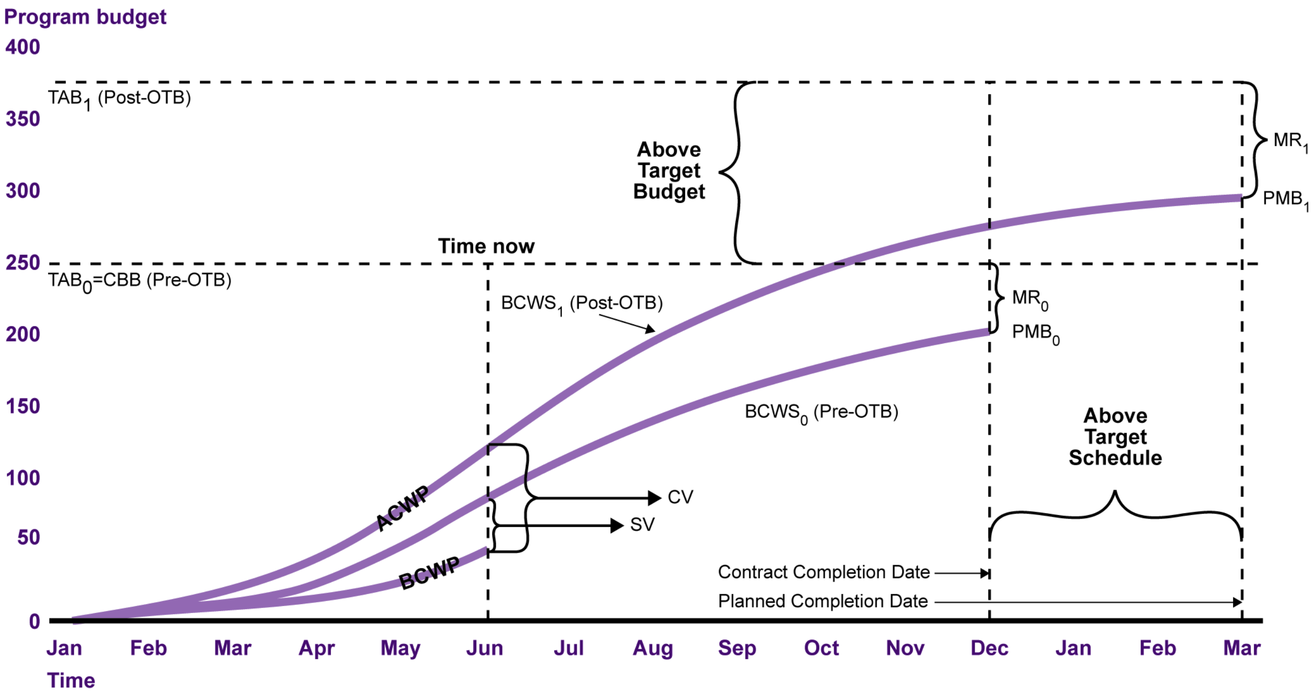
Variance option	Description
Eliminate	
All variances	Eliminate cost and schedule variances for all work breakdown structure (WBS) elements by setting budgeted cost of work scheduled (BCWS) and budgeted cost of work performed (BCWP) equal to actual cost of work performed (ACWP). The most common type of 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 associated budgets.

Variance option	Description
Cost variance only	While rare, in some situations cost variance drives an overtarget budget but schedule information is valid. Cost 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 contractor performance report 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: GAO analysis of OSD's Over Target Baseline and Over Target Schedule Guide (Arlington, VA: December 5, 2012). | GAO-20-195G

While cost and schedule variances can be adjusted in various ways, under no circumstances should the value of actual cost of work performed (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. Reviewing how management reserve was consumed prior to the overtarget budget may offer important insights into the amount to set aside. 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 38 shows how a single point adjustment results in a change to the performance measurement baseline.

Figure 38: Establishing a New Baseline with a Single Point Adjustment



Source: DOD. | GAO-20-195G

Note: TAB = total allocated budget; CBB = contract budget baseline; OTB = overtarget budget; ACWP = actual cost of work performed; BCWP = budgeted cost of work performed; BCWS = budgeted cost of work scheduled; CV = cost variance; SV = schedule variance; MR = management reserve; PMB = performance management baseline.

In figure 38, the performance measurement baseline (BCWS) is shifted upward to align with actual costs to date (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 and the schedule has slipped. 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 following few months, management should monitor the use of management reserve to determine whether realistic budgets were estimated for the remaining work or new risks occurred after the overtarget budget.

However, single point adjustments should not be made regularly and not solely to improve contract performance metrics. 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 accurately predict performance trends.

In other words, single point adjustments should be used sparingly to foster 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 be performed. The revised schedule should be complete, integrated, realistic in duration, and coordinated among key vendors and subcontractors. Further, the schedule logic should be complete and activity durations should represent the effort associated with the remaining work. Any effect on schedules for government-furnished equipment or resources should also be considered before the integrated 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, activity durations are backed by historical 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, and travel.

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:

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;

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; and

select meaningful performance indicators to monitor contractor efforts to implement and adhere to the new baseline.

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, continual 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.

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.

In addition, DOD requires contractors to 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. The form also evaluates contractors' actual cost and fee data and compares them to the negotiated contract value, estimated costs, and budget forecast data. Data from these types of reports are important for determining whether the government has adequate funding to complete the program, based on the contractor's historical performance trends. Therefore, these reports 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?

Perhaps the greatest benefit of EVM is the discipline of planning the entire program before starting any work. This planning brings forth better visibility and accountability, which aid program managers and contractors in identifying risks and the possible need for over target baselines. 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 a validated system and continuous surveillance of the system to ensure successful completion of a program.

Auditing EVM Systems and Data

Our research has identified a number of best practices that are the basis of effective earned value management and should result in reliable and high-quality earned value management data that can be used for making informed decisions. These best practices have been collapsed into three high level characteristics of a reliable earned value management system:

Comprehensive: a comprehensive EVM system is in place. If the EVM data are to be used to manage a program, the contractors' (and subcontractors') EVM system should be certified to ensure that it complies with the agency's implementation of the 32 guidelines. In addition to a certified system, an Integrated Baseline Review (IBR) must be conducted to ensure that the performance measurement baseline accurately captures all of the work to be accomplished. In order to develop the performance measurement baseline, an integrated network schedule should be developed and maintained. This schedule should reflect the program's work breakdown structure, clearly show the logical sequencing of activities, and identify the resources necessary to complete the activities in order to develop the time-phased budget baseline. Lastly, there should be a rigorous EVM system surveillance program in place. Effective surveillance ensures that the contractor is following its own corporate processes and procedures and confirms that the contractor's processes and procedures continue to satisfy the guidelines.

Accurate: the data resulting from the EVM system are reliable. To ensure the contractor reported data are reliable, it is important to make sure the data are reasonable and do not contain anomalies that would make them invalid. If errors are not detected, then the data will be inaccurate, potentially leading to bad decision making. In addition, the contractor reported data should be consistent between the different formats. Reliable EVM data are necessary to generate meaningful EACs. 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.

Informative: the program management team is using earned value data for decision-making purposes. For EVM data to be useful they must be reviewed regularly. 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. Management should focus on corrective actions and identify ways to manage cost, schedule and technical scope to meet program objectives. Management also needs to ensure that the performance measurement baseline is updated accordingly as changes occur. It is imperative that changes be incorporated into the EVM system as soon as possible to maintain the validity of the performance measurement baseline.

During a program EVM review, auditors should examine the best practices related to each characteristic in order to determine the quality of the overall characteristic. The following shows the characteristics and associated best practices.

Table 30: EVM Best Practices

Characteristic	Best Practice
Comprehensive	The program has a certified EVM system
	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
	The schedule reflects the work breakdown structure, the logical sequencing of activities, and the necessary resources
	EVM system surveillance is being performed
Accurate	EVM system data do not contain anomalies
	EVM system data are consistent among various reporting formats
	Estimates-at-complete are realistic
Informative	EVM system data are reviewed on a regular basis
	Management uses EVM system data to develop corrective action plans
	The performance measurement baseline is updated to reflect changes

Source: GAO. | GAO-20-195G

Survey of EVM

Process Tasks

- Conduct an integrated baseline review that validates the performance measurement baseline
- Receive contract performance reports and conduct monthly EVM Analysis
- Use EVM data to analyze performance
  - validate the data,
  - 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.
- Use EVM data to 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.

- Continue EVM until the program is complete
- Ensure management is kept informed on updates to EACs and other EVM data
- Ensure the EVM System was validated for compliance with the EIA-748 guidelines
- Conduct regular EVM system surveillance to ensure the contractor's effective management of cost, schedule, and technical performance and compliance with EIA-748 guidelines

Best Practices

Establish a comprehensive EVM System

- The program has a certified EVM system.
  - The program has an EVM system that is certified to be compliant with the 32 EVM system guidelines.
  - Documentation identifies when the certification was performed and who did the certification.
- 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.
  - An IBR was conducted for implementation on a program.
  - The IBR identified risks and verified that the baseline's budget and schedule are adequate for performing the work
- The schedule reflects the work breakdown structure, the logical sequencing of activities, and the necessary resources
  - There is evidence that the program has scheduled the authorized work in a way that identifies the program WBS, and describes the sequence of work and the time-phased budget.
- EVM surveillance is being performed by independent and qualified staff.
  - Surveillance reviews are conducted regularly by independent and qualified staff.

Ensure that the data resulting from the EVM system are reliable.

- EVM data do not contain any anomalies.
    - EVM data are validated and reviewed for anomalies
- EVM data are consistent among various reporting formats.
    - EVM data is consistent among all reporting formats.
    - EVM data is reported to management and stakeholders in program briefings and traceable to the EVM reporting formats.
- The estimate at complete is realistic.

Ensure that the program management team is using earned value data for decision-making purposes.

- EVM data, including cost and schedule variances, are reviewed on a regular basis and analysis is conducted on EVM trends and metrics
- Management uses EVM data to develop corrective action plans.
- The performance measurement baseline is updated to reflect changes.

Likely Effects if Criteria Are Not Fully Met

- Unless EVM is implemented at the program level rather than solely at the contract level, the program may not have an effective means to measure how well the government and its contractors are meeting a program's approved cost, schedule, and performance goals.
- Without continuous planning through program-level EVM, program managers may not be able to adequately plan for the receipt of material, for example government-furnished equipment, to ensure that the contractor can execute the program as planned.
- Unless EVM is implemented at the program level rather than solely at the contract level, program managers may have difficulty identifying 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 communicated.
- If a program reports a high amount of level of effort for measuring earned value, it may not be providing objective data and the EVM system will not perform as expected. When level of effort is used excessively for measuring status, the program is not implementing EVM as intended and will fall short of the benefits EVM can offer.
- A continual shift of the baseline budget to match actual expenditures in order to mask cost variances—a rubber baseline—results in

deceptive baselines by covering up variances early in the program, delaying insight until they are difficult, if not impossible, to mitigate.

- If changes are not incorporated quickly, the performance measurement baseline can become outdated. As a result, variances do not reflect reality, which hampers management in realizing the benefits of EVM.
- Unless changes are incorporated into the EVM system as soon as possible, the validity of the performance measurement baseline will not be maintained.
- 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.
- If an IBR is not conducted, management will lack 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.
- Using poor estimates to develop the performance measurement baseline will result in an unrealistic baseline for performance measurement.
- If the performance measurement baseline is not validated through an IBR, there will be less confidence in the accuracy and soundness of monthly EVM reporting.
- If contract performance report data do not accurately reflect how work is being planned, performed, and measured, they cannot be relied on for analyzing actual program status.
- If variance analysis thresholds are not periodically reviewed and adjusted, they may not provide management with the necessary view on current and potential problems.
- If the contract performance report is not detailed enough, cost and schedule trends and their likely effects on program performance will not be transparent.
- If EVM data are not analyzed and reviewed at least monthly, problems may not be addressed as soon as they occur. As a result, cost and schedule overruns may not be avoided, or at least have their effect lessened.
- Unless past performance captured in in a contract performance report is analyzed, management may lack insight into how a program will continue to perform and important lessons learned.

- If contract performance report data are not validated, existing errors will not be detected and the data will be skewed, resulting in erroneous metrics and poor decision making.
- If the contract performance report data contain anomalies, the performance measurement data may be inaccurate.
- Unless EVM data are graphed to determine trends, management may lack valuable information about a program's performance, which is important for accurately predicting costs at completion.
- Unless management knows the reasons for variances, they may not be able to make informed decisions about the best course of action.
- Unless a contractor's estimate-at-complete (EAC) is compared to independent estimates and completion and trend data, management may lack insight into its reasonableness. In addition, requests for additional funds, if necessary, may lack credibility.
- Unless EACs are created not only at the program level but also at lower levels of the WBS, areas that are performing poorly will be masked by other areas doing well.
- Unless management has accurate progress assessments of program status, it may not be able to make informed decisions that lead to greater success; additionally, the ability to act quickly to resolve program problems will be hampered.
- Unless management knows whether the activities that are contributing to a schedule variance are on the critical path or may ultimately be on that path if mitigation is not pursued, it will not be able to project when a program will finish,
- If EVM measures such as variances or indexes are used as award fee criteria, emphasis will be put on the contractor's meeting a predetermined number instead of achieving program outcomes. It may encourage the contractor to behave in undesirable ways, such as overstating performance or changing the baseline budget to meet variance thresholds and secure potential profit.
- Unless the contractor's (and subcontractors') EVM system is validated, there will be a lack of assurance that that it complies with the agency's implementation of the EIA-748 guidelines; that it provides reliable data for managing the program and reporting its status to the government; and that it is actively used to manage the program.
- Unless the contractor's EVM system is subjected to periodic surveillance, the government will lack assurance that it:

- summarizes timely and reliable cost, schedule, and technical performance information directly from its internal management system;
    - complies with the contractor's implementation of EIA-748 guidelines;
    - provides timely indications of actual or potential problems by performing spot checks, sample data traces, and random interviews;
    - maintains baseline integrity;
    - 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.
- If a program requests several overtarget budgets, there may be a severe underlying management problem that should be investigated before a new budget is implemented.

Appendix I: Objectives, Scope, and Methodology

To update this Guide, we sought input and feedback from all who were interested between June and October 2016. We received comments from the public, private companies, trade industry groups, and university researchers, as well as extensive comments from leading practitioners in government agencies and government working groups. We vetted each comment we received on whether it was actionable, within scope, technically correct, and feasible.

We shared new and significantly revised chapters with a committee of cost estimating, scheduling, and earned value management analysis experts. These specialists met at GAO headquarters semi-annually. The meetings were open to all with interest and expertise in cost estimating, schedule, and earned value management, as well as program managers and agency executives. Attendees were from government agencies, private companies, independent consultant groups, trade industry groups, and academia from around the world. We sent agendas to approximately 600 experts, and received feedback and discussion on agenda items through the meeting discussion and from telephone participants and email from members. Meeting minutes were documented and archived.

We reviewed each best practice and revised it if necessary. We based our revisions on our experience applying the best practices in audits since 2007, and endeavored to improve definitions, eliminate redundancy, and more clearly map the steps, best practices, and characteristics associated with a high-quality cost estimate. These changes are summarized in the introduction of this Guide. This revision therefore contains changes from, and supersedes, the 2009 Guide.

We conducted our work from June 2016 to March 2020 in accordance with all sections of GAO's Quality Assurance Framework that are relevant to our objectives. The framework requires that we plan and perform the engagement to obtain sufficient and appropriate evidence to meet our stated objectives and to discuss any limitations in our work. We believe that the information and data obtained, and the analysis conducted, provide a reasonable basis for the guidance in this product.

Appendix II: Case Study Backgrounds

We drew the material in the Guide's 30 case studies from the 26 GAO reports described in this appendix. Table 31 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 31: Case Studies Drawn from GAO Reports Illustrating This Guide

Case study	GAO report	Steps illustrated	Chapter
1, 14	GAO-07-96: *Space Acquisitions*	7	1, 10
2	GAO-14-648: *Federal Real Property*		1
3	GAO-19-223: *Nuclear Waste Cleanup*		1
4, 21	GAO-17-575: *Ford Class Aircraft Carrier*		2, 16
5	GAO-11-325: *Joint Strike Fighter*		2
6	GAO-17-281: *Information Technology*		2
7	GAO-14-82: *Defense Management*	3	6
8	GAO-14-231: *Plutonium Disposition Program*	4	7
9	GAO-15-225: *2020 Census*	4	7
10	GAO-19-497: *Columbia Class Submarine*	5	8
11	GAO-18-158, *Columbia Class Submarine*	5	8
12	GAO-16-439: *F-35 Sustainment*	6	9
13	GAO-12-741: *Coast Guard*	6	9
15, 17	GAO-18-600: *Coast Guard Acquisitions*	7, 9	10, 12
16	GAO-17-29: *Joint Intelligence Analysis Complex*	8	11
18, 29	GAO-16-628: *2020 Census*	9	12, Appx XIII
18	GAO-18-635: *2020 Census*	9	12
19	GAO-18-479: *VA Construction*	10	13
20, 23	GAO-15-596: *Space Launch System*	12	15, 17
22	GAO-15-29: *Project and Program Management*		16
24	GAO-05-183: *Defense Acquisitions*		19
25	GAO-16-112: *James Webb Telescope*		19
26	GAO-13-22: *NASA*		20
27	GAO-04-643R: *Airborne Laser*		20
28	GAO-16-22: *Amphibious Combat Vehicle*		Appx XII
30	GAO-17-398: *Service Contracts*		Appx XIII

Source: GAO. | GAO-20-195G

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, 14: From Space Acquisitions, GAO-07-96, November 17, 2006

Estimated costs for the Department of Defense's (DOD) major space acquisition programs had increased by about $12.2 billion from initial estimates for fiscal years 2006 through 2011. Cost growth for ongoing Air Force programs above initial estimates accounted for a substantial portion of this 44 percent increase. For example, Space Based Infrared System High program costs were originally estimated at $4 billion, but the program was now estimated to cost over $10 billion. Estimated costs for the National Polar-orbiting Operational Satellite System program had grown from almost $6 billion at program start to over $11 billion.

For the most part, cost growth had not been caused by poor cost estimating, but rather the tendency to start programs before knowing whether requirements could be achieved within available resources—largely because of pressures to secure funding. At the same time, however, unrealistic program office cost estimates had exacerbated space acquisition problems. Specifically, with budgets originally set at unrealistic amounts, DOD had to resort to continually shifting funds to and from programs, and such shifts had costly, reverberating effects.

GAO's analyses of six space programs found that original cost estimates were particularly unrealistic about the promise of savings from increased contractor program management responsibilities, the constancy and availability of the industrial base, savings that could be accrued from heritage systems, the amount of weight growth that would occur during a program, the availability of mature technology, the stability of funding, the stability of requirements, and the achievability of planned schedules. At times, estimates that were more realistic in these areas were available to the Air Force, but they were not used.

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*, GAO-07-96.

Case Study 2: From *Federal Real Property*, GAO-14-648, September 19, 2014

Department of Homeland Security (DHS) and General Services Administration (GSA) were managing an estimated $4.5 billion construction project at the St. Elizabeth's Campus in Washington, D.C. The project, designed to consolidate DHS's executive leadership, operational management, and other personnel at one secure location rather than at multiple locations throughout the Washington, D.C., metropolitan area, had a projected completion date of 2026.

DHS and GSA planning for the DHS headquarters consolidation did not fully conform with leading capital decision-making practices intended to help agencies effectively plan and procure assets. DHS and GSA officials reported that they had taken some initial actions that may facilitate consolidation planning in a manner consistent with leading practices, such as adopting recent workplace standards at the department level and assessing DHS's leasing portfolio. For example, DHS had an overall goal of reducing the square footage allotted per employee across DHS in accordance with current workplace standards. Officials acknowledged that this could allow more staff to occupy less space than when the campus was initially planned in 2009. DHS and GSA officials also reported analyzing different leasing options that could have affected consolidation efforts. However, consolidation plans, which were finalized between 2006 and 2009, had not been updated to reflect these changes.

According to DHS and GSA officials, the funding gap between what was requested and what was received from fiscal years 2009 through 2014 was over $1.6 billion. According to these officials, this gap has escalated estimated costs by over $1 billion—from $3.3 billion to the current $4.5 billion—and delayed scheduled completion by over 10 years, from an original completion date of 2015 to the current estimate of 2026. However, DHS and GSA had not conducted a comprehensive assessment of current needs, identified capability gaps, or evaluated and prioritized alternatives to help them adapt consolidation plans to changing conditions and address funding issues as reflected in leading practices. DHS and GSA reported that they had begun to work together to consider changes to their plans, but as of August 2014, they had not announced when new plans will be issued and whether they would fully conform to leading capital decision-making practices to help plan project implementation.

DHS and GSA did not follow relevant GSA guidance and GAO's leading practices when developing the cost and schedule estimates for the St. Elizabeth's project, and the estimates were unreliable. For example, GAO found that the 2013 cost estimate did not include a life cycle cost analysis of the project, including the cost of operations and maintenance; was not regularly updated to reflect significant program changes, including actual costs; and did not include an independent estimate to help track the budget, as required by GSA guidance. Also, the 2008 and 2013 schedule estimates did not include all activities for the government and its contractors needed to accomplish project objectives. GAO's comparison of the cost and schedule estimates with leading practices identified the same concerns, as well as others. For example, a sensitivity analysis had not been performed to assess the reasonableness of the cost estimate. For the 2008 and 2013 schedule estimates, resources (such as labor and materials) were not accounted for and a risk assessment had not been conducted to predict a level of confidence in the project's completion date.

Because DHS and GSA project cost and schedule estimates informed Congress's funding decisions and affected the agencies' abilities to effectively allocate resources, there was a risk that funding decisions and resource allocations could have been made based on information that was not reliable or was out of date.

GAO reported its findings on September 19, 2014 in *Federal Real Property: DHS and GSA Need to Strengthen the Management of DHS Headquarters Consolidation*, GAO-14-648.

Case Study 3: From *Nuclear Waste Cleanup*, GAO-19-223, February 19, 2019

Fifty years of federal nuclear weapons production and energy research during the Cold War generated millions of gallons of liquid radioactive waste, millions of cubic meters of solid radioactive waste, thousands of tons of spent nuclear fuel and special nuclear material, and large quantities of contaminated soil and water. In 1989, the Department of Energy (DOE) established its nuclear waste cleanup program by creating the Office of Environmental Management (EM). The EM program's mission is to complete the safe cleanup of this Cold War legacy and to work to reduce associated risks and costs within the established regulatory framework.

EM manages most of its cleanup of nuclear waste (77 percent of its fiscal year 2019 budget) under a category that EM refers to as operations activities, using less stringent requirements than are used for its capital asset projects. EM's mission is to complete the cleanup of nuclear waste at 16 DOE sites and to work to reduce risks and costs within its established regulatory framework. In December 2018, DOE reported that it faced an estimated $494 billion in future environmental cleanup costs.

GAO was asked to examine EM's operations activities. The report examined, among other objectives, (1) how EM manages its cleanup work and (2) the extent to which EM's cleanup policy followed selected leading practices for program and project management.

Our analysis of EM contractors' EVM systems for operations activities found that EM had not followed best practices for a reliable EVM system. The EVM data for contracts covering operations activities contained numerous, unexplained anomalies in all the reports GAO reviewed, including missing or negative values for some of the completed work to date. Negative values should occur rarely, if ever, in EVM reporting because they imply the undoing of previously scheduled or performed work. In addition, GAO found problems with the estimate at completion in all 20 contractors' EVM systems. More specifically, GAO found (1) many instances where the actual costs exceeded the estimates at completion even though there was still a significant amount of work remaining; (2) several occasions where the estimates at completion were less than half of the original budget at the beginning of the project; and (3) several contractors reported estimates at completion of zero dollars when their original budgets were for hundreds of millions of dollars. These problems indicated that the EVM systems were not being updated in a timely manner or were not well monitored since the estimate at completion values were too optimistic and highly unlikely.

Even though EM required most of its contractors for operations activities to maintain EVM systems, EM's 2017 policy generally did not require that EVM systems be maintained and used in a way that follow EVM best practices. Until EM updated its cleanup policy to require that EVM systems be maintained and used in a way that follow EVM best practices, EM leadership may not have had access to reliable performance data to make informed decisions in managing its cleanup work and to provide to Congress and other stakeholders on billions of dollars' worth of cleanup work every year.

GAO reported its findings on February 19, 2019 in *Nuclear Waste Cleanup: DOE Could Improve Program and Project Management by Better Classifying Work and Following Leading Practices*, GAO-19-223.

Case Study 4, 21: From *Ford-Class Aircraft Carrier*, GAO-17-575, June 13, 2017

The Navy intended for the Ford class aircraft carrier to improve combat capability while reducing acquisition and life cycle costs. However, as GAO reported on extensively since 2007, the lead ship experienced cost growth of nearly 23 percent, with a reduced capability expected at delivery. CVN 78 was estimated to cost $12.9 billion, while the next ship, CVN 79, was estimated to be $11.4 billion. The Navy planned to buy 1-2 more ships in the coming years.

The cost estimate for the second Ford class aircraft carrier, CVN 79, was not reliable and did not address lessons learned from the performance of the lead ship, CVN 78. As a result, the estimate did not demonstrate that the program could meet its $11.4 billion cost cap. Cost growth for the lead ship was driven by challenges with technology development, design, and construction, compounded by an optimistic budget estimate. Instead of learning from the mistakes of CVN 78, the Navy developed an estimate for CVN 79 that assumed a reduction in labor hours needed to construct the ship that was unprecedented in the past 50 years of aircraft carrier construction.

After developing the program estimate, the Navy negotiated 18 percent fewer labor hours for CVN 79 than were required for CVN 78. CVN 79's estimate was optimistic compared to the labor hour reductions calculated in independent cost reviews conducted in 2015 by the Naval Center for Cost Analysis and the Office of Cost Assessment and Program Evaluation. Navy analysis showed that the CVN 79 cost estimate may not have sufficiently accounted for program risks, with the current budget likely insufficient to complete ship construction.

The Navy's reporting mechanisms, such as budget requests and annual acquisition reports to Congress, provided limited insight into the overall Ford class program and individual ship costs. For example, the program requested funding for each ship before that ship obtained an independent cost estimate. During an 11-year period prior to 2015, no independent cost estimate was conducted for any of the Ford class ships; however, the program received over $15 billion in funding. In addition, the program's selected acquisition reports—annual cost, status, and performance reports to Congress—provided only aggregate program cost for all three ships currently in the class, a practice that limited transparency into individual ship costs. As a result, Congress had diminished ability to oversee one of the most expensive programs in the defense portfolio.

GAO reported these findings on June 13, 2017 in *Ford-Class Aircraft Carrier: Follow-On Ships Need More Frequent and Accurate Cost Estimates to Avoid Pitfalls of Lead Ship*, GAO-17-575.

Case Study 5: From *Joint Strike Fighter*, GAO-11-325, April 7, 2011

The F-35 Lightning II, also known as the Joint Strike Fighter (JSF), is the Department of Defense's (DOD) most costly and ambitious aircraft acquisition, seeking to simultaneously develop and field three aircraft variants for the Air Force, Navy, Marine Corps, and eight international partners. The JSF is critical for recapitalizing tactical air forces and will require a long-term commitment to very large annual funding outlays. The estimated investment at the time was $382 billion to develop and procure 2,457 aircraft.

DOD continues to substantially restructure the JSF program, taking positive actions that should lead to more achievable and predictable outcomes. Restructuring has consequences—higher up-front development costs, fewer aircraft in the near term, training delays, and extended times for testing and delivering capabilities to warfighters.

Total development funding was $56.4 billion to complete in 2018, a 26 percent increase in cost and a 5-year slip in schedule compared to the baseline in 2011. DOD also reduced procurement quantities by 246 aircraft through 2016, but had not calculated the net effects of restructuring on total procurement costs nor approved a new baseline. Affordability for the U.S. and partners is challenged by a near doubling in average unit prices since program start and higher estimated life cycle costs. Going forward, the JSF requires unprecedented funding levels in a period of more austere defense budgets.

GAO reported its findings on April 7, 2011 in *Joint Strike Fighter: Restructuring Places Program on Firmer Footing, but Progress Still Lags*, GAO-11-325.

Case Study 6: From *Information Technology*, GAO-17-281, February 7, 2017

Department of Housing and Urban Development (HUD) relies extensively on IT to deliver services and manage programs in support of its mission. For fiscal year 2017, HUD requested $36 million for IT investments intended to deliver modernized enterprise-level capabilities that better support the department's mission. Critical to the success of such efforts is the department's ability to develop reliable cost estimates that project life cycle costs and provide the basis for, among other things, informed decision making and realistic budget formulation.

The cost estimates that HUD developed for the four selected information technology (IT) investments were unreliable and, thus, lacked a sound basis for informing the department's investment and budgetary decisions. GAO's Cost Estimating and Assessment Guide (*Cost Guide*) defines best practices that are associated with four characteristics of a reliable estimate—comprehensive, well documented, accurate, and credible. However, none of the cost estimates for the selected investments exhibited all of these characteristics. Only one estimate—for the Customer Relationship Management investment—more than minimally met best practices associated with any of the four characteristics because it partially met the practices for a comprehensive and accurate estimate. The remaining three investments minimally or did not meet the best practices associated with the four characteristics. For example, the Enterprise Data Warehouse estimate minimally met all four characteristics; the Enterprise Voucher Management System estimate did not meet the characteristic for being accurate and minimally met the other three characteristics; and the Federal Housing Administration Automation and Modernization estimate did not meet the characteristic for being credible, while minimally meeting the remaining characteristics.

The significant weaknesses in the cost estimates for the selected investments could largely be attributed to the department's lack of guidance for developing reliable cost estimates. HUD officials responsible for the selected investments stated that the department had not required the development of estimates that exhibited the four characteristics of a reliable estimate. As a result, according to these officials, cost estimating practices had been decentralized and inconsistent across the department. While HUD drafted guidance in June 2015 that was intended to conform to the best practices in GAO's *Cost Guide*, the department had not yet finalized the guidance because it had focused on establishing the infrastructure needed to support improved cost estimation practices. Until HUD finalized and ensured the implementation of guidance to improve its cost estimating practices, the department was at risk of continuing to make investment decisions based on unreliable information.

GAO recommended that to increase the likelihood that its IT investments develop reliable cost estimates, the Secretary of HUD should finalize, and ensure the implementation of, guidance that incorporates the best practices called for in the GAO *Cost Estimating and Assessment Guide.*

GAO reported its findings on February 7, 2017 in GAO, *Information Technology: HUD Needs to Address Significant Weaknesses in Its Cost Estimating Practices*, GAO-17-281.

Case Study 7: From *Defense Management*, GAO-14-82, December 17, 2013

In 2006, the United States and Japan planned to relocate 17,600 U.S. Marines and dependents from Japan to Guam. However, in 2012, representatives from the countries developed a revised plan under which 6,300 Marines and dependents would relocate to Guam.

Some investments had been made to improve Guam's public infrastructure, but many deficiencies and regulatory compliance issues continued to exist. The reliability, capacity, and age of much of the public infrastructure—especially the island's utilities—indicated a need for additional upgrades to be able to meet current and future demands related to the realignment. Further, some infrastructure sectors, such as water and wastewater, faced issues complying with federal regulations. Other sectors, such as the fire and police departments, were experiencing staffing and other shortages that affected their ability to serve Guam's population.

Despite the reduction of Marines and dependents relocating to Guam, DOD had not yet revalidated the public infrastructure requirements based on the revised realignment plan or differentiated between requirements needed to address long-standing conditions and those related to the realignment. This revalidation was not expected to be completed until 2015. Even so, DOD had requested over $400 million for Guam public infrastructure projects in its budget requests since fiscal year 2012. It was unclear if all of these projects were necessary to the same extent given the reduction in forces. For example, if DOD decided to locate the Marines on the naval base that handled all of its own water/wastewater needs, public water/wastewater improvements would not have been needed to support the Marines. Congress had placed limitations on the use of funding, in part until certain information was provided related to the realignment. Without revalidating and differentiating between requirements, DOD could not clearly identify what Guam public infrastructure requirements were needed to directly support the realignment.

The $1.3 billion cost estimate for improvements to Guam's water and wastewater systems that DOD had used to support budget requests for fiscal years 2013 and 2014 was not reliable. GAO assessed that the estimate minimally met the best practice criteria for three of the four key characteristics—comprehensive, well documented, and accurate—for a reliable cost estimate as identified in the GAO *Cost Estimating and Assessment Guide* and did not satisfy best practice criteria for the fourth characteristic of being credible. GAO determined that officials adhered to some best practices for a reliable estimate but did not, for example, include all relevant costs; sufficiently explain why certain assumptions and adjustments were made; incorporate actual costs or inflation adjustments; or adequately address risk and uncertainty.

GAO recommended that, to provide DOD and Congress with sufficient information regarding the requirements and costs associated with DOD's Guam realignment plans and the public infrastructure necessary to support that realignment, the Secretary of Defense should direct the Department of the Navy's Joint Guam Program Office in concert with the Office of Economic Adjustment to, as future cost estimates for Guam public infrastructure projects are developed, fully incorporate the best practices identified by GAO for developing high-quality cost estimates. As a result of GAO's recommendation, in August 2015 DOD followed the standards set forth in GAO's Cost Estimating and Assessment Guide and revised its cost estimates for public infrastructure needs on Guam. In doing so, DOD reduced its estimate and future budget requests.

GAO reported its findings on December 17, 2013 in *Defense Management: Further Analysis Needed to Identify Guam's Public Infrastructure Requirements and Costs for DOD's Realignment Plan*, GAO-14-82.

Case Study 8: From *Plutonium Disposition Program*, GAO-14-231, February 13, 2014

The Department of Energy's (DOE) National Nuclear Security Administration (NNSA), a separately organized agency within DOE, manages the Plutonium Disposition program to dispose of surplus weapons-grade plutonium by burning it as Mixed Oxide (MOX) fuel—a mixture of plutonium and uranium oxides—in specially modified commercial nuclear reactors. In 2012, DOE forecasted cost increases of close to $3 billion over the previous estimates for the program's two construction projects, the MOX facility and the Waste Solidification Building (WSB) for disposing of waste from the MOX facility.

NNSA identified various drivers for the close to $3 billion increase in the estimated cost of the Plutonium Disposition program's two construction projects—the MOX Fuel Fabrication Facility and the WSB. These drivers included DOE's approval of the MOX facility's cost and schedule estimates before design was complete and schedule delays in construction of the WSB. According to NNSA, the cost of critical system components for the MOX facility averaged 60 percent higher than estimated as a result of approval of estimates before design was complete.

GAO's assessment of NNSA's process for developing its draft life cycle cost estimate found, in part, that the estimate was only partially comprehensive. GAO found that work breakdown structures were developed for the MOX and WSB projects and other components of the program, but that NNSA had not formalized a program-level work breakdown structure. A typical work breakdown structure provides a clear picture of what needs to be accomplished, how the work will be done, and a basis for identifying resources and tasks for developing a cost estimate. Without a program-level work breakdown structure, NNSA could not ensure that its life cycle cost estimate captured all relevant costs, which could lead to cost overruns.

GAO recommended that to identify lessons learned from and provide assurance of preventing recurrence of cost increases for the MOX facility and WSB, and to develop reliable cost estimates for the Plutonium Disposition program, the Secretary of Energy should direct the DOE and NNSA Offices of Acquisition and Project Management and the NNSA office responsible for managing the Plutonium Disposition program, as appropriate, to revise and update the program's life cycle cost estimate following the 12 key steps described in the GAO *Cost Estimating and Assessment Guide* for developing high-quality cost estimates, such as conducting an independent cost estimate to provide an objective and unbiased assessment of whether the estimate can be achieved. In 2017, NNSA directed its Office of Cost Estimating and Program Evaluation to develop a new life cycle estimate for the plutonium disposition program based on NNSA's preferred approach of dilute and dispose. That estimate was completed in March 2018. The estimate was directed to be done in accordance with GAO cost estimating and assessment best practices. Further, to ensure that the estimate followed best practices, NNSA officials said that they planned to contract with the U.S. Army Corps of Engineers for an independent review to ensure the cost estimate followed GAO's best practices.

GAO reported these findings on February 13, 2014 in *Plutonium Disposition Program: DOE Needs to Analyze the Root Causes of Cost Increases and Develop Better Cost Estimates*, GAO-14-231.

Case Study 9: From *2020 Census*, GAO-15-225, February 5, 2015

The U.S. Census Bureau (Bureau) planned to significantly change the methods and technology it used to count the population with the 2020 Decennial Census, such as offering an option for households to respond to the survey via the Internet. This involved developing and acquiring IT systems and infrastructure to support the collection and processing of Internet response data. GAO was asked to review the Bureau's efforts to deliver an Internet response option for the 2020 census. Among other objectives, GAO was asked to assess the reliability of estimated costs and savings for Internet response. To do this, GAO reviewed Bureau studies, cost estimates, project plans, schedules, and other documentation.

The Bureau had taken preliminary steps and planned to further examine the impact of introducing an Internet response option on historically hard-to-count segments of the population (these include, but are not limited to, minorities, renters, children, low-income households, and low-education households). For example, the Bureau was applying lessons learned from its implementation of an Internet response option for another household survey, called the American Community Survey, which is conducted on a smaller scale than the decennial census. Additionally, the Bureau planned two 2020 census field tests in 2015 that were expected to provide data on Internet response rates among different demographic groups, including the historically hard-to-count populations.

The Bureau's preliminary estimated costs of about $73 million for the Internet response option were not reliable because its estimate did not conform to best practices. For example, the estimate had not been updated to reflect significant changes related to the Internet response option that had occurred since it was developed in 2011. Additionally, the unreliability of the Bureau's cost estimate for the Internet response option cast doubt on the reliability of associated potential cost savings estimates. Officials recognized weaknesses in the Bureau's cost estimate and stated that they planned to update it based on a preliminary decision for the overall design of the 2020 census.

GAO recommended that to ensure that the Bureau was better positioned to deliver an Internet response option for the 2020 Decennial Census, the Secretary of Commerce should direct the Under Secretary for Economic Affairs to direct the Director of the Census Bureau to ensure that the estimated costs associated with the Internet response option were updated to reflect significant changes in the program and to fully meet the characteristics of a reliable cost estimate. The Department of Commerce agreed with the recommendation and took steps to implement it. In August 2017, the Census Bureau finalized its Census Enterprise Data Collection and Processing (CEDCAP) Cost Analysis Requirements Description (CARD) that included a basis for estimating the costs associated with the Internet response option. Subsequently, in December 2017, the Bureau finalized its updated 2020 Decennial life cycle cost estimate that included the CEDCAP CARD as an input to the estimate. GAO's April 2018 analysis of the updated cost estimate found that the Bureau had made significant improvements in its cost estimation process across the four characteristics of a reliable estimate. As a result, the Bureau was better positioned to deliver an Internet response option for the 2020 Decennial Census.

GAO reported these findings on February 5, 2015 in *2020 Census: Key Challenges Need to Be Addressed to Successful Enable Internet Response*, GAO-15-225.

Case Study 10: From *Columbia Class Submarine*, GAO-19-497, April 8, 2019

The Navy has identified the Columbia class submarine program as its top acquisition priority. It plans to invest over $100 billion to develop and purchase 12 nuclear-powered ballistic missile submarines to replace aging Ohio class submarines by 2031. The Navy's goal was to complete a significant amount of the Columbia class submarine's design—83 percent—before lead submarine construction began in October 2020. The Navy established this goal based on lessons learned from another submarine program in an effort to help mitigate its aggressive construction schedule. The shipbuilder had to use a new design tool to complete an increasingly higher volume of complex design products. The shipbuilder hired additional designers to improve its design progress. The Navy also planned to start advance construction of components in each major section of the submarine, beginning in fiscal year 2019, when less of the design would be complete

Navy cost estimators identified labor costs as a primary source of cost risk, but the Navy's $115 billion procurement cost estimate was not reliable partly because it was based on overly optimistic assumptions about the labor hours needed to construct the submarines. The Navy anticipated that it would need 12 million labor hours to directly construct the lead submarine. This represented 17 percent fewer labor hours than what was needed for the lead Virginia class submarine, when adjusted for weight differences. To develop this estimate, Navy estimators relied heavily on historical labor hour data from the construction of the lead Virginia class submarine and cost data from the Ohio class submarine program for unique ballistic submarine components, such as missiles. However, the labor hour estimate was overly optimistic—with assumptions on construction efficiencies that were either unsubstantiated or unprecedented compared to Virginia class and other shipbuilding historical data.

Compared to the Navy's estimate, Columbia's estimated touch labor hours, as calculated by other organizations, were more conservative. For example, the Congressional Budget Office questioned the Navy's assumption that ballistic submarines are less expensive to build than attack submarines, after accounting for weight differences. They estimated that for the overall class, including the lead and follow-on submarines, the Navy would more likely realize an 8 percent reduction rather than the 19 percent reduction estimated by the Navy. If the program's optimistic assumptions were not realized, the program may have required more funding than originally planned to construct the Columbia class.

The Navy told GAO it would continue to update its lead submarine cost estimate, but an independent assessment of the estimate would not be complete in time to inform the Navy's 2021 budget request to Congress to purchase the lead submarine. Without these reviews, the cost estimate—and, consequently, the budget—may have been unrealistic. A reliable cost estimate is especially important for a program of this size and complexity to help ensure that its budget is sufficient to execute the program as planned.

In addition, the Navy was using the congressionally-authorized National Sea-Based Deterrence Fund to construct the Columbia class. The Fund allowed the Navy to purchase material and start construction early on multiple submarines prior to receiving congressional authorization and funding for submarine construction. The Navy anticipated achieving savings through use of the Fund, such as buying certain components early and in bulk, but did not include the savings in its cost estimate. The Navy may have overestimated its savings as higher than those historically achieved by other such programs. Without an updated cost estimate and cost risk analysis, including a realistic estimate of savings, the fiscal year 2021 budget request may not have reflected funding needed to construct the submarine

GAO reported these findings on April 8, 2019 in *Columbia Class Submarine: Overly Optimistic Cost Estimate Will Likely Lead to Budget Increases*, GAO-19-497.

Case Study 11: From *Columbia Class Submarine*, GAO-18-158, December 21, 2017

The Navy's Columbia class ballistic missile submarines will replace the 14 Ohio class that currently provide the sea-based leg of the U.S. nuclear triad, slated to begin retiring in 2027. The first Columbia must begin patrols in 2031 to prevent a gap in deterrent capabilities; the class will ultimately carry up to 70 percent of the nation's strategic nuclear capability. The program is a top Navy priority with an expected cost of $267 billion over its life cycle, including $128 billion to research, develop, and buy 12 submarines.

GAO found that additional development and testing were required to demonstrate the maturity of several Columbia class submarine technologies that were critical to performance, including the Integrated Power System, nuclear reactor, common missile compartment, and propulsor and related coordinated stern technologies. As a result, it was unknown whether they would work as expected, be delayed, or cost more than planned. Any unexpected delays could postpone the deployment of the lead submarine past the 2031 deadline.

Further, the Navy underrepresented the program's technology risks in its 2015 Technology Readiness Assessment (TRA) when it did not identify these technologies as critical. Development of these technologies was key to meeting cost, schedule, and performance requirements. A reliable TRA serves as the basis for realistic discussions on how to mitigate risks as programs move forward from the early stages of technology development. Not identifying these technologies as critical meant Congress may not have had the full picture of the technology risks and their potential effect on cost, schedule, and performance goals as increasing financial commitments were made. The Navy was not required to provide Congress with an update on the program's progress, including its technology development efforts, until fiscal year 2020—when $8.7 billion for lead ship construction would have already been authorized. Periodic reporting on technology development efforts in the interim could have provided decision-makers assurances about the remaining technical risks as the Navy asked for increasing levels of funding.

Consistent with GAO's identified best practices, the Navy intended to complete much of the submarine's overall design prior to starting construction to reduce the risk of cost and schedule growth. However, the Navy awarded a contract for detail design while critical technologies remained unproven—a practice not in line with best practices that led to cost growth and schedule delays on other programs. Proceeding into detail design and construction with immature technologies can lead to design instability and cause construction delays. The Navy planned to accelerate construction of the lead submarine to compensate for an aggressive schedule, which may have led to future delays if the technologies were not fully mature before construction started in 2021.

GAO reported these findings on December 21, 2017 in *Columbia Class Submarine: Immature Technologies Present Risks to Achieving Cost, Schedule, and Performance Goals*, GAO-18-158.

Case Study 12: From *F-35 Sustainment*, GAO-16-439, April 14, 2016

The F-35 is the most ambitious and expensive weapon system in Department of Defense's (DOD) history, with sustainment costs comprising the vast majority of DOD's $1.3 trillion cost estimate. Central to F-35 sustainment is the Autonomic Logistics Information System (ALIS)—a complex system supporting operations, mission planning, supply-chain management, maintenance, and other processes.

The F-35 program was approaching several key milestones: the Air Force and Navy were to declare the ability to operate and deploy the F-35 in 2016 and 2018 respectively, and full-rate production of the aircraft was to begin in 2019. However, ALIS had experienced developmental issues and schedule delays that put aircraft availability and flying missions at risk.

DOD was aware of risks that could have affected ALIS, but did not have a plan to ensure that ALIS was fully functional as key program milestones approached. ALIS users, including pilots and maintainers, in GAO's focus groups identified benefits of the system, such as the incorporation of multiple functions into a single system. However, users also identified several issues that could have resulted in operational and schedule risks. DOD was taking some steps to address these and other risks such as resolving smaller ALIS functionality issues between major software upgrades and considering the procurement of additional ALIS infrastructure, but the department was attending to issues on a case-by-case basis. DOD did not have a plan that prioritized ALIS risks to ensure that the most important are expediently addressed and that DOD had a fully functional ALIS as program milestones drew close. By responding to issues on a case-by-case basis rather than in a holistic manner, there was no guarantee that DOD would address the highest risks by the start of full-rate production in 2019, and as a result, DOD may have encountered further schedule and development delays, which could have affected operations and potentially led to cost increases.

DOD had estimated total ALIS costs to be about $16.7 billion over the F-35's 56-year life cycle, but performing additional analyses and including historical cost data would have increased the credibility and accuracy of DOD's estimate. GAO's cost estimating best practices state that cost estimates should include uncertainty analyses to determine the level of uncertainty associated with the estimate in order to be credible. In addition, credible cost estimates should include sensitivity analyses to examine how changes to individual assumptions and inputs affect the estimate as a whole. DOD's guidance did not require the department to perform these analyses for ALIS, and DOD officials stated that they had not done so in part because ALIS constitutes less than 2 percent of the F-35's estimated total sustainment costs. Program officials said that if ALIS was not fully functional, the F-35 could not be operated as frequently as intended, but a DOD commissioned plan found that schedule slippage and functionality problems with ALIS could have led to $20-100 billion in additional costs. Without uncertainty and sensitivity analyses, it was unclear how ALIS could affect costs. GAO also found that using historical cost data would have made DOD's cost estimate more accurate.

GAO reported these findings on April 14, 2016 in *F-35 Sustainment: DOD Needs a Plan to Address Risks Related to Its Central Logistics System*, GAO-16-439.

Case Study 13: From *Coast Guard*, GAO-12-741, July 31, 2012

The Coast Guard's legacy vessels were either approaching or had exceeded their designed life expectancies. The Coast Guard is replacing these vessels with a more capable fleet; however, cost and management problems have led to delays in the delivery of new vessels. From fiscal years 2005 through 2011, the physical condition of the Coast Guard's legacy vessels was generally poor; and the Coast Guard had taken two key actions to improve the vessels' condition: reorganizing its maintenance command structure and implementing sustainment initiatives for portions of its legacy vessel fleet. The Coast Guard's primary measure of a vessel's condition is the operational percent of time free of major casualties (a major casualty is a deficiency in mission essential equipment that causes the major degradation or loss of a primary mission). This measure showed that the 378-foot high endurance cutters (HEC), the 210-foot and 270-foot medium endurance cutters (MEC), and 110-foot patrol boats generally remained well below target levels from fiscal years 2005 through 2011. To improve the condition of the vessel fleet, in 2009, the Coast Guard reorganized its maintenance command structure to focus on standardization of practices, and reported it was on schedule to complete sustainment initiatives by fiscal year 2014, which were intended to improve vessel operating and cost performance.

Annual maintenance expenditures for the legacy vessel fleet—such as those associated with scheduled maintenance costs—declined from fiscal years 2005 to 2007 and then rose from fiscal years 2007 to 2011; and the Coast Guard's maintenance cost estimating process did not fully reflect best practices. Scheduled maintenance expenditures rose from $46.1 million to $85.2 million from fiscal years 2008 to 2009, an increase Coast Guard officials attributed to better identifying maintenance needs and receiving supplemental funding. GAO's Cost Estimating and Assessment Guide states that a high-quality and reliable cost estimate includes best practice characteristics, three of which are relevant to the Coast Guard's process: well documented, comprehensive, and accurate. The Coast Guard's process partially met these characteristics. For example, it was partially comprehensive because it defined the program, among other things, but did not document all cost-influencing ground rules and assumptions (e.g., inflation rate). Annual cost estimates for legacy vessel fleet maintenance that incorporate established best practices would have provided better information to inform the Coast Guard's decisions in effectively allocating available resources in the constrained federal budget environment.

GAO recommended that to strengthen the comprehensiveness, documentation, and accuracy of the Coast Guard's annual depot-level maintenance cost estimates for its legacy vessel fleet, the Secretary of Homeland Security should direct the Commandant of the Coast Guard to ensure that the Coast Guard's annual depot-level maintenance cost estimates conform to cost-estimating best practices. In July 2013, the Coast Guard issued the Government Estimating for Ship Repair Process Guide, which the Coast Guard reported was to incorporate best practices for cost estimating that could be adapted for use in estimating the cost of legacy vessel repairs. The document made improvements in each of the three relevant characteristics: comprehensiveness, documentation, and accuracy.

GAO reported these findings on July 31, 2012 in *Coast Guard: Legacy Vessels' Declining Conditions Reinforce Need for More Realistic Operational Targets*, GAO-12-741.

Case Study 15, 17: From *Coast Guard Acquisitions*, GAO-18-600, September 4, 2018

To maintain heavy polar icebreaking capability, the Coast Guard—a component of the Department of Homeland Security (DHS) — and the Navy are collaborating to acquire up to three new heavy polar icebreakers through an integrated program office. The Navy planned to award a contract in 2019. GAO has found that before committing resources, successful acquisition programs begin with sound business cases, which include plans for a stable design, mature technologies, a reliable cost estimate, and a realistic schedule.

GAO found that the Coast Guard did not have a sound business case in March 2018, when it established the cost, schedule, and performance baselines for its heavy polar icebreaker acquisition program, because of risks in four key areas:

Design. The Coast Guard set program baselines before conducting a preliminary design review, which put the program at risk of having an unstable design, thereby increasing the program's cost and schedule risks. While setting baselines without a preliminary design review is consistent with DHS's current acquisition policy, it is inconsistent with acquisition best practices. Based on GAO's prior recommendation, DHS was currently evaluating its policy to better align technical reviews and acquisition decisions.

Technology. The Coast Guard intended to use proven technologies for the program, but did not conduct a technology readiness assessment to determine the maturity of key technologies prior to setting baselines. Coast Guard officials indicated such an assessment was not necessary because the technologies the program planned to employ had been proven on other icebreaker ships. However, according to best practices, such technologies can still pose risks when applied to a different program or operational environment, as in this case. Without such an assessment, the program's technical risk was underrepresented.

Cost. The life cycle cost estimate that informed the program's $9.8 billion cost baseline substantially met GAO's best practices for being comprehensive, well documented, and accurate, but only partially met best practices for being credible. The cost estimate did not quantify the range of possible costs over the entire life of the program. As a result, the cost estimate was not fully reliable and may have underestimated the total funding needed for the program.

Schedule. The Coast Guard's planned delivery dates were not informed by a realistic assessment of shipbuilding activities, but rather driven by the potential gap in icebreaking capabilities once the Coast Guard's only operating heavy polar icebreaker—the Polar Star—reaches the end of its service life.

GAO's analysis of selected lead ships for other shipbuilding programs found the icebreaker program's estimated construction time of 3 years was optimistic. As a result, the Coast Guard was at risk of not delivering the icebreakers when promised and the potential gap in icebreaking capabilities could have widened.

GAO reported its findings on September 4, 2018 in *Coast Guard Acquisitions: Polar Icebreaker Program Needs to Address Risks before Committing Resources*, GAO-18-600.

Case Study 16: From *Joint Intelligence Analysis Complex*, GAO-17-29, November 3, 2016

Department of Defense's (DOD) Joint Intelligence Analysis Complex (JIAC), which provides critical intelligence support for the U.S. European and Africa Commands and U.S. allies, is currently located in what DOD has described as inadequate and inefficient facilities at Royal Air Force (RAF) Molesworth in the United Kingdom. To address costly sustainment challenges and instances of degraded theater intelligence capabilities associated with the current JIAC facilities, the Air Force plans to spend almost $240 million to consolidate and relocate the JIAC at RAF Croughton in the United Kingdom.

GAO assessed the cost estimate for the military construction project to consolidate and relocate the JIAC at RAF base Croughton and found that it partially met three and minimally met one of the four characteristics of a reliable cost estimate defined by GAO best practices. For example, it minimally met the credibility standard because it did not contain a sensitivity analysis; such analyses reveal how the cost estimate is affected by a change in a single assumption, without which the estimator will not fully understand which variable most affects the estimate. Unless the DOD's methodology incorporated all four characteristics of a high-quality, reliable estimate in preparing future cost estimates for the JIAC construction project, it would not provide decision-makers with reliable information.

After DOD's 2013 decision to consolidate the JIAC at RAF Croughton, DOD organizations conducted multiple reviews in response to congressional interest in Lajes Field, Azores (Portugal) as a potential alternative location for the JIAC. These reviews produced different cost estimates, in particular for housing and communications infrastructure, because the DOD organizations that developed them relied on different assumptions. DOD officials said that these reviews were not conducted with the same level of rigor as formal cost estimates, because DOD had concluded its analysis of alternatives and no credible new evidence had been produced to indicate the department should revisit its initial decision to consolidate the JIAC at RAF Croughton.

GAO reported these findings on November 3, 2016 in *Joint Intelligence Analysis Complex: DOD Needs to Fully Incorporate Best Practices into Future Cost Estimates*, GAO-17-29.

Case Study 18, 29: From *2020 Census*, GAO-18-635, August 17, 2018 and GAO-16-628, June 30, 2016

To help control costs while maintaining accuracy, the Census Bureau was introducing significant change to how it conducted the decennial census in 2020. Its planned innovations included reengineering how it built its address list, improving self-response by encouraging the use of the Internet and telephone, using administrative records to reduce field work, and reengineering field operations using technology to reduce manual effort and improve productivity. The Bureau estimated that if it succeeded with these innovations it could conduct the 2020 Census for $12.5 billion in constant 2020 dollars. By contrast, the 2020 Census would cost $17.8 billion in constant 2020 dollars if the Bureau had repeated the 2010 Census design and methods, according to the Bureau's estimates.

As early as 2011, the Bureau began developing preliminary cost estimates of the 2020 Census in order to approximate potential savings from its plans to reengineer the census, and, according to the Bureau, to begin developing the methodology for producing the decennial life cycle cost estimates.

The Bureau’s October 2015 release of the latest cost estimate marked the transition from the “research” to “implementation” phases of the 2020 Census. According to the Bureau, this was the Bureau’s first attempt to model the life cycle cost of its planned 2020 Census, in contrast to its earlier 2011 estimate which the Bureau said was intended to produce an approximation of potential savings and to begin developing the methodology for producing decennial life cycle cost estimates covering all phases of the decennial life cycle.

However, GAO found that the October 2015 cost estimate for the 2020 Census did not fully reflect characteristics of a high-quality estimate and could not be considered reliable. Overall, GAO found the cost estimate partially met the characteristics of two best practices (comprehensive and accurate) and minimally met the other two (well documented and credible). One reason why GAO’s overall assessment was low was because the estimate was not well documented. Improving cost estimation practices would increase the reliability of the Bureau’s cost estimate, which would in turn help improve decision making, budget formulation, progress measurement, course correction when warranted, and accountability for results.

Best practices state a risk and uncertainty analysis should be performed to determine the level of risk associated with the cost estimate. The Bureau carried out such an analysis only for a portion of estimated costs for fiscal years 2018 to 2020. According to Bureau officials, they scoped the analysis narrowly to those 3 years when most of the census costs occur. GAO found that, as a result, the Bureau’s risk and uncertainty analysis (modeled costs) covered $4.6 billion, only about 37 percent of the $12.5 billion total estimated life cycle cost, and less than one-half of the total estimated cost of the census during future fiscal years.

In October 2017, the Department of Commerce announced that the projected life cycle cost of the 2020 Census had climbed to $15.6 billion, a more than $3 billion (27 percent) increase over its 2015 estimate. A high-quality, reliable cost estimate is a key tool for budgeting, planning, and managing the 2020 Census. Without this capability, the Bureau was at risk of experiencing program cost overruns, missed deadlines, and performance shortfalls.

Since GAO’s June 2016 report, in which we reviewed the Bureau’s 2015 version of the cost estimate, the Bureau had made significant progress. For example, the Bureau had put into place a work breakdown structure (WBS) that defined the work, products, activities, and resources necessary to accomplish the 2020 Census and is standardized for use in budget planning, operational planning, and cost estimation, The Bureau also improved their risk and uncertainty analysis methodology for the 2017 life cycle cost estimate, using a combination of modeling based on Monte Carlo simulation and other methods to develop the contingency estimates.

GAO reported these findings on June 30, 2016 in *2020 Census: Census Bureau Needs to Improve Its Life cycle Cost Estimating Process*, GAO-16-628 and on August 17, 2018 in *2020 Census: Census Bureau Improved the Quality of Its Cost Estimation but Additional Steps Are Needed to Ensue Reliability*, GAO-18-635.

Case Study 19: From *VA Construction*, GAO-18-479, July 31, 2018

The Veterans Health Administration (VHA) is the largest integrated health care system in the United States, providing care through the Department of Veterans Affairs (VA) to millions of veterans a year at about 1,240 VA medical centers and outpatient clinics throughout the country. The President's 2019 budget request for VA estimated that VHA would require approximately $57 billion for enhancements, additions, and maintenance of current medical facilities and for bringing new, additional medical facilities into operation. VHA, to address some of these needs, relies on the minor construction program for facility enhancements and additions and the non-recurring maintenance (NRM) program for maintenance projects. These VHA programs manage and fund projects that generally cost $10 million or less. However, in recent years GAO and the VA's Inspector General had identified weaknesses in these programs. For example, in 2012, GAO recommended that VA improve its budget estimates for the NRM program due to higher than estimated spending on NRM projects—$867 million more than initially anticipated for NRM construction in 2011. VA's Inspector General also reported on weaknesses in VA's management of Minor Construction projects in 2012, and NRM projects in 2014.

A reliable cost estimate is critical to the success of any construction program. Such an estimate provides the basis for informed decision making, realistic budget formulation and program resourcing, and accountability for results. For example, VA relies on these estimates to make annual funding decisions for various facilities. Additionally, because these estimates inform VA's overall annual budget requests, Congress relies on them to make annual appropriations decisions.

The GAO *Cost Estimating and Assessment Guide* identifies 12 steps that, when incorporated into an agency's cost-estimating guidance, should result in reliable and valid cost estimates that management can use to make informed decisions. GAO found that VHA's guidance for medical center engineering staff and contractors on how to prepare cost estimates for minor construction program projects—specifically VHA's Minor Construction Handbook, VA's *Manual for Preparation of Cost Estimates and Related Documents*, and the *Veterans Affairs Medical Center Unit* Cost Guide *By Project Type*—did not fully incorporate these 12 steps, raising the possibility of unreliable cost estimates affecting decisions on how many such projects the agency can fund at one time.

For example, according to the *Cost Guide*, documentation provides total recall of the estimate's detail so that the estimate can be replicated by someone other than those who prepared it. Documentation 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. VHA's guidance required that supporting documents be submitted once a project is approved. However, it did not require all detail to be shown, including parameters, assumptions, descriptions, methods, and the calculations used to develop the estimate. By revising the cost-estimating guidance to address the 12 steps in the GAO *Cost Estimating and Assessment Guide*, such as considering each project's scope and complexity, VHA would have greater assurance that its cost estimates for minor construction and NRM projects are reliable.

GAO reported these finding on July 31, 2018 in *VA Construction: Management of Minor Construction and Non-Recurring Maintenance Programs Could Be Improved*, GAO-18-479.

Case Study 20, 23: From *Space Launch System*, GAO-15-596, July 16, 2015

National Aeronautics and Space Administration's (NASA) Space Launch System (SLS) program is NASA's first heavy-lift launch vehicle for human space exploration in over 40 years. For development efforts related to the first flight of SLS, NASA established its cost and schedule commitments at $9.7 billion and November 2018, respectively. The program, however, had continued to pursue more aggressive internal goals for cost and schedule. GAO was asked to assess a broad range of issues related to the SLS program, including examining the extent to which the SLS's cost and schedule estimates for its first test flight were reliable.

The SLS program substantially complied with five of six relevant best practices, but could not be deemed fully reliable because they only partially met the sixth best practice—credibility. While an independent NASA office reviewed the estimate developed by the program and as a result the program made some adjustments, officials did not commission the development of a separate independent estimate to compare to the program estimate to identify areas of discrepancy or difference. In addition, the program did not cross-check its estimate using an alternative methodology. The purpose of developing a separate independent estimate and cross-checking the estimate is to test the program's estimate for reasonableness and, ultimately, to validate the estimate. The continued accuracy of the estimates was also questionable because officials had no plans to update the original estimates created in 2013. GAO's cost estimating best practices call for estimates to be continually updated through the life of the program to provide decision-makers with current information to assess status. Moreover, as stressed in prior GAO reports, SLS cost estimates only covered one SLS flight in 2018 whereas best practices call for estimating costs through the expected life of the program.

Limited cost and schedule reserves placed the program at increased risk of exceeding its cost and schedule commitments. Although the SLS program was committed to a November 2018 launch readiness date, it had been pursuing an internal goal for launch readiness of December 2017, with the time between December 2017 and November 2018 being designated as schedule reserve. The SLS program expected to use a significant amount of schedule reserve, in part to address some technical challenges, and planned to shift its internal goal from December 2017 to tentatively July 2018. This shift would reduce the amount of available schedule reserve from 11 months to just 4 months. In addition, the program planned for cost reserves of less than 4 percent each year and had already allocated those funds for the year, which left no reserve funding available to address unanticipated issues.

Earned value management (EVM) data for SLS remained incomplete and provided limited insight into progress toward the program's external committed cost and schedule baselines because it tracked progress relative to the program's internal goals—which had proven unrealistic. EVM data is intended to provide an accurate assessment of program progress and alert managers of impending schedule delays and cost overruns. GAO analysis of available SLS contractor EVM data indicated that the contractors might incur cost overruns ranging from about $367 million to about $1.4 billion, which was significantly higher than what the contractors were reporting—$89 million. SLS was implementing a program-level EVM system that, once complete, would include all contractor work and work conducted in-house by NASA to provide more comprehensive information on program progress relative to internal goals.

Tracking to internal goals, however, provided limited information relative to progress toward external commitments. The SLS program lacked comprehensive program-level reporting to alert managers of impending delays and cost overruns to external commitments.

GAO recommended that to ensure that the SLS cost and schedule estimates better conform with best practices and are useful to support management decisions, the NASA Administrator should direct SLS officials to update the SLS cost and schedule estimates, at least annually, to reflect actual costs and schedule and record any reasons for variances before preparing their budget requests for the ensuing fiscal year. To the extent practicable, these updates should also incorporate additional best practices including thoroughly documenting how data were adjusted for use in the update and cross-checking results to ensure they are credible. In July 2018, NASA provided GAO the results of its latest assessment of the SLS's cost and schedule estimates against its Agency Baseline Commitment. NASA explained how data were adjusted for the updated estimate and the reasons for variances between the original estimate and the current estimate.

GAO reported these findings on July 16, 2015 in *Space Launch System: Management Tools Should Better Track to Cost and Schedule Commitments to Adequately Monitor Increasing Risk*, GAO-15-596.

Case Study 22: From *Project and Program Management*, GAO-15-29, November 25, 2014

The National Nuclear Security Administration (NNSA)—a semiautonomous agency within the Department of Energy (DOE)—is responsible for managing the nation's nuclear security missions. These missions include maintaining the safety, security, and effectiveness of the U.S. nuclear weapons stockpile and reducing the threat posed by nuclear proliferation. To examine the extent to which DOE and NNSA cost estimating requirements and guidance for its projects and programs reflect best practices for developing and reviewing cost estimates, GAO reviewed DOE and NNSA requirements and guidance related to cost estimating for projects and programs and compared them with the best practices identified in our 2009 *Cost Estimating and Assessment Guide.*

DOE and NNSA cost estimating requirements and guidance for projects generally did not reflect best practices for developing cost estimates. DOE's 2010 project management order required the use of only one of the 12 cost estimating best practice steps. Specifically, the order required an ICE be prepared at critical decision point 2 (approve project performance baseline) and critical decision point 3 (approve start of construction) for projects with an estimated cost of $100 million or greater. The order required the development of an ICE at CD-3 if warranted by risk and performance indicators or as designated by DOE or NNSA management. In addition, NNSA's 2014 requirement for an ICE or independent cost review could subject additional projects with an estimate of a cost of less than $100 million to an ICE, but this would have depended on whether NNSA chose to conduct an ICE rather than the less rigorous independent cost review. None of the other cost estimating requirements in the order, such as the need for a cost estimate at each CD point, ensured that project cost estimates would be prepared in accordance with cost estimating best practices. For example, the order did not require any of the other 11 best practice steps, such as conducting a risk and uncertainty analysis, identifying ground rules and assumptions, documenting the estimate, developing a point estimate, or determining the estimating structure. According to the DOE officials responsible for developing DOE's project management order, DOE had chosen to not require all cost estimating best practices in the order and instead included suggested approaches for developing cost estimates in the DOE cost estimating guide that accompanied the order. However, because neither DOE nor NNSA required the use of most cost estimating best practices for its projects, it was unlikely that NNSA and its contractors would consistently develop reliable cost estimates.

DOE's 2011 cost estimating guide described most of the best practices, but it was not mandatory and it was not referenced in the order. We found that the guide fully or substantially described 10 of the 12 steps. However, the guide only partially or minimally contained information about the other 2 steps—determining the estimating structure and conducting a sensitivity analysis. As a result, DOE and NNSA had not provided its contractors with all the detailed guidance needed to consistently develop reliable cost estimates.

GAO recommended that, to enhance NNSA's ability to develop reliable cost estimates for its projects and for its programs that have project-like characteristics, the Secretary of Energy DOE, among other things: (1) revise DOE's project management order to require that DOE, NNSA, and its contractors develop cost estimates in accordance with the 12 cost estimating best practices, and (2) revise DOE's cost estimating guide so that it fully reflects the 12 cost estimating best practices. In June 2015, based in part upon GAO's work, the Secretary of Energy issued a memo to enhance and clarify departmental policy related to project management. The memo outlined changes that recent GAO reports had noted as areas for improvement. Specifically, the memo required that the DOE project management order, the cost estimating guide, and the

Department of Energy Acquisition Regulations be revised consistent with the cost estimating best practices. The memo further specified that these and other provisions of the memo were to be made effective immediately and implemented as required project management procedures. This action satisfied this recommendation.

GAO reported these findings on November 25, 2014 in *Project and Program Management: DOE Needs to Revise Requirements and Guidance for Cost Estimating and Related Reviews,* GAO-15-29.

Case Study 24: From *Defense Acquisitions*, GAO-05-183, February 28, 2005

The U.S. Navy invests significantly to maintain technological superiority of its warships. In 2005 alone, $7.6 billion was devoted to new ship construction in six ship classes—96 percent of which was allocated to four classes: Arleigh Burke class destroyer, Nimitz class aircraft carrier, San Antonio class amphibious transport dock ship, and the Virginia class submarine. For the eight ships GAO assessed, the Congress had appropriated funds to cover the $2.1 billion increase in the ships' budgets. GAO's analysis indicated that total cost growth on these ships could reach $3.1 billion or even more if shipyards did not maintain current efficiency and meet schedules.

Cost growth for the CVN 77 aircraft carrier and the San Antonio lead ship (LPD 17) was particularly pronounced. Increases in labor hour and material costs together accounted for 77 percent of the cost growth on the eight ships. Shipbuilders frequently cited design modifications, the need for additional and more costly materials, and changes in employee pay and benefits as the key causes of this growth. For example, the San Antonio's lead ship's systems design continued to evolve even as construction began, which required rebuilding of completed areas to accommodate the design changes. Materials costs were often underbudgeted, as was the case with the Virginia class submarines and Nimitz class aircraft carriers. For the CVN 77 carrier, the shipbuilder was estimating a substantial increase in material costs.

Navy practices for estimating costs, contracting, and budgeting for ships have resulted in unrealistic funding of programs, increasing the likelihood of cost growth. Despite inherent uncertainties in the ship acquisition process, the Navy did not account for the probability of cost growth when estimating costs. Moreover, the Navy did not conduct an independent cost estimate for carriers or when substantial changes occurred in a ship class, which could have provided decision-makers with additional knowledge about a program's potential costs. In addition, contract prices were negotiated and budgets established without sufficient design knowledge and construction knowledge. When unexpected events did occur, the incomplete and untimely reporting on program progress delayed the identification of problems and the Navy's ability to correct them.

While DOD guidance allows some flexibility in program oversight, GAO found that reporting on contractor performance was inadequate to alert the Navy to potential cost growth for the eight case study ships. With the significant risk of cost growth in shipbuilding programs, it is important that program managers receive timely and complete cost performance reports from the contractors. However, earned value management—a tool that provides both program managers and the contractor insight into technical, cost, and schedule progress on their contracts—was not used effectively.

The quality of the cost performance reports, whether submitted monthly or quarterly, was inadequate in some cases—especially with regard to the variance analysis section, which describes any cost and schedule variances and the reasons for these variances and serves as an official, written record of the problems and actions taken by the shipbuilder to address them. Both the Virginia class submarine and the Nimitz class aircraft carrier programs' variance analysis reports discussed the root causes for any cost growth and schedule slippage and described how these variances were affecting the shipbuilders' projected final costs. However, the remaining case study ship programs generally tended to report only high-level reasons for cost and schedule variances with little to no detail regarding root cause analysis or mitigation efforts—making it difficult for managers to identify risk and take corrective action.

GAO recommended that to improve management of shipbuilding programs and promote early recognition of cost issues, the Secretary of Defense should direct the Secretary of the Navy to require shipbuilders to prepare variance analysis reports that identify root causes of reported variances, associated mitigation efforts, and future cost impacts. The Undersecretary of Defense for Acquisition, Technology, and Logistics directed components of the Department of Defense (DOD), including the Navy, to conduct a comprehensive review of earned value management system policies and practices in order to help improve the quality of cost/schedule reporting and surveillance in DOD programs. This review was intended to address recent audit findings and other identified deficiencies, such as the quality of variance analysis reports.

GAO reported these findings on February 28, 2005 in *Defense Acquisitions: Improved Management Practices Could Help Minimize Cost Growth in Navy Shipbuilding Programs*, GAO-05-183.

Case Study 25: From *James Webb Telescope*, GAO-16-112, December 17, 2015

The National Aeronautics and Space Administration's (NASA) James Webb Space Telescope (JWST) is one of NASA's most complex and expensive projects, at an anticipated cost of $8.8 billion. With significant integration and testing scheduled in the remaining years until the planned launch date, the JWST project would need to continue to address many challenges and identify problems, many likely to be revealed during its rigorous testing to come. The continued success of JWST hinged on NASA's ability to anticipate, identify, and respond to these challenges in a timely and cost-effective manner to meet its commitments.

The JWST project was meeting its schedule commitments, but it would soon face some of its most challenging integration and testing. JWST had almost 9 months of schedule reserve—down more than 2 months since GAO's last report in December 2014—but still above its schedule plan and the Goddard Space Flight Center requirement. However, as GAO also found in December 2014, all JWST elements and major subsystems continued to remain within weeks of becoming the critical path—the schedule with the least amount of schedule reserve—for the overall project. Given their proximity to the critical path, the use of additional reserve on any element or major subsystem may have reduced the overall project schedule reserve.

Before the planned launch in October 2018, the project had to complete five major integration and test events, three of which had not yet begun. Integration and testing is when problems are often identified and schedules tend to slip. At the same time, the project had to also address over 100 technical risks and ensure that potential areas for mission failure were fully tested and understood.

Based on analysis of James Webb Space Telescope (JWST) contractor EVM data over 17 months, GAO found that some of the data used to conduct the analyses were unreliable. First, we found that both Northrop Grumman and Harris were reporting optimistic EACs that did not align with their historical EVM performance and fell outside the low end of our independent EAC range. Second, GAO found various anomalies in contractor EVM data for both contractors that they had not identified throughout the 17-month period we examined. The anomalies included unexplained entries for negative values of work performed (meaning that work was unaccomplished or taken away rather than accomplished during the reporting period), work tasks performed but not scheduled, or actual costs incurred with no work performed. For Northrop Grumman, many were relatively small in value ranging from a few thousand to tens of thousands of dollars.

GAO recommended that to resolve contractor data reliability issues and ensure that the project obtained reliable data to inform its analyses and overall cost position, the NASA Administrator direct JWST project officials to require the contractors to identify, explain, and document all anomalies in contractor-delivered monthly earned value management reports. In February 2016, NASA issued letters to the contractors requiring them to explain all anomalies in the contractor earned value management reports.

GAO reported its findings on December 17, 2015 in *James Webb Telescope, Project on Track but May Benefit from Improved Contractor Data to Better Understand Costs*, GAO-16-112.

Case Study 26: From *NASA*, GAO-13-22, November 19, 2012

The National Aeronautics and Space Administration (NASA) historically has experienced cost growth and schedule slippage in its portfolio of major projects and has taken actions to improve in this area, including adopting the use of EVM. In 2012, GAO was asked to examine (1) the extent to which NASA is using EVM to manage its major space flight acquisitions, (2) the challenges that NASA has faced in implementing an effective EVM system, and (3) NASA's efforts to improve its use of EVM.

GAO found that 10 major spaceflight projects had not yet fully implemented EVM. As a result, NASA was not taking full advantage of opportunities to use an important tool that could help reduce acquisition risk. GAO assessed the 10 projects against three fundamental EVM practices that are necessary for maintaining a reliable EVM system and found shortfalls in two of three fundamental practices. Specifically, GAO found that, first, more than half of the projects did not use an EVM system that was fully certified as compliant with the industry EVM standard. Second, four of the 10 projects established formal surveillance reviews, which ensured that key data produced by the system was reliable; the remaining six projects provided evidence of monthly EVM data reviews. However, the rigor of both the formal and informal surveillance reviews was questionable given the numerous data anomalies we found. GAO also found that three projects had reliable EVM data while seven had only partially reliable data. For the EVM data to be considered reliable per best practices it must be complete and accurate with all data anomalies explained.

NASA undertook several initiatives aimed at improving the agency's use of EVM. For example, NASA strengthened its spaceflight management policy to reflect the industry EVM standard and developed the processes and tools for projects to meet these standards through its new EVM system. While these were positive steps, the revised policy contained only the minimum requirements for earned value management. For example, it lacked a requirement for rigorous surveillance of how projects were implementing EVM and also did not require use of the agency's newly developed EVM system to help meet the new requirements.

GAO reported these findings on November 19, 2012 in *NASA: Earned Value Management Implementation across Major Spaceflight Projects is Uneven*, GAO-13-22.

Case Study 27: From *Airborne Laser*, 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 last 8 years, the program's efforts to develop this technology have resulted in significant cost growth and schedule delay.

The prime contractor's costs for developing ABL have nearly doubled from the Air Force's original estimate and additional cost growth is occurring. The cost growth occurred primarily because the program did not adequately plan for and could not fully anticipate the complexities involved in developing the system. The Missile Defense Agency continues 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 accounts 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 first full demonstration of the ABL system. Cost growth has been spurred by rework that was necessary because rapid prototyping forced the program to integrate components before all subcomponents were fully tested. In addition, fabricating ABL's unique components and developing its complex software proved more costly and time-consuming than anticipated. Although ABL's prime contractor has added additional personnel to the contract, the program is faced with a bow wave of uncompleted work from prior years. Recognizing that the technology development activities directed by the contract could not be completed within the contract's cost ceiling, the ABL program office began development of a new cost estimate for completing these activities.

GAO reported these findings on May 17, 2004 in *Uncertainties Remain Concerning the Airborne Laser's Cost and Military Utility*, GAO-04-643R.

Case Study 28: From *Amphibious Combat Vehicle*, GAO-16-22, October 28, 2015

Since 1972, the primary platform for transporting Marines from ship to shore under hostile and hazardous conditions has been the Assault Amphibious Vehicle (AAV). In 2011, acquisition of a proposed replacement vehicle—the United States Marine Corps' (USMC) Expeditionary Fighting Vehicle (EFV)—was canceled following the expenditure of $3.7 billion from fiscal year 1995 through 2011 due to concerns regarding the program's affordability. Also in 2011, USMC subsequently began the acquisition process for the Amphibious Combat Vehicle (ACV), a potential replacement vehicle for all or a portion of the AAV fleet. The ACV is intended to transport Marines from ship to shore and provide armored protection once on land. The ACV acquisition approach called for ACV development in three increments with increasing amphibious capability, ACV 1.1, 1.2 and 2.0., with ACV 1.1 scheduled to start development in November 2015.

The National Defense Authorization Act for Fiscal Year 2014 included a provision for GAO to annually review and report to the congressional defense committees on the ACV program until 2018. Previous reports in 2014 and 2015 described the efforts to initiate the ACV program and how its incremental acquisition approach compared to acquisition management best practices. This report included updates to the analysis of alternatives (AOA) best practices identified in prior GAO work.

GAO's assessment of the 2014 AOA found that overall it met best practices for AOAs and was, therefore, considered reliable. The USMC completed an AOA update for ACV 1.1 in late 2014 to support the release of the ACV 1.1 request for proposal. Over the years, other AOAs had been completed for related acquisitions, including the EFV, the Marine Personnel Carrier and the previous version of the ACV considered in 2012. These previous AOAs and other supporting studies comprised a body of work that informed the most recent ACV AOA update as well as the ACV 1.1 acquisition as a whole.

Considered in the context of the related body of work, the Amphibious Combat Vehicle (ACV) met 15 of the 22 AOA best practices, including ensuring that the AOA process was impartial and developing an AOA process plan, among others. Further, four of the remaining best practices were substantially met, two were partially met, and one was minimally met. For example, best practices call for the documentation of all assumptions and constraints used in the analysis. We found that the 2014

AOA did not include a full list of assumptions and constraints and any assumptions or constraints from previous analysis, if relevant, were not updated or referenced in the new analysis. As a result, it could have been difficult for decision-makers to make comparisons and trade-offs between alternatives. DOD's Cost Assessment and Program Evaluation staff also reviewed the 2014 AOA and found that it was sufficient. However, they identified a few areas of caution, including recommending additional testing of land mobility to further verify USMC assertions that the wheeled ACV 1.1 would have the same mobility in soft soil as tracked vehicles.

GAO reported these findings on October 28, 2015 in *Amphibious Combat Vehicle: Some Acquisition Activities Demonstrate Best Practices; Attainment of Amphibious Capability to be Determined*, GAO-16-22.

Case Study 30: From *Service Contracts*, GAO-17-398, May 17, 2017

Independent government cost estimates (IGCEs) are the government's best estimate of a contract's potential costs—an important tool for both program and contracting officials to provide information when planning for and awarding contracts. IGCEs are particularly critical for service contracts—accounting for more than $270 billion in government contract spending in fiscal year 2015—to ensure the costs associated with labor are fully understood. GAO was asked to review federal agencies' use of IGCEs. GAO examined the extent to which (1) selected departments developed IGCEs for service contracts and (2) selected departments' IGCEs were useful in supporting the acquisition planning process.

Officials at the departments in GAO's review—Defense, Homeland Security, Health and Human Services, Education, Labor, and Housing and Urban Development—developed independent government cost estimates (IGCE) for 62 of the contracts GAO reviewed. All of the departments in GAO's review have some guidance on IGCEs available—ranging from regulation to handbooks to checklists—with different emphasis on whether an IGCE is required. GAO found some cases where guidance dictated that an IGCE should have been prepared, but was not. According to officials, one reason for not preparing an IGCE was that the procurement was a task order issued under an existing contract. Federal internal control standards state that agencies should communicate quality information to achieve their objectives, such as including clear guidance for acquisition planning.

In the 62 contracts GAO reviewed with IGCEs, the IGCEs' use in acquisition planning varied—from determining funding needs to determining price reasonableness. The usefulness of an IGCE to a contracting officer depends in part on its supporting documentation, but most IGCEs did not document data sources and methodologies used IGCEs are the government's best estimate of a contract's potential costs—an important tool for both program and contracting officials to provide information when planning for and awarding contracts. IGCEs are particularly critical for service contracts—accounting for more than $270 billion in government contract spending in fiscal year 2015—to ensure the costs associated with labor are fully understood.

Lack of documented data sources and methodologies in an IGCE puts contracting officers at a disadvantage and could lead to additional, inefficient steps to validate IGCEs. Only two of the agencies in GAO's review had explicit guidance on what details to document in IGCEs, but officials were not always familiar with the available guidance. Instead, according to the officials GAO spoke with, they often follow program office practices and noted that training did not address how to develop and document an IGCE. GAO's cost estimating guidance and federal internal control standards emphasize the need for documentation, with GAO's guidance stating that well-documented cost estimates should describe the data sources used, underlying assumptions, and the estimating methodologies used to derive costs. Without clear guidance or more training on documentation of data sources and methodologies, departments may not be taking full advantage of this important acquisition tool.

GAO reported these findings on May 17, 2017 in *Service Contracts: Agencies Should Take Steps to More Effectively Use Independent Government Cost Estimates*, GAO-17-398.

Appendix III: Experts Who Helped Develop This Guide

The two lists in this appendix name the experts in the cost estimating, scheduling, and earned value 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
Air Force	John Cargill Abishek Krupanand Richard Mabe
Atkins and Faithful+Gould	Mike Debiak
Bond University	Jasper Mbachu
Cobec Consulting Inc	Dan French
Collins Aerospace	Cynthia Prince
David Consulting Group	Michael Harris
Department of Energy	Ivan Graff Kathlyn Hopkins Dan Melamed
Department of Homeland Security	Ray Sealey
ESI International	Bill Damare
General Services Administration	William Hunt
Government of Canada	Jason Heyes
Hornbacher & Associates	Keith Hornbacher
Hulett & Associates LLC	David Hulett
Idaho National Laboratory	John Baker
Independent Consultant	Chris Fostel Stanislaw Gasik Shobha Mahabir Geza Pap Alston Toussaint
Library of Congress	Robyn Wiley
MCR, LLC	Jay Goldberg
MITRE	Kevin Cincotta
National Aeronautics and Space Administration	Zachary Dolch Marc Greenberg Michelle King Yvonne Simonsen Steven M. Wilson

Organization	Expert
National Nuclear Security Administration	Harlan Swyers Raymond D. Vera
National Science Foundation	Kevin Porter
Naval Postgraduate School	Gregory K. Mislick Karen Richey Mislick
Naval Sea Systems Command	Michael Sanders
Navy	Wilson Rosa
Northrup Grumman	Paul Solomon
Office of Management and Budget	James Wade
Olde Stone Consulting, LLC	John D. Dreissnack
Perspecta	Darrell S. Cleavenger
PRICE Systems, LLC	Bruce Fad
Project Time and Cost	Timothy P. Jamison Chris Watson
PT Mitrata Citragraha	Paul D. Giammalvo
SAIC	Shane Gellenthien
Shoshanna Fraizinger Consulting Inc.	Shoshanna Fraizinger
Technomics	Jeffery Cherwonik
Tecolote Research, Inc.	Rey Carpio
Validation Estimating, LLC	John Hollmann
VR Capital Project	Vicente Ruiz

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
Air Force	Deb Cann Greg Hogan Michael Kvartunas Lisa Mably Thomas Newberry Ranae Woods
American University	Alexia Nalewaik
Army	Kate Calvert Aletha DeBiase Dave Holm Trevor Van Atta

Organization	Expert
AuGUR Consulting	Dave Ingalls Sam Kitchin Stephen Koeliner Kurt Wasileski Ryan Webster
Caliban – PT&C	Connie Liu
Census Bureau	Kevin Metcalf
Cerner Corporation	Stacy Ludwig
Chevo Consulting	Cyndy Iwan
ClearPlan Consulting, LLC	Brian Evans
Department of Defense	David Nelson
Department of Energy	Melvin Frank Autur Pamperaap Bryan Skokan
Department of Homeland Security	Michael D. DiVecchio Christopher J. Murray William Taylor
Earned Value Advisors	Eva Walter
Federal Aviation Administration	D. Dobbins Wendy Y. Hilton
Galorath Federal	Christian Smart
Gannett Fleming	David Gorski
Idaho National Laboratory	Rick L. Staten
Independent Consultant	Neil Albert Michael Andersen Anthony Corridore Michelle Jones Kevin Man Karl Rusch
Institute for Defense Analyses	Gregory A. Davis David M. Tate
Leidos	Andrea Nibert
LS Technologies LLC	Katherine Koman Evans
McDonough Bolyard Peck, Inc.	Sagar B. Khadka
Micro Planning International	Raphael M. Dua
Missile Defense Agency	Rick Hycoop
MITRE	Mike Boseman Lydia Gizdavcic Daniel Harper

Organization	Expert
National Aeronautics and Space Administration	Heidemarie E. Borchardt Joe Fischetti Paul Frazier Howard Leibowitz
National Oceanic and Atmospheric Administration	Maria Sims
National Science Foundation	Patrick R. Haggerty
Naval Air Systems Command	Beth Corcoran David Proctor John Scaparro
Naval Sea Systems Command	Albert Dirr
Navy	Justin Moul Lynne Sia-Bates David Tervonen Duncan Thomas
Northrup Grumman	Raymond Bollas
Nuclear Regulatory Commission	Ramona Bouling
PMO Projects Group	Alexandre Rodrigues
Professional Project Services	Gregory P. Dowd, Jr.
Project Management Institute	Charles R. Mahon Robin F. Pulverenti
Reed Integration	Robin Smith
Sandia National Laboratories	Vicki L. Frahm
Schumann Consulting, LLC	Debbie Schumann
Sellafield Ltd.	Stephen Jones
SFB PM Consulting	Stephen Bonk
Space Metrics, Inc	Jon Ginsberg
Technomics	Remmie Arnold
Tecolote Research, Inc.	Alf Smith
University of Bristol	Andrew Crossley

Appendix IV: Data Collection Instrument and Rationale

Table 32 lists key data items that are generally required for auditors to thoroughly assess the quality and reliability of a program cost estimate.

Table 32: Common Data Collection Items

Item	Rationale
Program management review briefings or similar documentation	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, including projected budget and OMB 300 reports	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.
Technical baseline description	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.
Work breakdown structure (WBS) and dictionary	The WBS 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.
Program cost estimate supporting documentation, showing the basis of the estimates, including methodologies, data sources, risk simulation inputs and results, sensitivity analyses, and the like	Only by assessing the estimate's underlying data and methodology can the auditor determine its quality. This information will address important concepts such as applicability of data, normalization of data, estimating methodologies, and parametric statistics.
Electronic cost estimate model	Access to the original electronic model will help auditors assess the estimate's underlying data and methodologies. It also allows auditors to confirm there are few, if any, mistakes in the estimate.
Independent cost estimate (ICE) and related documentation, including a discussion of how cost estimates were reconciled	The ICE cost model and related documentation allow auditors to confirm that decision-makers were provided with additional insight into the program's potential costs.
A risk management plan and a copy of the current risk register	Access to risk information helps auditors determine whether threats and opportunities have been properly quantified in the cost estimate.

Source: GAO. | GAO-20-195G

Table 33 lists key data items that may be applicable to an agency or a contract type, or are otherwise specific to a particular program's cost estimate. Requests for these data should be tailored as needed.

Table 33: Supplementary Common Data Collection Items

Item	Rationale
Nunn-McCurdy Amendment documentation	For DOD 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.
Statement of work	The SOW conveys 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). A statement of objective (SOO) and performance work statement (PWS) may also be used in the contractual process to establish desired service outcomes and performance standards.
Technology readiness assessments	A technology readiness assessment provides an evaluation of a system's technological maturity by major WBS elements. It is useful in identifying over-optimism in technology assumptions. For those elements associated with technologies that have not achieved the required maturity level, the auditor can assess whether satisfactory mitigation plans have been developed to ensure that acceptable maturity will be achieved before milestone decision dates.
Design review reports, preliminary and critical	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.
Acquisition decision memorandum	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.
Selected acquisition reports (SARs)	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.
EVM contract performance reports for the past 12 months and monthly thereafter during the audit	Contract performance reports are management reports essential to an auditor's ability to develop a comprehensive analysis. They are timely summary data from which to assess current and projected contract or program performance. The auditor can use them to reasonably project future program performance.
Cost and software data reporting	CSDRs provide the auditor with actual contractor development or procurement costs by WBS. Especially useful is the fact that recurring and nonrecurring costs are differentiated.
Integrated baseline review reports	The purpose of an IBR is to verify the technical content and realism of the interrelated performance budges, 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 handles these risks.

Item	Rationale
EVM surveillance reports for the past 12 months	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.
Integrated master schedule	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.

Source: GAO. | GAO-20-195G

Appendix V: Estimating Software Costs

We highlight software cost estimation because of its significance and complexity in major systems acquisition. This appendix illustrates how the steps in cost estimating apply to the software development environment, so that auditors can better understand the factors that can lead to software cost and schedule overruns and to the failure to deliver required functionality.

We review typical cost drivers and risks associated with software development, sustainment, and infrastructure. In this context, we examine components of a software cost estimate and methods to estimate software size. Next, we apply this knowledge to estimate the software development efforts and discuss parametric methods that support estimates. We also touch upon the associated development schedule. In addition to software development, we consider software sustainment. We close with overviews of information technology (IT) infrastructure.

Background

The size and relative cost of software continue to grow in many major systems the federal government acquires. In 1997, software accounted for less than half of a typical defense system's cost. However, its cost is projected to be 80 percent or more by 2020.[1] The growth in software code and the associated development cost for aircraft supports this trend in both the commercial and military realms. During the ten-year period between the first flights of the Boeing 757 and of the Boeing 777, software code increased 21-fold and the software development cost increased by a factor of more than 28-fold. On the military side, the first F-35 was flown 32 years after the first F-16 with 177 times as much computer code and the software development effort cost totaling almost 300 times as much.[2]

In 2018, the Project Management Institute reported that 14 percent of IT projects were deemed failures and that on average 9 percent of every dollar spent on IT projects was wasted. Among the projects surveyed, 56 percent reported on-time completion while 60 percent were completed within budget. Even so, half of the projects reported requirements creep.[3]

[1]Zubrow, David, Robert Stoddard, Ipek Ozkaya, William Novak. "SEI Research Combats Mounting Acquisition Costs." *Software Engineering Institute 2017 Year in Review*. 2017: 12.

[2]https://savi.avsi.aero/about-savi/savi-motivation/exponential-system-complexity/ (accessed January 31, 2020).

[3]Project Management Institute, "Pulse of the Profession 2018" (2018).

Software often costs more and takes longer to complete than expected and fails to meet intended performance objectives. Historically, many projects have relied on an approach known as waterfall which consists of a “grand design” of extensive planning followed by a long development period. The resulting product in many cases did not meet user requirements. One approach to reduce the risks from broadly-scoped, multiyear projects is to shorten the software delivery timeframe. These shorter efforts incorporate user feedback on the newly delivered functionality, which can guide future development to meet needs as they evolve. These efforts may be described generally as spiral development. One specific approach of this type is Agile software development.

Agile software development supports the practice of continuous software delivery and is well-suited for projects in which the best solution comprises distinct features, some of which may be discovered during development rather than planned up front. Specifically, Agile calls for the delivery of software in short, incremental segments rather than in the typically long, sequential phases of a traditional waterfall development approach. Agile allows for flexibility and adaptation when the customer needs change. The frequent iterations effectively measure progress, reduce technical and programmatic risk, and allow the development team to rapidly respond to feedback from stakeholders’ changing requirements. Because of the importance of Agile development, this subject is treated in more detail in its own guide.[4]

Software life cycle costs are not limited to code development. They also include any pre-deployment testing, information technology infrastructure and services, and sustainment after the system is deployed. Estimates for each of these elements in the software life cycle rely on different approaches. A comparison of the program of interest to similar programs may reveal useful techniques to construct estimates of the various cost elements.

Unique Components of Software Estimation

The software life cycle differs from that of hardware in several respects. Software development costs are mainly from labor whereas hardware development programs have a greater share of their cost from material. Additionally, hardware programs have a production phase with significant

[4]A detailed discussion of Agile software development is presented in the draft GAO *Agile Assessment Guide* which is scheduled for public release in summer 2020.

recurring effort, but because software is trivial to copy, there is no production phase and little or no recurring effort.

Despite these differences, software and hardware share similarities in their cost estimating approaches because they follow the same basic development process. In both cases, estimates may draw on the same types of methods—analogy, engineering build-up, parametric—with size and complexity being cost drivers. The effort required to develop software depends on its purpose and its level of integration with other systems. Finally, how quickly hardware and software can be produced depends on the developer's capability, available resources, and familiarity with the environment. Thus, the approach to estimating software costs has two basic elements: the size of the software to be developed and the development effort to accomplish it.

Estimating Software Size

Cost estimators begin a software estimate by evaluating the sizes of the deliverables to be developed. Software programs that are complex, perform many functions, have safety-of-life requirements, and require high reliability are typically larger than simpler programs.

Estimating software size requires detailed knowledge about a program's functions, including scope, complexity, and interactions. Several methods exist to measure software size. These include the Common Software Measurement International Consortium (COSMIC) Functional Sizing Method, function point analysis, object point analysis, source lines of code (SLOC), and use case, among others. Although the methods differ from one another and may apply to different types of software development, they are all tools to arrive at a numerical estimate that characterizes the size of the software code to be developed.

Each software sizing method draws on different inputs, and some approaches may be more useful than others depending on where a program is in its development phase. Some methods are designed to estimate future work based on known requirements without regard to the software's design, which may be useful early in development. Others may require knowledge of the software's planned architecture to estimate work based on expected interactions among the user, hardware, and software components. Other methods consider modifications needed to standard software to meet user needs. In all cases, the applicability of a particular sizing method will depend on the type of software under development and on the availability of data on comparable efforts.

SLOC has been used widely for years as a software sizing metric, and many organizations have databases of historical SLOC counts for various types of completed programs, making it the predominant method for sizing software. If the decision is made to use historical SLOC to estimate software size, the cost estimator needs to make sure that the program being estimated is similar in size, language, and application to the historical data. In addition, the cost estimator must ensure that SLOC is reported consistently.

Consistency in software sizing is critical. Reported and estimated lines of code can vary significantly depending on the software language used and on the methodology to count SLOC. Moreover, many sizing methods lack a standards body that controls their counting rules. In the absence of a uniform counting convention, different users may take one of the source definitions for the basic approach and modify the rules internally to suit their purposes. This can result in dissimilar counts across organizations leading to problems with accuracy and reproducibility. The test of a reliable sizing method is that two individuals working independently can apply the same rules to an identical problem and arrive at commensurate results.

The following questions highlight issues to bear in mind when considering methodologies to estimate software size:

- Are the rules for the sizing technique rigorously defined in a widely accepted format?
- Are the rules under the control of a recognized, independent controlling body and updated from time to time?
- 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?
- Are the source documents or artifacts for estimating the size metric available to the cost estimators?

After choosing a software estimation method, estimators should consider whether the software will be newly written or will be based on the modification of existing code. Modifications include reused (code used verbatim with no modifications); adapted (existing code that needs to be redesigned, may need to be converted, and may require further modification); and auto-generated code. Although modifying software may save time compared to writing fresh code, their incorporation into a new program usually requires more effort than anticipated. For instance, the time it takes to add reused code depends on whether significant integration, reverse engineering, and additional design, validation, and testing are required. If the effort to incorporate reused software is too large, it may be more cost effective to write new code.

The Office of Management and Budget (OMB) issued a memorandum[5] to ensure that new custom-developed source code be made available for reuse across the federal government. To facilitate this transition, OMB has identified four supporting requirements needed to adopt open source software. Among them, OMB has highlighted the need to secure data rights to government-wide reuse. In addition, it is essential to document the source code to facilitate its use and adoption.

Using historical data to test expectations about how much code to reuse is a best practice that can mitigate the potential for cost overruns. When assessing the potential for software reuse, analysts should consider the following:

- Code reused from other programs typically requires additional adapting effort compared to code carried over from a previous organic release.
- Upgrade projects tend to achieve higher levels of code reuse success than new projects. This is likely a result of having more familiarity with the software structure, compilation, and capability that are designed into an existing program.
- Software that was appropriately designed for reuse from the outset requires less effort to integrate into a new program. Code designed for reuse contains modular attributes that comply with open system architecture guidelines, making reuse more efficient and effective thereby increasing the chance of successful reuse.
- Even seemingly simple efforts, such as re-deploying unmodified software onto a new or upgraded platform, often face complications due to unforeseen differences including how the new hardware processes the software and integration issues with other systems.

[5]Office of Management and Budget, Executive Office of the President, *M-16-21: Federal Source Code Policy: Achieving Efficiency, Transparency, and Innovation through Reusable and Open Source Software*, (Washington, D.C.: August 2016).

When possible, cost estimators should check the estimated software size using two different methodologies. Developing software estimates based on several different approaches that are compared and converge toward a consensus is a best practice. In addition, the estimate should reflect the expected growth in software size from requirements growth or underestimation (that is, optimism). This growth adjustment should be made before performing risk and uncertainty analysis. Moreover, the size estimate should be updated as data become available so that growth can be monitored.

Estimating Software Development Effort

Once the initial software size estimate is complete, it can be converted into software development effort—an estimate of the resources needed to develop the software. It is important to note whether the effort accounts only for the WBS elements associated with the software development or also includes all the other non-development activities.

The level of effort required depends on the type of software application being developed. For example, real-time embedded and systems software, such as safety critical applications, typically requires more effort than automated information system applications of the same size because of stringent quality and certification testing requirements. Moreover, operating systems that must reflect real time updates and great reliability need more careful design, development, and testing than simple software systems. Variations in activities can significantly affect overall costs, schedules, and productivity rates, so it is critical to appropriately match activities to the type of software application in the estimate.

To convert software size into software development effort, the size is usually divided by a productivity factor, for example the number of source lines of code, or function points, developed per labor work month. Other factors that may affect productivity include the language used; whether the code is new, reused, or auto-generated; the developer’s capability; and the development tools used, among others. Historical data from a similar application can support the estimate or factor that represents the development environment. Absent historical data, an estimator can use a factor based on industry benchmarks, although this can add uncertainty to the estimate.

Agile software development takes a different approach to estimating software development effort. Agile developers typically rely on relative estimation methods to determine the software size. First, since effort is commonly used as a proxy for cost, estimating effort can not only determine the program cost, but it can also reasonably predict how long both near-term and long-term deliverables may take to develop. Second, understanding the capacity (or the total amount of work that Agile teams can accomplish in one iteration) helps prioritize work and predict the cost of a delay when “must-have” features cannot be accomplished as expected. Finally, having the Agile team commit to near-term deliverables is important because those commitments materially affect customer planning and business objectives while at the same time make the Agile development team accountable for their work.

Agile program cost estimates have an advantage over traditional program cost estimates because they are regularly updated to reflect changes in accordance with the program cadence. Agile’s regular cycle of iterations and releases provides numerous opportunities to continuously refine the estimate based on learning what the customer wants. However, there are many different ways to employ relative estimation which may not be consistent across different Agile projects, or even across different development teams working on the same Agile program. Like traditional software development, consistency in the counting method is key to developing a reliable sizing estimate.

Parametric Software Estimation

Commercially available parametric tools can supplement a cost estimator’s techniques. They incorporate models typically built using a broad data set obtained from a variety of software efforts, which may be helpful when developers lack access to data. However, because parametric tools are often closed systems—also called black boxes—the developer cannot easily test the model.

Parametric tools can be used to estimate the cost to develop and maintain software. They are often based on historical data collected from actual projects and typically generate cost, schedule, effort, and risk estimates based on inputs by the user. These inputs may include software size, personnel capabilities, experience, development environment, amount of code reuse, programming language, and labor rates. With these data inputs, the tool draws upon cost estimating relationships and analogies from 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.

It is important to understand the source of the sizing data used in a regression model. One based on historical data reporting initial estimates at contract award will differ from another that uses historical data reporting final size at contract completion.

Parametric tools may add value 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 their effects on the estimate.

Scheduling Software Development

Once software development effort is estimated, it can be used to estimate the schedule. Scheduling is affected by many factors, including:

- staff availability;
- budget availability;
- an activity's dependence on prior tasks;
- the concurrence of scheduled activities;
- the activities that make up the critical path;
- the number of work shifts;
- the number of effective work hours per shift;
- whether overtime can be authorized; and
- geographic location of workers, including effects of different time zones.

Significantly large software development efforts frequently experience cost and schedule growth. The complexities inherent in managing configuration, communications, and design assumptions typically hinder software development productivity. In addition, schedule delays have a ripple effect on support efforts such as program management and systems engineering.

Management pressure on software developers to keep to an unrealistic schedule can lead to other problems. For example, to meet schedule constraints, developers may reduce the time for requirements analysis, which can affect the quality of the software developed. In addition, developers may create minimal or no documentation, which can result in higher software sustainment costs. Moreover, to reduce schedule time, developers may decide to build more components in parallel, defer functionality, postpone rework, or minimize functional testing. While these actions may save some time initially, they can result in additional time, effort, and risk for the program.

Rework should be part of every software development schedule because it is unlikely that software can be delivered without any defects. Rework effort should include the time and resources associated with diagnosing the problem, designing and coding the fix, and retesting. To adequately account for rework, the estimate should anticipate a number of defects based on experience, and time and effort should be allocated for fixing them. We discuss scheduling more thoroughly in the GAO Schedule Assessment Guide,[6] including how to account for these risks so that the schedule is realistic.

Software Operations and Maintenance

Once the software has been developed, tested, and installed in its intended location, it must be maintained. Therefore, the software's operations and maintenance phase must be included in the life cycle cost estimate. During this phase, software is maintained by fixing any defects not discovered in testing (corrective maintenance), modifying the software to work with any changes or technology upgrades to its operating environment (adaptive maintenance), and adding new functionality—for example, in response to user requests for enhancements—(perfective maintenance). When adding a capability, the work is similar to a small scale development effort and the cost drivers are the same as in development.

Several factors drive the level of maintenance required. For example, if requirements from development are deferred until the operations and maintenance phase, or the requirements are 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 debug and will provide software maintenance personnel a better understanding of how the software was designed, making modifications easier.

Together with the need to maintain the software code, costs associated with help desk support need to be included in the software's operation and support phase. Help desk efforts include processing trouble calls and generating defect tickets for software correction and should be part of the software cost estimate. Help desk support to software users and perfective maintenance often make up the bulk of the software operations and maintenance effort.

[6]GAO, *Schedule Assessment Guide*, GAO-16-89G (Washington, D.C.: December 2015).

Commercial Off-the-Shelf Software (COTS)

In addition to developing customized software, users may consider COTS solutions. Using COTS 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 reduce software operations and maintenance costs.

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

Estimators tend to underestimate the effort in integrating and 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 effective use of the software.

Commercial software may be released with minimal testing, causing unpredictable problems, such as defects and system incompatibilities. When this happens, additional time is needed to analyze the cause of failures and fix them. While software developers can address these issues, they take time to accomplish. Therefore, adequate planning should be identified and estimated by the cost estimator to ensure that enough time and resources are available for correcting failures.

Enterprise Resource Planning Software

Enterprise resource planning (ERP) tools are administrative software systems based on commercial off-the-shelf software and may be used throughout an organization. ERP systems integrate information and business processes—including human resources, finance, manufacturing, and sales—to enter information once and to share it among departments throughout the organization. ERP systems force business process reengineering, potentially fostering improved operations that can lead to future savings. However, to achieve these savings requires an extensive knowledge of business processes by those designing and implementing ERPs. Performance following automation in the absence of this understanding will fail to meet expectations. 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.

GAO has previously reported on the challenges of implementing government ERPs resulting in cost increases and schedule delays. For example, in a 2010 report, we found that six of the nine DOD ERPs we examined had experienced schedule delays ranging from 2 to 12 years and five had incurred cost increases ranging from $530 million to $2.4 billion. DOD stated that the ERPs would replace over 500 legacy systems that cost hundreds of millions of dollars to operate annually. However, delays in implementing the ERPs required DOD to fund the legacy systems longer than anticipated, thereby reducing the funds available for other DOD priorities.[7]

Information Technology Infrastructure and Services

Software cost estimates must also include IT infrastructure and services. Even systems such as ships, aircraft, and mission control centers, with their significant hardware investment, have major IT infrastructure and services components. For some IT systems 90 percent of their costs are in the infrastructure and services required to support and run them. Yet in reports on 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.

IT infrastructure can be difficult to estimate because numerous definitions exist. One useful definition is that infrastructure consists of the equipment, systems, software, and services used in common across an organization, regardless of mission, or program. IT infrastructure also serves as the foundation for mission, or program-specific systems and capabilities.

The estimator should ask the following questions when estimating IT infrastructure and services:

- What is the cost of the system engineering to define the IT system?

[7]GAO, *DOD Business Transformation: Improved Management Oversight of Business System Modernization Efforts Needed*, GAO-11-53 (Washington, D.C: October 7, 2010).

- How much computing power is needed to support a system?
- How many help desk personnel are needed to support the users?
- How do buy and lease decisions affect expenses and profitability?
- What are the potential 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?
- Are the requirements clearly defined?

A quote from an IT system vendor is rarely sufficient for IT cost estimation. The cost estimator will still need to consider these elements:

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

Many vendors offer IT infrastructure either as “software as a service” or as “cloud computing.”[8] The decision to opt for vendor-operated IT infrastructure hardware requires weighing the convenience of utilizing external resources that become the responsibility of an outside organization against issues such as loss of control and security, as well as accepting potential resource sharing with other users. 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.

Many of the risks that affect software cost estimating apply to IT infrastructure. For example, in estimating the costs of any effort, a

[8]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.

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.

Appendix VI: Examples of Work Breakdown Structures

The Department of Defense (DOD) developed *Work Breakdown Structures for Defense Materiel Items* in 1968 to provide a framework and instructions for developing a Work Breakdown Structure (WBS).[1] Updated in 2018 as military standard 881D, the standard is mandatory for all Acquisition Category (ACAT) programs[2] and is a resource for developing a WBS for both government and private industry. It outlines the contents and components that should be considered for aircraft, missile, space, ground vehicle, and information systems. It gives examples and definitions, particularly in its appendixes A–L, which constitute the bulk of the document and on which tables 34–39 are based.

Table 40 presents a WBS template for a technology development program from NASA's Work Breakdown Structure Handbook.[3] Table 45 also shows an example of a Department of Energy program WBS. Tables 42-45 are from the Project Management Institute's *Practice Standard for Work Breakdown Structures*, second edition, published in October 2006. These examples of WBS were valid at the time of publication in 2020. It is advised that the source of the WBS be checked before it is used to see if any updates have been made.

Table 34: Aircraft System Work Breakdown Structure

Level 2 element		Level 3 element	
1.1	Aircraft system, integration, assembly, test, and checkout		
1.2	Air vehicle		
		1.2.1	Air vehicle integration, assembly, test, and checkout
		1.2.2	Airframe
		1.2.3	Propulsion
		1.2.4	Vehicle subsystems
		1.2.5	Avionics
		1.2.6	Armament/weapons delivery
		1.2.7	Auxiliary equipment

[1]Department of Defense, *Department of Defense Handbook: Work Breakdown Structures for Defense Materiel Items*, MIL-HDBK-881A (Washington, D.C.: April 1975).

[2]As described in DOD's Instruction 5000.02T *Operation of the Defense Acquisition System*, all defense acquisition programs are designated by an acquisition category (ACAT) I through III depending on cost threshold and other factors.

[3]National Aeronautics and Space Administration, *Work Breakdown Structure (WBS) Handbook*, NASA/SP-2010-3404 (Washington, D.C.: January 2010).

Level 2 element		Level 3 element	
		1.2.8	Furnishings and equipment
		1.2.9	Air vehicle software release 1…n (specify)
		1.2.10	Other air vehicle 1…n (specify)
1.3	Payload/mission system		
		1.3.1	Payload integration, assembly, test, and checkout
		1.3.2	Survivability payload 1…n (specify)
		1.3.3	Reconnaissance payload 1…n (specify)
		1.3.4	Electronic warfare payload 1…n (specify)
		1.3.5	Armament/weapons delivery payload 1…n (specify)
		1.3.6	Payload software release 1…n (specify)
		1.3.7	Other payload 1…n (specify)
1.4	Ground/host segment		
		1.4.1	Ground segment integration, assembly, test, and checkout
		1.4.2	Ground control systems
		1.4.3	Command and control subsystem
		1.4.4	Launch equipment
		1.4.5	Recovery equipment
		1.4.6	Transport vehicles
		1.4.7	Ground segment software release 1…n (specify)
		1.4.8	Other ground/host segment 1…n (specify)
1.5	Aircraft system software release 1…n (specify)		
1.6	System engineering		
		1.6.1	Software systems engineering
		1.6.2	Integrated logistics support systems engineering
		1.6.3	Cybersecurity systems engineering
		1.6.4	Core systems engineering
		1.6.5	Other systems engineering 1…n (specify)
1.7	Program management		
		1.7.1	Software program management

Level 2 element		Level 3 element	
		1.7.2	Integrated logistics support program management
		1.7.3	Cybersecurity management
		1.7.4	Core management
		1.7.5	Other management 1…n (specify)
1.8	System test and evaluation		
		1.8.1	Development test and evaluation
		1.8.2	Operational test and evaluation
		1.8.3	Cybersecurity test and evaluation
		1.8.4	Mock-ups/system integration labs
		1.8.5	Test and evaluation support
		1.8.6	Test facilities
1.9	Training		
		1.9.1	Equipment
		1.9.2	Services
		1.9.3	Facilities
		1.9.4	Training software 1…n (specify)
1.10	Data		
		1.10.1	Data deliverables 1…n (specify)
		1.10.2	Data repository
		1.10.3	Data rights 1…n (specify)
1.11	Peculiar support equipment		
		1.11.1	Test and measurement equipment
		1.11.2	Support and handling equipment
1.12	Common support equipment		
		1.12.1	Test and measurement equipment
		1.12.2	Support and handling equipment
1.13	Operational/site activation by site 1…n (specify)		
		1.13.1	System assembly, installation and checkout on site
		1.13.2	Contractor technical support
		1.13.3	Site construction
		1.13.4	Site/ship/vehicle conversion
		1.13.5	Interim contractor support
1.14	Contractor logistics support		
1.15	Industrial facilities		
		1.15.1	Construction/conversion/expansion

Level 2 element	Level 3 element
	1.15.2 Equipment acquisition or modernization
	1.15.3 Maintenance (industrial facilities)
1.16 Initial spares and repair parts	

Source: Department of Defense, Office of the Assistant Secretary of Defense for Acquisition, Performance Assessments and Root Cause Analysis (OASD(A)/PARCA), Department of Defense Standard Practice: Work Breakdown Structures for Defense Materiel Items, MIL-STD-881D (Washington, D.C.: April 9, 2018), appendix. A. | GAO-20-195G

Table 35: Missile/Ordnance Systems Work Breakdown Structure

Level 2 element	Level 3 element
1.1 Missile/ordnance system integration, assembly, test, and checkout	
1.2 Air vehicle/munition	
	1.2.1 Air vehicle/munition integration, assembly, test, and checkout
	1.2.2 Airframe
	1.2.3 Propulsion subsystem 1…n (specify)
	1.2.4 Power and distribution
	1.2.5 Guidance
	1.2.6 Navigation
	1.2.7 Controls
	1.2.8 Communications
	1.2.9 Payload
	1.2.10 On board test equipment
	1.2.11 On board training equipment
	1.2.12 Auxiliary equipment
	1.2.13 Air vehicle software release 1…n
1.3 Encasement device	
	1.3.1 Encasement device integration, assembly, test and checkout
	1.3.2 Encasement device structure
	1.3.3 Encasement device software release 1…n (specify)
	1.3.4 Other encasement device subsystems 1…n (specify)
1.4 Command and/or launch	
	1.4.1 Command and/or launch integration, assembly, test and checkout
	1.4.2 Surveillance, identification and tracking sensors

Level 2 element		Level 3 element	
		1.4.3	Communications
		1.4.4	Launcher
		1.4.5	Adapter kits
		1.4.6	Launch and guidance control
		1.4.7	Ready magazine
		1.4.8	Auxiliary equipment
		1.4.9	Command and/or launch software release 1…n (specify)
		1.4.10	Other command and/or launch 1…n (specify)
1.5	Missile/ordnance system software release 1…n (specify)		
1.6	Platform integration, assembly, test and checkout 1…n (specify)		
1.7	Systems engineering		
		1.7.1	Software systems engineering
		1.7.2	Integrated logistics support systems engineering
		1.7.3	Cybersecurity systems engineering
		1.7.4	Core systems engineering
		1.7.5	Other systems engineering 1…n (specify)
1.8	Program management		
		1.8.1	Software program management
		1.8.2	Integrated logistics support program management
		1.8.3	Cybersecurity management
		1.8.4	Core program management
		1.8.5	Other program management 1…n (specify)
1.9	System test and evaluation		
		1.9.1	Development test and evaluation
		1.9.2	Operational test and evaluation
		1.9.3	Cybersecurity test and evaluation
		1.9.4	Mock-ups/system integration labs
		1.9.5	Test and evaluation support
		1.9.6	Test facilities
1.10	Training		

Level 2 element	Level 3 element
	1.10.1 Equipment
	1.10.2 Services
	1.10.3 Facilities
	1.10.4 Training software 1…n (specify)
1.11 Data	
	1.11.1 Data deliverables 1…n (specify)
	1.11.2 Data repository
	1.11.3 Data rights 1…n (specify)
1.12 Peculiar support equipment	
	1.12.1 Test and measurement equipment
	1.12.2 Support and handling equipment
1.13 Common support equipment	
	1.13.1 Test and measurement equipment
	1.13.2 Support and handling equipment
1.14 Operational/site activation by site 1…n (specify)	
	1.14.1 System assembly, installation and checkout on site
	1.14.2 Contractor technical support
	1.14.3 Site construction
	1.14.4 Site/ship/vehicle conversion
	1.14.5 Interim contractor support
1.15 Contractor logistics support	
1.16 Industrial facilities	
	1.16.1 Construction/conversion/expansion
	1.16.2 Equipment acquisition or modernization
	1.16.3 Maintenance (industrial facilities)
1.17 Initial spares and repair parts	

Source: Department of Defense, Office of the Assistant Secretary of Defense for Acquisition, Performance Assessments and Root Cause Analysis (OASD(A)/PARCA), Department of Defense Standard Practice: Work Breakdown Structures for Defense Materiel Items, MIL-STD-881D (Washington, D.C.: April 9, 2018), appendix C. | GAO-20-195G

Table 36: 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, communications and surveillance

Level 2 element		Level 3 element	
		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		
		1.2.1	Software systems engineering
		1.2.2	Integrated logistics support systems engineering
		1.2.3	Cybersecurity systems engineering
		1.2.4	Core systems engineering
		1.2.5	Other systems engineering 1…n (specify)
1.3	Program management		
		1.3.1	Software program management
		1.3.2	Integrated logistics support program management
		1.3.3	Cybersecurity management
		1.3.4	Core program management
		1.3.5	Other program management 1…n (specify)
1.4	System test and evaluation		
		1.4.1	Development test and evaluation
		1.4.2	Operational test and evaluation
		1.4.3	Cybersecurity test and evaluation
		1.4.4	Mock-ups/system integration labs
		1.4.5	Test and evaluation support
		1.4.6	Test facilities
1.5	Training		
		1.5.1	Equipment
		1.5.2	Services
		1.5.3	Facilities
		1.5.4	Training software 1…n (specify)
1.6	Data		
		1.6.1	Data deliverables 1…n (specify)
		1.6.2	Data repository
		1.6.3	Data rights 1…n (specify)
1.7	Peculiar support equipment		

Level 2 element		Level 3 element	
		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 by site 1…n (specify)		
		1.9.1	System assembly, installation and checkout on site
		1.9.2	Contractor technical support
		1.9.3	Site construction
		1.9.4	Site/ship/vehicle conversion
		1.9.5	Interim contractor support
1.10	Contractor logistics support		
1.11	Industrial facilities		
		1.11.1	Construction/conversion/expansion
		1.11.2	Equipment acquisition or modernization
		1.11.3	Maintenance (industrial facilities)
1.12	Initial spares and repair parts		

Source: Department of Defense, Office of the Assistant Secretary of Defense for Acquisition, Performance Assessments and Root Cause Analysis (OASD(A)/PARCA), Department of Defense Standard Practice: Work Breakdown Structures for Defense Materiel Items, MIL-STD-881D (Washington, D.C.: April 9, 2018), appendix E. | GAO-20-195G

Table 37: Space System Work Breakdown Structure

Level 2 element		Level 3 element	
1.1	Systems engineering, integration and test, and program management (SEIT/PM) and support equipment		
		1.1.1	Systems engineering
		1.1.2	Assembly, integration, and test
		1.1.3	Program management
		1.1.4	Support equipment
1.2	Space vehicle 1…n (specify)		
		1.2.1	SEIT/PM and support equipment
		1.2.2	Bus

Level 2 element		Level 3 element	
		1.2.3	SEIT/PM and support equipment (if applicable for integration of multiple payloads)
		1.2.4	Payload 1…n (specify)
		1.2.5	Booster adapter
		1.2.6	Space vehicle storage
		1.2.7	Launch systems integration
		1.2.8	Launch operations
		1.2.9	Mission operations support
		1.2.10	Space vehicle other
1.3	Ground segment		
		1.3.1	SEIT/PM and support equipment
		1.3.2	Ground functions 1…n (specify)
		1.3.3	Ground terminal/gateway 1…n (specify)
		1.3.4	External network (T-COMM)
		1.3.5	User equipment
		1.3.6	Facilities 1…n (specify)
		1.3.7	Vehicles and shelters
1.4	Orbital transfer vehicle		
1.5	Launch vehicle 1…n (specify)		

Source: Department of Defense, Office of the Assistant Secretary of Defense for Acquisition, Performance Assessments and Root Cause Analysis (OASD(A)/PARCA), Department of Defense Standard Practice: Work Breakdown Structures for Defense Materiel Items, MIL-STD-881D (Washington, D.C.: April 9, 2018), appendix F. | GAO-20-195G

Table 38: Ground Vehicle System Work Breakdown Structure

Level 2 element		Level 3 element	
1.1	Family of vehicles		
		1.1.1	Lead variant
		1.1.2	Variant 2…n (specify)
		1.1.3	Equipment kits 1…n (specify)
1.2	Secondary vehicle		
1.3	Systems engineering		
		1.3.1	Software systems engineering
		1.3.2	Integrated logistics support systems engineering
		1.3.3	Cybersecurity systems engineering
		1.3.4	Core systems engineering
		1.3.5	Other systems engineering 1…n (specify)

Level 2 element		Level 3 element	
1.4	Program management		
		1.4.1	Software program management
		1.4.2	Integrated logistics support program management
		1.4.3	Cybersecurity management
		1.4.4	Core program management
		1.4.5	Other program management 1…n (specify)
1.5	System test and evaluation		
		1.5.1	Development test and evaluation
		1.5.2	Operational test and evaluation
		1.5.3	Cybersecurity test and evaluation
		1.5.4	Mock-ups/system integration labs
		1.5.5	Test and evaluation support
		1.5.6	Test facilities
1.6	Training		
		1.6.1	Equipment
		1.6.2	Services
		1.6.3	Facilities
		1.6.4	Training software 1…n (specify)
1.7	Data		
		1.7.1	Data deliverables 1…n (specify)
		1.7.2	Data repository
		1.7.3	Data rights 1…n (specify)
1.8	Peculiar support equipment		
		1.8.1	Test and measurement equipment
		1.8.2	Support and handling equipment
1.9	Common support equipment		
		1.9.1	Test and measurement equipment
		1.9.2	Support and handling equipment
1.10	Operational/site activation by site 1…n (specify)		
		1.10.1	System assembly, installation and checkout on site
		1.10.2	Contractor technical support
		1.10.3	Site construction
		1.10.4	Site/ship/vehicle conversion

Level 2 element		Level 3 element	
		1.10.5	Interim contractor support
1.11	Contractor logistics support		
1.12	Industrial facilities		
		1.12.1	Construction/conversion/expansion
		1.12.2	Equipment acquisition or modernization
		1.12.3	Maintenance (industrial facilities)
1.13	Initial spares and repair parts		

Source: Department of Defense, Office of the Assistant Secretary of Defense for Acquisition, Performance Assessments and Root Cause Analysis (OASD(A)/PARCA), Department of Defense Standard Practice: Work Breakdown Structures for Defense Materiel Items, MIL-STD-881D (Washington, D.C.: April 9, 2018), appendix G. | GAO-20-195G

Table 39: Information Systems/Defense Business Systems (Investment) Work Breakdown Structure

Level 2 element		Level 3 element	
1.1	Information Systems(IS)/Defense Business Systems (DBS) Development/customization/configuration		
		1.1.1	Custom application 1…n (specify)
		1.1.2	Enterprise service element 1…n (specify)
		1.1.3	Enterprise/management information systems 1…n (specify)
		1.1.4	External system interface development 1…n (specify)
		1.1.5	System level hardware (specify)
1.2	System level integration		
1.3	Systems engineering		
		1.3.1	Software systems engineering
		1.3.2	Integrated logistics support systems engineering
		1.3.3	Cybersecurity systems engineering
		1.3.4	Core systems engineering
		1.3.5	Other systems engineering 1…n (specify)
1.4	Program management		
		1.4.1	Software program management

Level 2 element	Level 3 element
	1.4.2 Integrated logistics support program management
	1.4.3 Cybersecurity management
	1.4.4 Core program management
	1.4.5 Other program management 1…n (specify)
1.5 Change management	
1.6 Data management	
1.7 System test and evaluation	
	1.7.1 Development test and evaluation
	1.7.2 Operational test and evaluation
	1.7.3 Cybersecurity test and evaluation
	1.7.4 Mock-ups/system integration labs
	1.7.5 Test facilities
1.8 Training	
	1.8.1 Equipment
	1.8.2 Services
	1.8.3 Facilities
	1.8.4 Training software 1…n (specify)
1.9 Data	
	1.9.1 Data deliverables 1…n (specify)
	1.9.2 Data repository
	1.9.3 Data rights 1…n (specify)
1.10 Peculiar support equipment	
	1.10.1 Test and measurement equipment
	1.10.2 Support and handling equipment
1.11 Common support equipment	
	1.11.1 Test and measurement equipment
	1.11.2 Support and handling equipment
1.12 Operational infrastructure/site activation by site 1…n (specify)	
	1.12.1 Initial hardware procurement
	1.12.2 Initial software license procurement
	1.12.3 Initial software release (pre-IOC) modification/enhancement
	1.12.4 Site activation
	1.12.5 Interim operations and support (pre-IOC)

Level 2 element	Level 3 element
1.13 Industrial facilities	
	1.13.1 Construction/conversion/expansion
	1.13.2 Equipment acquisition or modernization
	1.13.3 Maintenance (industrial facilities)
1.14 Initial spares and repair parts	

Source: Department of Defense, Office of the Assistant Secretary of Defense for Acquisition, Performance Assessments and Root Cause Analysis (OASD(A)/PARCA), Department of Defense Standard Practice: Work Breakdown Structures for Defense Materiel Items, MIL-STD-881D (Washington, D.C.: April 9, 2018), appendix J. | GAO-20-195G

Table 40: Technology Development Project Work Breakdown Structure

Level 1 element	Level 2 element
1.0 Technology development (TD) project	
	1.1 TD project management
	1.2 TD project analysis
	1.3 Advanced concepts
	1.4 Technology development
	1.5 Validation and test
	1.6 Safety and mission assurance
	1.7 Education and public outreach
	1.8 Technology transfer

Source: National Aeronautics and Space Administration, Work Breakdown Structure (WBS) Handbook, NASA/SP-2010-3404 (Washington, D.C.: January 2010), appendix C. | GAO-20-195G

Table 41: Particle Accelerator System Work Breakdown Structure

Level 2 element	Level 3 element
1.1 Injection subsystem	
	1.1.1 Ion source
	1.1.2 Vacuum chamber
	1.1.3 Extractor
	1.1.4 Magnets
	1.1.5 Vacuum
	1.1.6 Diagnostic/monitoring
	1.1.7 Radio frequency power subsystem
	1.1.8 Controls and power conversion subsystem
	1.1.9 Lasers
	1.1.10 Collimators

Level 2 element		Level 3 element	
		1.1.11	Support structure
1.2	Accelerator subsystem	1.2.1	Vacuum chamber
		1.2.2	Magnets
		1.2.3	Diagnostics/monitoring
		1.2.4	Radio frequency power subsystem
		1.2.5	Cooling subsystem
		1.2.6	Support structure
1.3	Insertion devices	1.3.1	Bending magnets
		1.3.2	Wave length shifters
		1.3.3	Wigglers
		1.3.4	Undulators
		1.3.5	Radio frequency power subsystem
		1.3.6	Support structure
1.4	Beam transport lines (low, high energy, dump)	1.4.1	Magnets
		1.4.2	Collimators
		1.4.3	Diagnostics/monitoring
		1.4.4	Support structure

Source: Department of Energy, Work Breakdown Structure Handbook (Washington, D.C.: August 16, 2012), appendix H. | GAO-20-195G

Table 42: 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

Level 2 element		Level 3 element	
1.5	Long-term bio-venting 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	Pre-draft 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		

Source: Project Management Institute, Inc. *Project Standard for Work Breakdown Structures*, Second Edition, 2006. | GAO-20-195G

Table 43: Pharmaceutical Management 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
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	Post-approval regulatory support program
1.4	Lead identification	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 study(ies)

Level 2 element		Level 3 element	
		1.5.2	Drug interaction study(ies)
		1.5.3	Renal effect study(ies)
		1.5.4	Hepatic effect study(ies)
		1.5.5	Bioequivalency study(ies)
		1.5.6	Other clinical pharmacology study(ies)
1.6	Preclinical program	1.6.1	Tox/ADME support
		1.6.2	Client pharmacology support
1.7	Phase I clinical study program	1.7.1	Pharmacokinetic/pharmacodynamics study(ies)
		1.7.2	Dose ranging study(ies)
		1.7.3	Multiple dose safety study(ies)
1.8	Phase II clinical study program	1.8.1	Multiple dose efficacy study(ies)
		1.8.2	Other clinical study(ies)
1.9	Phase III clinical study program	1.9.1	Pivotal registration study(ies)
		1.9.2	Other clinical study(ies)
1.10	Submission/launch phase	1.10.1	Pre-launch preparation
		1.10.2	Launch
		1.10.3	Post-launch support
1.11	Phase IV/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

Source: Project Management Institute, Inc. *Project Standard for Work Breakdown Structures*, Second Edition, 2006. | GAO-20-195G

Table 44: 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 structures
		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 (non-government) / permitting (government)
		1.3.2	Environmental impact
		1.3.3	Labor agreements
		1.3.4	Land acquisition
		1.3.5	Other legal/regulatory requirements
1.4	Testing	1.4.1	System test
		1.4.2	Acceptance test
		1.5.6	Other clinical pharmacology study(ies)
1.5	Startup		
1.6	Project management		

Source: Project Management Institute, Inc. *Project Standard for Work Breakdown Structures*, Second Edition, 2006. | GAO-20-195G

Table 45: Telecom 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

Level 2 element		Level 3 element	
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
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 non-penalty environment
		1.6.2	First action site
		1.6.3	Deployment
1.7	Life cycle support	1.7.1	Customer training and education
		1.7.2	Turnover to customer
		1.7.3	Customer acceptance
		1.7.4	Support and maintenance
1.8	Project management		

Source: Project Management Institute, Inc. *Project Standard for Work Breakdown Structures*, Second Edition, 2006. | GAO-20-195G

Appendix VII: 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 is reduced by a constant percentage. It is represented by the formula

Y = AXb, where

Y = the cost of the Xth unit,
A = the first unit (T1) cost,
X = the unit number, and

b = the slope coefficient of the learning curve, defined as $\frac{\ln slope}{\ln 2}$.

The rate of learning, b, causes the cost to decrease at a constant rate as the quantity produced doubles.

That is, if the slope is 80 percent, the cost of the second production unit is 80 percent of the cost of the first production unit, the fourth production unit is 80 percent of the cost of the second production unit, and so on. Simply stated, as the quantity doubles, the cost reduces by the learning curve slope. For example, assume the first production unit cost $1,000 and the learning curve is 80 percent:

$$\mathrm{b} = \frac{\ln slope}{\ln 2}$$

$$\mathrm{b} = \frac{\ln 0.8}{\ln 2}$$

$$\mathrm{b} = -0.322$$

<u>Cost of the second production unit</u>

$$\mathrm{Y} = \mathrm{AX^b}$$

$$\mathrm{Y} = (\$1{,}000)(2^{-0.322}) = \$800$$

Cost of third production unit

$$\mathrm{Y} = (\$1{,}000)(3^{-0.322}) = \$702$$

Cost of fourth production unit

$$Y = (\$1{,}000)(4^{-0.322}) = \$640$$

Cumulative Average Formulation

Cumulative average formulation, or cumulative average theory, (CAT) is commonly associated with T. P. Wright, who initiated an important discussion of this method in 1936.[1] 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:

$\bar{Y}$ = AXb, where

$\bar{Y}$ = the cumulative average cost of X units,
A = the first unit (T1) cost,
X = the cumulative number of units, and

b = the constant slope coefficient of the learning curve (where slope equals 2b).

In cumulative average theory, if the average cost of the first 10 units is $100 and the slope is 90 percent, the average cost of the first 20 units is $90, the average cost of the first 40 units is $81, and so on.

Choosing between Unit Formulation and Cumulative Average

The difference between unit and cumulative average theory is that unit theory calculates each unit or lot individually, while cumulative average theory calculates the cumulative average cost of all units collectively to date. The difference between unit formulation and cumulative average theory is in where the curve affects the overall cost. Using a cumulative average for the first few units will yield higher cost savings than using unit theory with the same slope. As the number of units increases, the difference between the results decreases.

There are no firm rules that would cause a cost estimator to select one approach over the other, but 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

[1]Wright, T.P., “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.

2. industry standards
3. historical experience
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 theory was used to model the production cost for a previous version of a modified commercial jet, the estimator should choose unit theory.

Industry Standards

Certain industries sometimes tend to prefer one method over the other. For example, some space systems are better modeled using cumulative average theory. If an analyst were estimating one of these space systems, cumulative average theory should be used, since it is an industry standard.

Historical 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 theory best models production environments in which the contractor is 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 theory 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.

Production Rate Effects and Breaks in Production

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 factors such as overtime, capital purchases, hiring actions, and training costs.

These effects can be modeled by adding a rate variable to the unit learning formula. The equation becomes:

$Y = AXbQr$, where

- Y = the cost of the X^{th} unit
- A = the first unit (T1) cost,
- X = the unit number
- b = the constant slope coefficient of the learning curve, defined as $\frac{\ln slope}{\ln 2}$
- Q = production rate (that is, quantity per time period or lot)
- r = rate coefficient, defined as $\frac{\ln rate\ slope}{\ln 2}$, where rate slope = 2r)

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. Production breaks can last anywhere from a few weeks to several years, depending on the situation. Depending upon the length of the break, cost analysts need to account for learning that is lost due to workers forgetting how to efficiently produce items. Examining a production break can be divided into two questions:

1. How much learning achieved to date has been lost (or forgotten) because of the break in production?
2. 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. An analyst can then answer the second question by using the "Retrograde Method," which determines which unit on the original learning curve is the appropriate unit from where to start again from a cost perspective.

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 was lost due to the break. The Anderlohr method divides learning loss into five categories: personnel learning, supervisory learning, continuity of production, methods, and 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 the number of production line staff has been reduced, so that supervisors who may no longer be familiar with the job are unable 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 necessary. 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 or be lost 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 46).

Table 46: 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. | GAO-20-195G

In the table, if the production break is 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 were 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 up the curve is 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 may 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. First, a cost estimator accounts for the number of equivalent prototype units, based on both partial and complete units. This allows the estimator to capture the effects of units that are not representative of a complete unit 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 – the first unit produced after the equivalent units were produced.

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 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 entirely continuous improvement is not appropriate and that some adjustment is required. This could be because prototype manufacturing was accomplished in a development laboratory rather than in a normal production environment, or because engineering personnel were used rather than production personnel. Numerous reasons are possible for less than totally continuous cost improvement; the analyst must thoroughly evaluate each program's 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 development 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 development 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 historical 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 recurring and nonrecurring efforts. The recurring cost of end-of-production units is often higher than would have been projected from a program's historical cost improvement curve. This is referred to as toe-up. The main reasons for toe-ups 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 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 broadly accepted. In truth, such costs are often ignored. If, however, the analyst has access to relevant historical 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;
- 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.

Appendix VIII: Technology Readiness Levels

Technology Readiness Levels (TRLs) are metrics used to describe the maturity level of new or existing technologies and/or systems. Technology Readiness Assessments (TRAs) are the primary method for much of the federal government to apply TRLs to assess the maturity of programs in development. The findings are generally described as TRL numbers—characteristics of levels of technical maturity based on demonstrations of capabilities.

Experts agree that TRLs are the most common measure for systematically communicating the readiness of new technologies or new applications of existing technologies to be incorporated into a product. Government agencies and other organizations commonly use TRLs to describe the maturity of a given technology within its development life cycle. Some organizations have tailored the TRL definitions to suit their product development applications. but, in general, TRLs are measured along a 1-9 scale, starting with level 1 being preliminary research of the basic concept, moving to laboratory demonstrations around level 4, and proven technology programs at level 9, where the technology is integrated into a product and successfully operated in its intended environment. Figure 39 includes the nine TRL levels and descriptions DOD, NASA, and other organizations use. Additional examples of government agencies' TRL definitions and descriptions can be found in the GAO *Technology Readiness Assessment Guide: Best Practices for Evaluating the Readiness of Technology for Use in Acquisition Programs and Projects* (GAO-20-48G).

Figure 39: Technology Readiness Levels

Technology readiness level (TRL)	Description
1 Basic principles observed and reported	Scientific research begins to be translated into applied research and development. Examples include paper studies of a technology's basic properties.
2 Technology concept and/or application formulated	Invention begins. Once basic principles are observed, practical applications can be invented. Applications are speculative, and there may be no proof or detailed analysis to support the assumptions. Examples are limited to analytic studies.
3 Analytical and experimental critical function and/or characteristic proof of concept	Active research and development is initiated. This includes analytical studies and laboratory studies to physically validate the analytical predictions of separate elements of the technology. Examples include components that are not yet integrated or representative.
4 Component and/or breadboard validation in laboratory environment	Basic technological components are integrated to establish that they will work together. This is relatively low fidelity compared with the eventual system. Examples include integration of ad hoc hardware in the laboratory.
5 Component and/or breadboard validation in relevant environment	Fidelity of breadboard technology increases significantly. The basic technological components are integrated with reasonably realistic supporting elements so they can be tested in a simulated environment. Examples include high fidelity laboratory integration of components.
6 System/subsystem model or prototype demonstration in a relevant environment	Representative model or prototype system, which is well beyond that of TRL 5, is tested in its relevant environment. Represents a major step up in a technology's demonstrated readiness. Examples include testing a prototype in a high-fidelity laboratory environment or in a simulated operational environment.
7 System prototype demonstration in an operational environment	Prototype near or at planned operational system. Represents a major step up from TRL 6 by requirement demonstration of an actual system prototype in an operational environment (e.g., in an aircraft, a vehicle, or space).
8 Actual system completed and qualified through test and demonstration	Technology has been proven to work in its final form and under expected conditions. In almost all cases, this TRL represents the end of true system development. Examples include developmental test and evaluation of the system in its intended weapon system to determine if it meets design specifications.
9 Actual system 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. Examples include using the system under operational mission conditions.

Source: GAO simplification of agency documents. | GAO-20-195G

Appendix IX: Integrated Baseline Review

IBR Overview

The objectives of the integrated baseline review (IBR) are to gain insight into cost and schedule risk areas associated with a program or contract and to develop confidence in the program's acquisition plans. The focus of the review should be primarily to assess the adequacy of the baseline plan to execute the approved program or contract.

An IBR is most effective if the focus is on areas of the greatest risk to the program. Government and contractor program managers should try for mutual understanding of risks and formulate a plan to respond to and track these risks through the EVM and risk management processes. In addition, developing this cooperation promotes communication and increases the likelihood of effectively managing program risks.

Components of the IBR process include:

- IBR Program Management: identifying program scope to review, including appropriate control accounts and associated documentation needs, program management planning such as obtaining required technical expertise, and scheduling review dates;
- IBR Team: identifying the size, responsibilities, training, and experience of the IBR team;
- IBR Execution: conducting the IBR;
- IBR Risks: classifying risks by severity and developing risk evaluation criteria; and
- IBR Findings: developing an approach for conveying and summarizing findings.

IBR Program Management

Program managers should develop a plan for conducting the IBR by first identifying areas of program scope the team will review. To do this, they should be familiar with the contract statement of work and use appropriate documents, including the life cycle cost estimate (LCCE) and program risk assessment, to select 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.

Because an IBR provides a mutual understanding of the performance measurement baseline and associated risks, identifying potential threats and opportunities early allows for developing a plan to respond to them. An IBR should not be postponed indefinitely; it should begin with a small team as early as possible to help clarify plans for program execution. Thus, the IBR should be initiated as early as possible—before award, when appropriate, and no later than 6 months after. If the contractor has reasonably developed an integrated baseline, preparing for the IBR should require minimal time. The duration of the IBR is based on program and contract scope, complexity, and risk; typically, it lasts several days.

IBR Team

Each IBR requires participation from specific program, technical, and schedule experts. The typical IBR team consists of the government program manager, technical experts, EVM analysts, cost estimators, and other technical expert personnel who may help during the review. The team's size should be determined by the program's complexity and the risk associated with achieving program objectives. Staff from a variety of disciplines—such as program management, systems engineering, software engineering, manufacturing, integration and testing, and 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. The IBR team may at times also include subcontractor personnel.

Team members must have appropriate training before the IBR is conducted to ensure that they can correctly identify and assess program risk. Team members should be trained as needed so they understand the cost, schedule, and technical aspects of the performance measurement baseline and the processes that will be used to manage them.

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.

In the weeks leading up to the IBR, the IBR team typically participates in a day of training tailored to the subject program that includes:

- basic IBR fundamentals and review of the methodology to be followed;
- detailed roles and responsibilities of team members;

- guidance on baseline discussions with CAMs 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.

IBR Execution

In executing the IBR, the team assesses the adequacy, realism, and risks of the baseline by examining if the rationale supporting lower-level control accounts is reasonable. The team should also assess whether managers have appropriately implemented required management processes. To be most effective, maturity indicators should be assessed to ensure that a value-added assessment of the performance measurement baseline can be accomplished. Areas to review include:

- Work definition
- Integrated schedule
- Resources, labor, and materials (which should be fully planned and scheduled)

Once the team has determined that the program is defined at an appropriate level, the next key objective is to interview control account managers. Interviews should focus on areas of significant risk as well as 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.

During the interview process, the IBR team meets with specific control account managers to understand how they plan to 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.

After completing the IBR, the team assesses whether they have achieved the goals of understanding the performance measurement baseline and creating a plan of action for responding to risks. They should develop a closure plan that assigns staff responsibility for each risk identified in the IBR. Significant risks should 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 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. The team should discuss whether management reserve will cover new risks identified in the IBR. Finally, if the team finds deficiencies in the EVM system, it should record them in a corrective action request and ask the EVM specialist to monitor their status.

IBR Risks

Identifying potential program risk is one main goal of an IBR. Risks are generally categorized as cost, management process, resource, schedule, and technical (see table 47).

Program managers should also outline the criteria for evaluating risks in table 47 and develop a method for tracking them within the risk management process. All risks identified in the IBR should be monitored.

Table 47: 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 the inability to establish and maintain valid, accurate, and timely performance data, including subcontractors' data.

Category	Definition
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 and unexpected downtime precluding or limiting the use of 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, and design maturity.

Source: Adapted from Department of Defense, Office of the Secretary of Defense (AT&L), The Program Manager's Guide to the Integrated Baseline Review Process (Washington, D.C.: April 2003). | GAO-20-195G

IBR Findings

After completing IBR activities, the IBR team is responsible for developing the final action item reports, which are then formally submitted to the contractor. The contractor is given about a month to respond. The team reviews the contractor's response and a determination is made as to whether the contractor has sufficiently addressed the action items. The action item may be closed, more information may be requested from the contractor, or a risk may be introduced into the risk management plan. In some cases, IBR reports can remain open for a significant amount of time.

When closing IBR actions, it is important to ensure that these items receive ongoing attention from the program manager (both government and contractor) based on lessons learned. An 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. The contractor should be held accountable to track the action items and provide status updates until the government approves closure.

Although a formal IBR report is not usually required, the government program manager should create a memorandum for the record describing the findings and the program manager should retain all backup documentation. Finally, the government should make a determination about whether the performance measurement baseline is reliable and accurate for measuring true performance.

IBR Assessment

When auditing a program that has conducted an IBR, there are several documents to review and questions to evaluate to determine if the IBR process was properly completed. The list of documents to be reviewed include

1. EVM contract performance reports (CPR), Formats 1-5, for the past 12 months
2. The most recent IBR report
3. IBR team training briefings and documentation
4. Any corrective action reports (CARs) generated by the IBR
5. The integrated master schedule (IMS) in its native software format
6. EVMS guidance or policy
7. Copy of EVM Certification to demonstrate EIA-748 compliance
8. Copy of any adverse opinions of the contractor's financial accounting system
9. Copy of any EVM trends and metric analysis reports
10. Work Breakdown Structure (WBS) and WBS Dictionary
11. Statement of work
12. Work package descriptions
13. Risk plans
14. Staffing plans
15. Control account plans
16. Bases of estimates

IBR Appendix Checklist

IBR Program Management:

Did management develop a plan for conducting the IBR?

a. Did they identify program scope to review, including appropriate control accounts and associated documentation needs?

b. Did management identify the size, responsibilities, and experience of the IBR team?

c. Was program management planning performed, such as providing training, obtaining required technical expertise, and scheduling review dates?

d. Did management classify risks by severity and develop risk evaluation criteria?

e. Did management develop an approach for conveying and summarizing findings?

f. Did management request the appropriate documents from the contractor to enable the government team to prepare for the IBR?

IBR Team:

1. What personnel were assigned to the government IBR team? Did the team include experts in functional areas such as cost estimating, schedule analysis, earned value analysis, and contracting? Did the team include expertise in program management, systems engineering, software engineering, manufacturing, integration and testing, and logistics?
2. Did the program office conduct IBR training for the IBR team?

IBR Execution:

1. Was the IBR performed within 6 months of contract award or rebaselining?
2. Were the following maturity indicators assessed to ensure that a meaningful assessment of the performance measurement baseline (PMB) could be accomplished during the IBR?
   a. Work definition
      i. Was a WBS developed?
      ii. Were specifications flowed down to subcontractors?
      iii. Was an internal statement of work for work package definitions developed?
   b. Integrated schedule
      i. Were the lowest and master levels of the schedule vertically integrated?
      ii. Were tasks horizontally integrated?
      iii. Were product handoffs identified?
      iv. Were subcontractor schedules integrated with the prime master schedule?

c. Resources, labor, and material

   i. Were constrained resources identified or rescheduled?
   ii. Were staffing resources leveled?
   iii. Were subcontractor baselines integrated with the prime baseline?
   iv. Were schedule and budget baselines integrated?
   v. Were work package earned value measures defined?
   vi. Was the baseline validated at the lowest levels and approved by management?

3. Did the team assess the PMB by examining the following criteria?
   a. Was the technical scope of work fully included?
   b. Were key milestones identified in the schedule?
   c. Did supporting schedules reflect a logical flow to accomplish tasks?
   d. Was the duration of each task realistic?
   e. Was the network schedule logic accurate?
   f. Was the critical path identified?
   g. Were resources – budgets, facilities, personnel, skills – available and sufficient for accomplishing tasks?
   h. Were tasks planned to be objectively measured for technical progress?
   i. Was the rationale supporting PMB control accounts reasonable?
   j. Did managers appropriately implement required management processes?

4. Were interviews held with the control account managers?
   a. Did the interviews focus on areas of significant risk and management processes that may affect the ability to monitor risks?
   b. Did the interviews address how the baseline was developed and discuss the supporting documentation?

IBR Risks:

1. Did program management develop a response for each risk identified in the IBR and assign staff responsibility for each risk?
2. If significant risks were identified, were they included in the program's risk management plan and risk register?
3. Was the risk assessment presented to senior management to promote awareness?

IBR Findings:

1. Was the IBR report (or other documentation that described the IBR findings) retained in official program management files? Was a determination made that the PMB is reliable and accurate for measuring performance?
2. Did the IBR team document how earned value will be assessed and whether the measurements are objective and reasonable?
3. If the team found deficiencies in the EVM system, were they recorded in corrective action requests and monitored?
4. After the IBR was completed, did the following management processes continue?
   a. Did the baseline maintenance process continue to ensure that the PMB continues to reflect the current plan to complete the remaining work? Did the process follow a disciplined process for incorporating changes?

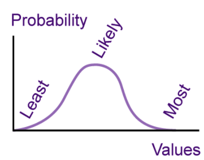
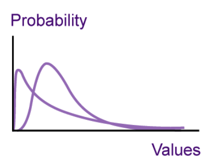
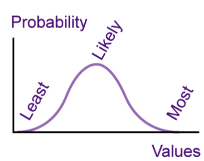
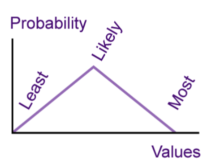
   b. Did the risk management process continue to document and classify risks by probability of occurrence, magnitude of their consequences, and the risk handling technique employed?

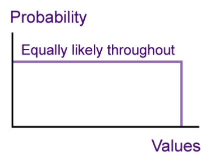
   c. Did scheduling, estimate-to-compete development, and EVM analysis continue to be performed?

Appendix X: Common Probability Distributions

A wide variety of probability distributions are available for modeling cost risk and uncertainty. The triangular, lognormal, beta, uniform, and normal distributions are the most common distributions that cost estimators use to perform a risk and 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 cost estimating literature and are available through a variety of estimating tools. 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. Table 48 lists the five most common probability distributions used in risk analysis.

Table 48: Common Probability Distributions

Distribution	Description	Shape	Typical application
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
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 percent 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. Because data must be symmetrical, it is not as useful for defining risk, which is usually asymmetrical, but can be useful for scaling estimating error
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

Distribution	Description	Shape	Typical application
Uniform	Has no peaks because all values, including highest and lowest possible values, are equally likely		With engineering data or analogy estimates

Source: DOD and NASA. | GAO-20-195G

Appendix XI: Best Practices for the Analysis of Alternatives Process

Background

The Analysis of Alternatives (AOA) process compares the operational effectiveness, cost, and risks of a number of potential alternatives to address valid needs and shortfalls in operational capability. This process helps ensure that the best alternative that satisfies the mission need is chosen on the basis of the selection criteria, such as safety, cost, or schedule.

GAO has identified 22 best practices for an AOA process by (1) compiling and reviewing commonly mentioned AOA policies and guidance used by different government and private-sector entities, and (2) incorporating experts' comments on a draft set of practices to develop a final set of practices.[1]

These practices can be applied to a wide range of activities and situations in which a preferred alternative to the development plan in place must be selected from a set of possible options, as well as to a broad range of capability areas, projects, and programs. These practices can also provide a framework to help ensure that entities consistently and reliably select the program alternative that best meets the mission need. The guidance below is an overview of the key principles that lead to a successful AOA process and is not meant as a prescriptive "how to" guide with detailed instructions for each best practice identified because each entity may have its own process in place.

The 22 best practices that GAO identified are grouped into the following phases:

- **Initialize the AOA process:** includes best practices that are applied before starting the process of identifying, analyzing, and selecting alternatives. This includes determining the mission need and functional requirements, developing the study time frame, creating a study plan, and determining who conducts the analysis.
- **Identify alternatives:** includes best practices that help ensure the alternatives that will be analyzed are sufficient, diverse, and viable.

[1]GAO first identified 24 best practices to establish an AOA process in *DOE and NNSA Project Management: Analysis of Alternatives Could Be Improved by Incorporating Best Practices* (GAO-15-37). GAO refined these best practices and condensed them to 22 best practices in *Amphibious Combat Vehicle: Some Acquisition Activities Demonstrate Best Practices; Attainment of Amphibious Capability to be Determined* (GAO-16-22). The AOA process best practices listed in this guide further refine and supersede those described in GAO-15-37 and GAO-16-22.

- **Analyze alternatives:** includes best practices that compare the alternatives selected for analysis in terms of costs, benefits and risks. The best practices in this category help ensure that the team conducting the analysis uses a standard, quantitative process to analyze the alternatives.
- **Document and review the AOA process:** includes best practices that are applied throughout the AOA process, such as documenting in a single document all steps taken to initialize, identify, and analyze alternatives, selecting a preferred alternative, and independently reviewing the AOA.
- **Select a preferred alternative:** includes the final step of comparing alternatives and selecting a preferred alternative that best meets the mission need.

The five phases address different themes of analysis necessary to complete the AOA process and comprise the beginning of the AOA process (defining the mission need and functional requirements) through the final step of the AOA process (select a preferred alternative).

There are three key entities that are directly involved in the AOA process: the customer, the decision-maker, and the AOA team.

- The **customer** refers to the group that is the one who implements the final decision (i.e. the program office, agency, and the like). A complex AOA process that impacts multiple agencies can have multiple customers.
- The **decision-maker** is the person or entity that signs off on the final decision and analysis documented by the AOA report, and who will select the preferred alternative based on the established selection criteria. The decision-maker should remain informed throughout the AOA process. For example, the decision-maker could form a committee that consists of management and other groups independent of the AOA process who possess the required technical expertise or broad organizational knowledge to keep the decision-maker appraised of and to inform the AOA process.
- The **AOA team** is the group who is involved in the day-to-day work of the AOA process and who conducts the identification and assessment of alternatives that is the foundation of the AOA process.

Best Practices for the Analysis of Alternatives Process

Conforming to the 22 best practices helps ensure that the AOA process is reliable and that the preferred alternative selected is the one that best meets the agency's mission need. Not conforming to the best practices may lead to an unreliable AOA, and the customer will not have assurance that the preferred alternative best meets the mission need. This appendix defines the 22 best practices and the five phases of the AOA process, and includes descriptions of potential effects if the best practices are not followed.

Phase: Initialize the AOA process

1. Define mission need

Definition: The customer defines the mission need (i.e., a credible gap between current capabilities and those required to meet the goals articulated in the strategic plan) without favoring a predetermined solution. To ensure that the AOA process does not favor one solution over another, the AOA is conducted before the design and development of the required capabilities. The customer decides when in a program's design an AOA should be performed, with the understanding that the more complete the design, the more information is available to support a robust analysis and to select a preferred alternative that best meets the mission need.

Effect: Allowing mission need to be defined in solution-specific terms creates a potential bias which could prevent the inclusion of viable alternatives and invalidate the analysis.

2. Define functional requirements

Definition: The customer defines functional requirements (i.e. the general parameters that the selected alternative must have in order to address the mission need) based on the mission need without a predetermined solution. The customer defines the capabilities that the AOA process seeks to refine through characterized gaps between capabilities in the current environment and the capabilities required to meet the stated objectives for the future environment. These functional requirements are realistic, organized, clear, prioritized, and traceable. It is advisable that functional requirements be set early in the AOA process, prior to the identification of alternatives, and agreed upon by all stakeholders.[2]

[2]Stakeholders are people who have an interest in or investment in the AOA and are impacted by and care about how the results of the AOA process.

Effect: Setting functional requirements to a standard other than the mission need allows bias to enter the study because the functional requirements might then reflect arbitrary measures, preventing the inclusion of viable alternatives. Additionally, functional requirements that are not tied to mission need make it difficult to quantify the benefits of each alternative relative to what is required and make it challenging for decision-makers to assess which capability gaps will be met for each alternative. If functional requirements are established after the AOA has begun, bias may influence the study's results.

3. Develop AOA time frame

Definition: The customer provides the team conducting the analysis enough time to conduct a robust and complete analysis. Since the AOA process requires a large team with diverse resources and expertise, the process needs sufficient time to be accomplished thoroughly. A detailed schedule to conduct the AOA is developed prior to starting the process. The duration of the AOA process depends on the number of viable alternatives and availability of the team members. The timeframe is tailored for the type of system to be analyzed and ensures that there is adequate time to properly accomplish all of the AOA process steps.

Effect: Recommending an alternative without adequate time to perform the analysis is a contributing factor to high dollar acquisitions that have overrun both cost and schedule while falling short of expected performance.

4. Establish AOA team

Definition: After the customer establishes the need for the AOA in steps 1 through 3, a diverse AOA team is established to develop the AOA. This team consists of members with a variety of necessary skill sets, specific knowledge, and abilities to successfully execute the study. For example, the AOA team includes individuals with skills and experience in the following areas: program management, federal contracting, cost estimating, risk management, sustainability, scheduling, operations, technology, earned value management, budget analysis, and any other relevant area of expertise. The AOA team can consist of both government and contractor support personnel, and the AOA team lead should be qualified and experienced to lead the AOA.

Effect: Without the appropriate expertise on the team, errors in the results and gaps in the analysis may occur, causing the AOA's completion to be delayed until more SMEs are identified and tasked to work as part of the AOA process.

5. Define selection criteria

Definition: The customer, with input as needed from the decision-maker and the AOA team, and prior to the analysis, defines selection criteria based on the mission need. The selection criteria are independent of a particular solution. For example, the selection criteria could consider trade-offs between costs and capabilities, schedule flexibility of the alternatives, analysis of risks for each alternative, and other factors identified by the customer or the AOA team.

Effect: If selection criteria are not established prior to the analysis in the AOA process based on documented based on the mission need, bias can enter the AOA process and prevent the decision-maker from forming an impartial and credible decision.

6. Weight selection criteria

Definition: The customer, with input as needed from the decision-maker and the AOA team, decides on the weighting of the selection criteria to reflect the relative importance of each criterion prior to the beginning of the AOA. The rationale for the weighting of the selection criteria should be documented and explained in the AOA report. The AOA team applies the selection criteria during the analysis phase to inform the decision-maker.

Effect: An unjustified weighting method can oversimplify the results and lead to an uninformed and biased decision.

7. Develop AOA process plan

Definition: The AOA team creates a process plan, including proposed methodologies for identifying, analyzing, and selecting alternatives prior to beginning the AOA process. This plan establishes the critical questions to be explored, the selection criteria, the basis of estimates, and measures that are used to rate, rank, and decide among the alternatives. Additionally, the plan includes the criteria used to determine each alternative’s viability. A road map and standard work breakdown structure are used to compare the alternatives with the baseline and with each other. The AOA process plan is captured in a document that will ultimately be included in the final AOA document described in best practice 18.

Effect: If methodologies for the remaining phases of the AOA study are not established and documented up front, the risk of applying poor methodologies as part of the AOA analysis increases, which could result in bias when selecting a preferred alternative.

Phase: Identify alternatives

8. Develop list of alternatives

Definition: The AOA team identifies and considers a diverse range of alternatives to meet the mission need. To fully address the capability gaps between the current environment and the stated objectives for the future environment, market surveillance and market research are performed to develop as many alternative solutions as possible for examination. Alternatives are mutually exclusive, that is, the success of one alternative does not rely upon the success of another.

Effect: If the AOA team does not perform thorough research to capture many diverse alternatives, the optimal alternative could be overlooked and invalidate the AOA's results and bias the process.

9. Describe alternatives

Definition: The AOA team describes alternatives in sufficient detail to allow for robust analysis. All scopes of identified alternatives are described in terms of functional requirements. This description is documented in enough detail to support the viability, cost, and benefit/effectiveness analyses.

Effect: Unless the AOA team adequately describes and documents the alternatives, the analysis will not provide sufficient detail to allow for valid cost-benefit estimates.

10. Include baseline alternative

Definition: The AOA team includes one alternative to represent the status quo to provide a basis of comparison among alternatives. It is critical for the AOA team to first understand the status quo, which represents the existing capability's baseline where no action is taken, before comparing alternatives. The baseline is well documented as an alternative in the study and is used to represent the current capabilities and also for explicit comparison later in the study.

Effect: If the status quo is not examined, then there is no benchmark for comparison, allowing arbitrary comparisons between alternatives and hindering the credibility of the study.

11. Assess alternatives' viability

Definition: The AOA team screens the list of alternatives to eliminate those alternatives that are not viable, and it documents the reasons for eliminating any alternatives. All alternatives are examined using predetermined qualitative technical and operational factors to determine their viability. Only those alternatives found viable are examined fully during the analysis phase. However, all assumptions regarding the alternatives' viable and nonviable status are fully documented, including reasons why an alternative is not viable, in order to justify the recommendation. Additionally, if program budgets are known, viable alternatives that are not affordable within the projections are dropped from final consideration.

Effect: Not eliminating alternatives based on viability could needlessly extend the study's duration and burden the AOA team or lead to the selection of a technically nonviable alternative. Furthermore, unless the AOA team considers affordability as part of the final recommendation, an alternative that is not feasible based on the current fiscal environment could be selected. Documenting the alternatives that are not deemed viable is important so that decision-makers can clearly see that the AOA team examined those alternatives and why those alternatives are not considered for further analysis, confirming that the AOA process is comprehensive.

Phase: Analyze alternatives

12. Identify significant risks and mitigation strategies

Definition: The AOA team identifies and documents the significant risks and mitigation strategies for each analyzed alternative. Risks are ranked in terms of significance to the mission need and functional requirements. All risks are documented for each alternative along with any overarching or alternative specific mitigation strategies. Schedule risk, cost risk, technical feasibility, risk of technical obsolescence, dependencies between a new program and other projects or systems, procurement and contract risk, resource risks, and other risks are examined.

Effect: Not documenting the risks and related mitigation strategies for each alternative prevents decision-makers from performing a meaningful trade-off analysis necessary to select a preferred alternative.

13. Determine and quantify benefits/effectiveness

Definition: The AOA team uses a standard process to identify and document the benefits and effectiveness of each analyzed alternative. The AOA team drafts a metric framework that details the methods used to evaluate and quantify the measures of effectiveness and measures of performance for the whole mission need. The AOA team quantifies the benefits and effectiveness of each alternative over the alternative's full life cycle, if possible. Just as costs cover the entire life cycle for each alternative, the benefits and effectiveness measures cover each alternative's life cycle, if possible, in order to determine each alternative's net present value (NPV), defined as the discounted value of expected benefits minus the discounted value of expected costs. In cases where the means to monetize a benefit are too vague (for example, intangibles like scientific knowledge), the AOA team treats those benefits as strategic technical benefits and uses scalability assessments to quantify those benefits so that they are compared across all viable alternatives. In situations where benefits cannot be quantified, the AOA team explains why this is the case as part of their analysis and documentation.

Effect: If the AOA team does not determine a standard process to quantify benefits and clearly establish criteria against which to measure all alternatives, bias is introduced to the study. Additionally, if the AOA team does not examine effectiveness over the entire life cycle, decision-makers cannot see the complete picture and are prevented from making an informed decision.

14. Tie benefits/effectiveness to mission need and functional requirements

Definition: The AOA team explains and documents how each measure of effectiveness supports the mission need and functional requirements. The AOA team explains how the measures of effectiveness describe the way the current environment is expected to evolve to meet the desired environment; the team also explains how the measures are tied to the specific mission need and functional requirements. This is the hierarchy that connects the overarching requirements to the data that are needed.

Effect: Unless the AOA team thoroughly explains and documents how the measures of effectiveness relate to the specific mission need and functional requirements, decision-makers will not have proper insight into the impact of each alternative.

15. Develop life cycle cost estimates (LCCEs)

Definition: The AOA team develops a LCCE for each analyzed alternative, including all costs from inception of the program through design, development, deployment, operation, maintenance, and disposal. The AOA team includes a cost expert who is responsible for development of a comprehensive, well-documented, accurate, and credible cost estimate for each viable alternative in the study. The LCCE for each alternative follows the cost estimating process described in the GAO Cost Estimating and Assessment Guide, as appropriate for an early acquisition cost estimate, and uses a common cost element structure for all alternatives and includes all costs for each alternative. Costs that are the same across the alternatives (for example, training costs) are included so that decision-makers can compare the total cost rather than just the portion of costs that varies across all viable alternatives. The level of detail included in the LCCE should be consistent with the maturity of the alternatives. The AOA team expresses the LCCE in present value terms and explains why it chose the specific discount rate used. The AOA team ensures that economic changes, such as inflation and the discount rate, are properly applied, realistically reflected, and documented in the LCCE for all alternatives[3].

Effect: An LCCE that is incomplete (e.g. does not include cost estimates for all phases of an alternative's life cycle) does not provide an accurate and complete view of the alternatives' costs. Without a full accounting of life cycle costs, decision-makers will not have a comprehensive picture of the costs for each alternative and will have difficulty comparing the alternatives because comparisons may not be based on accurate information. Additionally, applying a discount rate is an important step in cost estimating because all cost data for each analyzed alternative must be expressed in like terms for comparison. Unless the AOA team properly normalizes costs to a common standard, any comparison would not be accurate, and any recommendations resulting from the flawed analysis would be negated. Properly normalizing costs is particularly important if various alternatives have different life cycle durations.

16. Include a confidence level or range for LCCEs

Definition: The AOA team presents the LCCE for each alternative with a confidence level or range, and not solely as a point estimate. Having a range of costs around a point estimate is useful because it conveys a level of confidence for each alternative to achieve a most likely cost. To document the level of risk associated with the point estimate for each analyzed alternative, the confidence level is included as part of the LCCE as part of the cost estimating Step 9, risk and uncertainty analysis. Decision-makers must have access to the confidence level associated with the point estimates for all viable alternatives in order to make informed decisions. Additionally, the AOA team uses a consistent method of comparing alternatives in order to present a comparable view of the risk associated with each alternative. For example, the comparison can be based on an established dollar value across alternatives (in order to observe the confidence level for each alternative at that dollar value). Alternatively, the comparison can be based on a predetermined confidence level across alternatives (in order to observe the dollar value associated with that confidence level for each alternative).

Effect: For decision-makers to make informed decisions, the alternatives' LCCEs must reflect the degree of uncertainty. Without cost risk and

[3]The present value of the estimate reflects the time value of money— the concept that a dollar today can be invested and earn interest.

uncertainty analysis the LCCEs for the viable alternatives are not credible.

17. Perform sensitivity analysis

Definition: The AOA team tests and documents the sensitivity of the cost and benefit and effectiveness estimates for each analyzed alternative to risks and changes in key assumptions. Major outcomes and assumptions are varied in order to determine each alternative's sensitivity to changes in key assumptions. This analysis is performed in order to rank the key drivers that could influence the cost and benefit estimates based on how they affect the final results for each alternative. Each alternative includes both a sensitivity analysis and a risk and uncertainty analysis that identifies a range of possible costs based on varying key assumptions, parameters, and data inputs. As explained in best practice 16 (include a confidence level or range for LCCEs), life cycle cost estimates are adjusted to account for risk and sensitivity analyses.

Effect: Failing to conduct a sensitivity analysis to identify the uncertainties associated with different assumptions negatively impacts the credibility of the AOA process by increasing the chance the AOA team will recommend an alternative without an understanding of the full impacts on life cycle costs, which could lead to cost and schedule overruns.

Phase: Document and review the AOA process

18. Document AOA process in a single document

Definition: The AOA team documents in a single document all steps taken to initialize, identify, analyze, and select alternatives. This document, which usually is a final report, describes all actions taken for all best practices of the AOA process. For example, the document clearly describes the preferred alternative and provides the detailed rationale for the recommendation based on analytic results. This document also includes, among all other things, the overall selection criteria and rational for their weighting; the rationale for nonviable or viable ratings for alternatives; a through description of alternatives; the ground rules, assumptions, and constraints for each alternative; the risk drivers and mitigation techniques; an analysis of the costs and benefits associated with each alternative; the trade-offs between costs, benefits, and risks; a description of the sensitivity analysis conducted and its results; the final rationale supporting the alternative selected by the AOA team or decision-makers, and the results and recommendations of the final independent review and any other reviews that took place throughout the AOA process.

Effect: Without a clear document that compiles all information, including standards used to rate and perform the analysis, it will not be apparent that the study is comprehensive, unbiased, and credible because the documentation does not explain the rationale for methodology or the calculations underlying the analysis. Having all the information related to all best practices of the AOA process in a single document also makes it easier for an independent reviewer to assess the AOA process.

19. Document ground rules, assumptions and constraints

Definition: The AOA team documents and justifies all ground rules, assumptions, and constraints used in the AOA process. Assumptions and constraints help to scope the AOA. Ground rules represent a common set of agreed upon standards that provide guidance and minimize conflicts in definitions. Assumptions are explicit statements used to specify precisely the environment to which the analysis applies, while constraints are requirements or other factors that cannot be changed to achieve a more beneficial approach. Ground rules, assumptions and constraints are detailed and justified for each alternative in the AOA plan.

Effect: Without documented and justified ground rules, assumptions and constraints it will be difficult for decision-makers to evaluate the alternatives.

20. Ensure AOA process is impartial

Definition: The AOA team conducts the analysis without having a predetermined solution in mind. The AOA process is an unbiased inquiry into the costs, benefits, and capabilities of all alternatives which informs the decision-making process rather than reflecting the validation of a predetermined solution.

Effect: An AOA process is not considered valid if it is biased. Performing a study with a predetermined solution distorts the results. The validity of the analysis is affected if bias is introduced to the inputs.

21. Perform independent review

Definition: An entity independent of the AOA process reviews the extent to which all best practices are followed. An independent review is one of the most reliable means to validate an AOA process. The AOA process is completed and documented with enough thoroughness to ensure that an independent organization outside of the program’s chain of command can review the AOA documentation and clearly understand the process and rationale that led to the selection of the preferred alternative. Part of the documentation includes approval and review from an office outside of the one that asked for or performed the AOA process. Recommendations provided by the review(s) throughout the AOA process should be followed by the AOA team. In the exceptional case that the AOA team does not follow a recommendation, the AOA team documents the reasons why those recommendations were not adopted. For certain projects, in addition to an independent review at the end of the AOA process, additional reviews are necessary at earlier stages of the process. Such reviews may be conducted after key steps are performed in the AOA process, for example the selection of the AOA team (Step 4), the development of the AOA process plan (Step 7), or the identification of viable alternatives (Step 11). While early reviews are not a substitute for the independent review conducted at the end of the AOA process, they help ensure that bias is not added throughout the course of the AOA process. Reviews throughout the AOA process can also keep the customer and the decision-maker informed of the process. Any issues with the AOA work conducted prior to the review can be corrected immediately, if necessary, rather than wait until the independent review at the end and redoing the work then.

Effect: Without independent reviews, the results are more likely to include organizational bias or lack the thoroughness needed to ensure that a preferred solution is chosen and not a favored solution, calling into question the credibility of the AOA process.

Phase: Select a preferred alternative

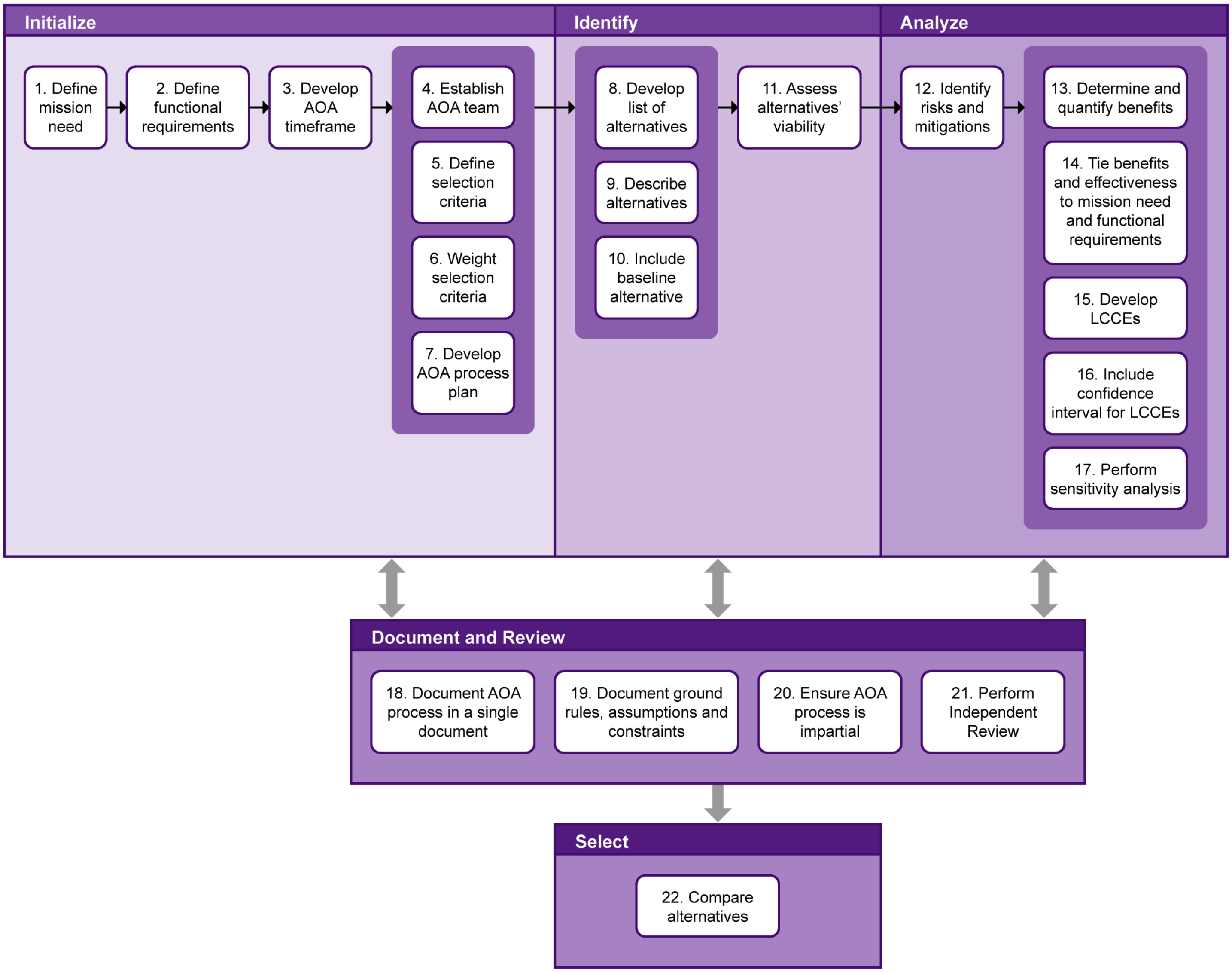
22. Compare Alternatives

Definition: The AOA team or the decision-maker compares the alternatives in order to select a preferred alternative that best meets the mission need. This should be done using NPV, if possible. NPV can be negative if discounted costs are greater than discounted benefits. NPV is the standard criteria used when deciding whether an alternative can be justified based on economic principles. In some cases, NPV cannot be used, such as when quantifying benefits is not possible. In these cases, the AOA team documents why NPV cannot be used. Furthermore, if NPV is not used to differentiate among alternatives, the AOA team should explain why another method has been applied, describe the other method that is used to differentiate, and ensure that the rationale used to select a preferred alternative is clearly documented so that a reviewer outside of the AOA process will be able to follow the logical reasoning.

Effect: Comparing items that have not been discounted (or normalized) does not allow for time series comparisons since alternatives may have different life cycle durations. Additionally, not clearly documenting the rationale used to select a preferred alternative will lower the confidence in the results of the AOA process and present the appearance of bias surrounding the selected alternative.

The phases should occur in sequence to prevent bias from entering the analysis and adding risk that the AOA team will analyze alternatives that have not been defined. The exception is the Document and Review phase that can be conducted throughout the AOA process. Some best practices can take place concurrently and do not have to follow the order presented above. For example, best practice 5 (define selection criteria) can be done at the same time as best practice 6 (weight selection criteria), and best practice 18 (document AOA process in a single document) can be done at the end of every step or every phase to ensure the AOA process is accurately and completely documented. The best practices represent an overall process that results in a reliable AOA that can be easily and clearly traced, replicated, and updated. Figure 40 shows the AOA process and how the steps in each phase are interrelated.

Figure 40: Analysis of Alternatives Process Chart



Source: GAO. | GAO-20-195G

Note: The figure displays the AOA process by each phase and step. The Initialize, Identify, Analyze, and Select phases should be conducted in order (as indicated by the arrows between those phases), but the Document and Review phase can be conducted throughout the AOA process. The small arrows in the middle of the figure indicate that the “Document and Review” phase is related to the other four phases. Within each phase, there are steps that can be done concurrently rather than in sequence. The concurrent steps are grouped together in dark boxes. The smaller arrows within each phase indicate the order that the steps in that phase should be performed. LCCEs = life cycle cost estimates.

AOA Process Reliability Assessment

An important best practice is conducting an independent review of the AOA process. It is important that the AOA process and its results be validated by an organization independent of the customer and decision-maker to ensure that a high-quality AOA is developed, presented, and defended to management. As shown in the figure, this review can occur throughout the AOA process life-cycle and helps verify that the AOA adequately reflects the program's mission need and provides a reasonable assessment of the cost and benefits associated with the alternatives.

Independent reviewers typically rely less on assumptions alone and, therefore, tend to provide more realistic analyses. Moreover, independent reviewers are less likely to automatically accept unproven assumptions associated with anticipated savings. That is, they bring more objectivity to their analyses, resulting in a reality check of the AOA process that reduces the odds that management will invest in an unreasonable alternative. After the AOA is complete, an AOA reliability assessment can be performed.to help improve an organization's AOA development process.

To that end, we established four characteristics that identify a high-quality, reliable AOA process. These characteristics are useful in evaluating if the AOA process is well documented, comprehensive, unbiased, and credible.

1. "Well-documented" - the AOA process is thoroughly described in a single document, including all source data, clearly detailed methodologies, calculations and results, and that selection criterion are explained. A well-documented AOA process is considered a key characteristic for a high-quality AOA. Without good documentation, the customer, the decision-maker, or independent reviewers will not be convinced that the AOA results are comprehensive, unbiased, and credible; questions about the approach or data used to create the AOA cannot be answered; and the scope of the analysis cannot be thoroughly defined. Furthermore, without adequate documentation, an entity unfamiliar with the program will not be able to understand the rationale surrounding the selection of the preferred alternative.
2. "Comprehensive" - the AOA process ensures that the mission need is defined in a way to allow for a robust set of alternatives, that all analyzed alternatives have been considered, and that each alternative is analyzed thoroughly over the program's entire life cycle. Without a clearly defined mission need and comprehensive list of alternatives, the AOA process could overlook the alternative that best meets the

mission need. Furthermore, without considering the complete life cycle of each alternative, decision-makers will not have a complete picture of the alternatives analyzed.

3. “Unbiased” - the AOA process does not have a predisposition toward one alternative over another; it is based on traceable and verifiable information. If an AOA process is biased, the validity of the analysis is called into question. Furthermore, if the AOA process has the appearance of being biased, the customer, decision-maker, or independent reviewers may not act on the results of the AOA report and may request additional information, extending the time before the preferred alternative is selected or enacted.
4. “Credible” - the AOA process thoroughly discusses the limitations of the analyses resulting from the uncertainty that surrounds both the data and the assumptions for each alternative. If the AOA process is not credible, there is an increased chance that the AOA team will recommend an alternative without understanding the full impact of the life cycle costs, potential benefits, or how the alternatives relate to the status quo, which could result in the selection of a less than optimal alternative.

Table 49 shows the four characteristics and their associated AOA best practices.

Table 49: The Four Characteristics of the AOA Process and Their Corresponding Best Practices

Characteristics	AOA process best practice
Well-documented: The Analysis of Alternatives (AOA) process is thoroughly described, including all source data, methodologies, calculations and results, and selection criteria are explained. • Describes alternatives in sufficient detail to allow for robust analysis. • Records the risks and mitigation strategies for each alternative in order to allow decision-makers to perform a meaningful trade-off analysis. • Explains how each alternative’s identified measures of benefits/effectiveness support the mission need. • Details in a single document all processes, criteria, and data used to support the AOA process’s final decision • Includes a detailed list of ground rules, assumptions, risks, and mitigation strategies needed to provide a robust analysis for all alternatives.	9. Describe alternatives 12. Identify significant risks and mitigation strategies 14. Tie benefits/effectiveness to mission need and functional requirements 18. Document AOA process in a single document 19. Document ground rules, assumptions, and constraints
Comprehensive: The level of detail for the AOA process ensures no alternatives are omitted and that each alternative is examined thoroughly for the program’s entire life cycle.	1. Define mission need 2. Define functional requirements 3. Develop AOA time frame

Characteristics	AOA process best practice
• Defines the mission need and functional requirements independently of a particular solution. • Ensures that there is adequate time to thoroughly analyze a comprehensive range of alternatives • Screens a diverse range of alternatives. • Assesses the identified alternatives for viability and explains why certain alternatives were not considered for further analysis. • Compares alternatives across their entire life cycle rather than focusing on one phase of the acquisition process	8. Develop list of alternatives 11. Assess alternatives' viability 15. Develop Life cycle cost estimates (LCCE)
Unbiased: The AOA process does not have a predisposition towards one alternative over another but is based on traceable and verified information • Ensures that the appropriate personnel are assigned to the task and there is enough time to complete a thorough study. • Documents a standard process that weights the selection criteria based on mission need and quantifies the benefit/effectiveness measures to ensure the AOA process is conducted without a pre-determined solution in mind. • Compares solutions to select a preferred alternative based on pre-established weighted selection criteria and Net Present Value techniques.	4. Establish AOA team 6. Weight selection criteria 7. Develop AOA process plan 13. Determine and quantify benefits and effectiveness 20. Ensure AOA process is impartial 22. Compare alternatives
Credible: The AOA process discusses from any limitations of the analysis resulting from the uncertainty surrounding the data to assumptions made for each alternative • Defines selection criteria that is based on the mission need prior to the beginning of the AOA to help lead to an impartial decision • Includes a baseline scenario as the benchmark to enable comparison between alternatives. • Life cycle cost estimates developed for each alternative include a confidence level or range developed based on risk/uncertainty analysis. • Details the sensitivity of both costs and benefits to changes in key assumptions for all alternatives. • Independent review of the AOA process is performed to ensure that the study's results are logical and based on the documented data, assumptions, and analyses.	5. Define selection criteria 10. Include baseline alternative 16. Include a confidence level or range for LCCEs 17. Perform sensitivity analysis 21. Perform independent review

Source: GAO. | GAO-20-195G

As stated above, the AOA is intended to compare the operational effectiveness, cost, and risks of a number of potential alternatives to address valid needs and shortfalls in operational capability. The best practices that GAO identified in the AOA process ensure that the best alternative that satisfies the mission need is chosen on the basis of the selection criteria. Case study 28 discusses why the AOA process was important for a Marine Corps program.

Case Study 28: Assumptions in the AOA Process, from *Amphibious Combat Vehicle*, GAO-16-22

Since 1972, the primary platform for transporting Marines from ship to shore under hostile and hazardous conditions has been the Assault Amphibious Vehicle (AAV). According to DOD, the need to modernize the United States Marine Corps' (USMC) ability to move personnel and equipment from ship to shore is essential. Since 1995, USMC has undertaken a number of efforts to do this. In 2011, USMC subsequently began the acquisition process for the Amphibious Combat Vehicle (ACV), a potential replacement vehicle for all or a portion of the AAV fleet. The ACV is intended to transport Marines from ship to shore and provide armored protection once on land.

In late 2014, the USMC completed an AOA update to support the release of the request for proposal for ACV Increment 1. Over the years, other AOAs have been completed for related acquisitions, including the Expeditionary Fighting Vehicle, the Marine Personnel Carrier and a previous version of the ACV considered in 2012. These previous AOAs and other supporting studies comprise a body of work that informed the ACV AOA update as well as the ACV acquisition as a whole.

GAO's assessment of the 2014 AOA found that overall it met best practices for AOAs and was, therefore, considered reliable. Considered in the context of the related body of work, the Amphibious Combat Vehicle (ACV) met 15 of the 22 AOA best practices, including ensuring that the AOA process was impartial and developing an AOA process plan, among others. Further, four of the remaining best practices were substantially met, two were partially met, and one was minimally met. For example, best practices call for the documentation of all assumptions and constraints used in the analysis. GAO found that the 2014 AOA did not include a full list of assumptions and constraints and any assumptions or constraints from previous analysis, if relevant, were not updated or referenced in the new analysis. As a result, it could have been difficult for decision-makers to make comparisons and trade-offs between alternatives. DOD's Cost Assessment and Program Evaluation staff also reviewed the 2014 AOA and found that it was sufficient. However, they identified a few areas of caution, including recommending additional testing of land mobility to further verify USMC assertions that the wheeled ACV 1.1 would have the same mobility in soft soil as tracked vehicles.

GAO, Amphibious Combat Vehicle: Some Acquisition Activities Demonstrate Best Practices; Attainment of Amphibious Capability to be Determined, GAO-16-22 (Washington, D.C.: October 28, 2015).

GAO, *Amphibious Combat Vehicle: Some Acquisition Activities Demonstrate Best Practices; Attainment of Amphibious Capability to be Determined*, GAO-16-22 (Washington, D.C.: October 28, 2015).

Appendix XII: The Cost Estimating Process and Internal Control

Internal Control Systems

An internal control system is a continuous built-in component of operations, effected by people, that provides reasonable assurance, not absolute assurance, that an entity's objectives will be achieved. An effective internal control system helps an entity adapt to shifting environments, evolving demands, changing risks, and new priorities. As programs change and entities strive to improve operational processes and implement new technology, management continually evaluates its internal control system so that it is effective and updated when necessary.

A key factor in improving accountability in achieving an entity's mission is to implement an effective internal control system. As defined in *Government Auditing Standards*, internal control includes the plans, methods, policies, and procedures used to fulfill the mission, strategic plan, goals, and objectives of the entity.[1]

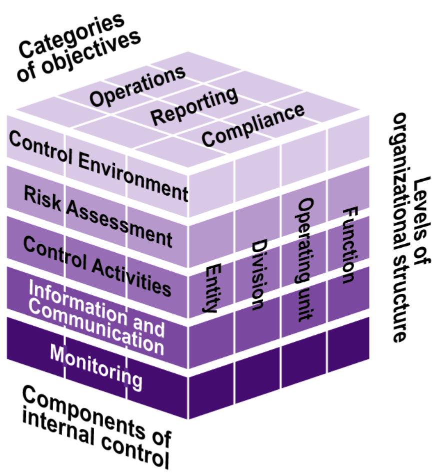
GAO's *Standards for Internal Control in the Federal Government* (known as the Green Book), provides the overall framework for establishing and maintaining an effective internal control system.[2] The Green Book provides managers criteria for designing, implementing, and operating an effective internal control system. It defines the standards through components and principles and explains why they are integral to an entity's internal control system. The Green Book also clarifies what processes management considers part of internal control. In a mature and highly effective internal control system, internal control may be indistinguishable from day-to-day activities personnel perform.

Standards in the Green Book are organized into five components of internal control. As shown in figure 41, the components apply to staff at all levels of the organization and to all categories of objectives.

[1]GAO, *Government Auditing Standards*, GAO-18-568G (Washington, D.C.: July 2018).

[2]GAO, *Standards for Internal Control in the Federal Government*, GAO-14-704G (Washington, D.C.: September 2014).

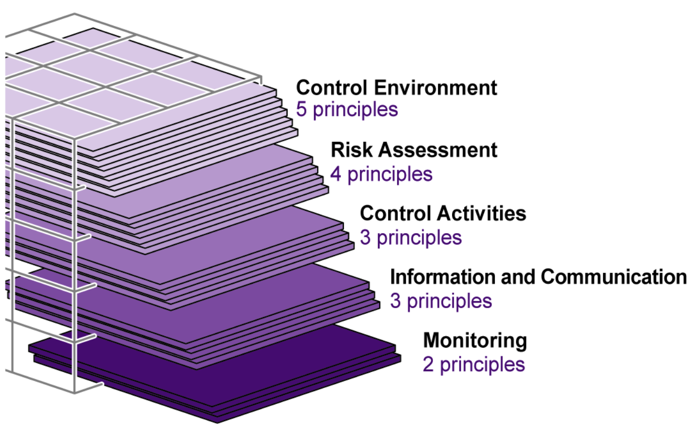
Figure 41: Internal Control Cube



Source: GAO. | GAO-20-195G

Each of the five components of internal control contains several principles. Principles are the requirements of each component (figure 42).

Figure 42: Principles of Internal Control



Source: GAO. | GAO-20-195G

The five components of internal control and their associated principles are as follows:

- **Control environment** - The foundation for an internal control system. It provides the discipline and structure to help an entity achieve its objectives.
    - Principle 1: The oversight body and management should demonstrate a commitment to integrity and ethical values.
    - Principle 2: The oversight body should oversee the entity's internal control system.
    - Principle 3: Management should establish an organizational structure, assign responsibility, and delegate authority to achieve the entity's objectives.
    - Principle 4: Management should demonstrate a commitment to recruit, develop, and retain competent individuals.
    - Principle 5: Management should evaluate performance and hold individuals accountable for their internal control responsibilities.
- **Risk assessment** - Assesses the risks facing the entity as it seeks to achieve its objectives. This assessment provides the basis for developing appropriate risk responses.
    - Principle 6: Management should define objectives clearly to enable the identification of risks and define risk tolerances.
    - Principle 7: Management should identify, analyze, and respond to risks related to achieving the defined objectives.
    - Principle 8: Management should consider the potential for fraud when identifying, analyzing, and responding to risks.
    - Principle 9: Management should identify, analyze, and respond to significant changes that could impact the internal control system.
- **Control activities** - The actions management establishes through policies and procedures to achieve objectives and respond to risks in the internal control system, which includes the entity's information system.
    - Principle 10: Management should design control activities to achieve objectives and respond to risks.
    - Principle 11: Management should design the entity's information system and related control activities to achieve objectives and respond to risks.
    - Principle 12: Management should implement control activities through policies.

- **Information and communication -** The quality information management and personnel communicate and use to support the internal control system.
  - Principle 13: Management should use quality information to achieve the entity's objectives.
  - Principle 14: Management should internally communicate the necessary quality information to achieve the entity's objectives.
  - Principle 15: Management should externally communicate the necessary quality information to achieve the entity's objectives.
  - Monitoring - Activities management establishes and operates to assess the quality of performance over time and promptly resolve the findings of audits and other reviews.
  - Principle 16: Management should establish and operate monitoring activities to monitor the internal control system and evaluate the results.
  - Principle 17: Management should remediate identified internal control deficiencies on a timely basis.

Each principle has important characteristics, called attributes, which explain principles in greater detail and contribute to their design, implementation, and operating effectiveness.

Cost Estimating Policy and Internal Control

Cost estimates are necessary 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. A realistic estimate of projected costs makes for effective resource allocation and increases the probability of a program's success. Thus, an entity's cost estimating process is an internal control because it helps the entity run its operations efficiently and effectively, report reliable information about its operations, and comply with applicable laws and regulations. Case Study 29 gives an example of how a lack of cost estimating policy is related to a deficiency in internal controls.

Case Study 29: Cost Estimating Policy and Internal Controls, from *2020 Census*, GAO-16-628

With a cost of about $13 billion, the 2010 Census was the most expensive population count in U.S. history, costing over 50 percent more than the $8.1 billion 2000 Census (in constant 2010 dollars). Some cost growth is to be expected because the population is growing and becoming more complex and difficult to count, which increases the workload of the Census Bureau (Bureau). However, the cost of counting each housing unit had escalated from $16 in 1970 to $94 in 2010 (in constant 2010 dollars).

For the 2020 Census, the Bureau intended to limit its per-household cost to not more than that of the 2010 Census, adjusted for inflation. To achieve this goal, the Bureau planned to significantly change how it conducts the census, in part by re-engineering key census-taking methods and infrastructure. In October 2015, the Bureau estimated that with its new approach it could conduct the 2020 Census for a life cycle cost of $12.5 billion in contrast to its estimate of $17.8 billion to repeat the design and methods of the 2010 Census (both in constant 2020 dollars).

GAO reviewed the extent to which the Bureau's life cycle cost estimate of October 2015 met best practices for cost estimation. Among other issues, GAO found the Bureau had little planning information among its documents supporting its cost estimate. Early fundamental planning and guidance documents, such as general policies and procedures for cost estimation, can contribute to consistent control over the process used to develop a cost estimate and help ensure that desired standards and practices are implemented. Internal controls for the federal government state that management should design control activities to achieve objectives, such as the development of a reliable cost estimate. These internal controls could take many forms, such as an operational plan, guidance on specific steps, and job aids for staff involved in the process. Internal controls would help the Bureau ensure continuity of operations across turnover in staff during the decennial life cycle, ensure that its cost estimation process follows best practices, and help it meet its objective of a reliable cost estimate.

GAO recommended the Bureau take these steps to put guidance, policies, and procedures in place in GAO's 2008 and 2012 reports on the Bureau's cost estimation process. In response to GAO's recommendation, in 2018 the Bureau established roles and responsibilities for oversight and approval of cost estimation processes, created a detailed description of the steps that should be taken to produce a high-quality cost estimate, and clarified the process for updating the cost estimate and associated documents over the life of a project. Such guidance should result in reliable cost estimates that management can use for making informed decisions.

GAO, *2020 Census: Census Bureau Needs to Improve Its Life cycle Cost Estimating Process,* GAO-16-628 (Washington, D.C.: June 30, 2016).

The 12 Steps of the Cost Estimating Process as Key Elements of Internal Control

As described in this Guide, certain steps should be followed if reliable cost estimates are to be developed. These steps result in an overall process of established, repeatable methods that create high-quality cost estimates that can be easily and clearly traced, replicated, and updated. As such, each step of the cost estimating process can be mapped to one or more principles of an internal control system. For example:

- Chapter 5 describes, as part of step 2, the importance of the cost estimating team's composition and organization. Ideally, cost estimates are prepared according to a schedule by a multidisciplinary team of people who have experience in estimating all cost elements of the program and who have access to subject matter experts who are familiar with the program or a program like it. Thus, an estimating plan relates to the control environment component of an internal control system internal control because it requires management to establish structure, responsibility, and authority (principle 3), demonstrate commitment to competence (principle 4), and enforce accountability (principle 5).
- As we describe in step 4 in chapter 7, 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. Furthermore, we state that a WBS is 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. Thus, a WBS relates to the information and communication component of an internal control system because it enables management to use quality information to achieve objectives (principle 13), internally communicates quality information (principle 14), and externally communicates quality information (principle 15).
- In step 9 (chapter 12), we describe the importance of a risk and uncertainty analysis. 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. 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. Thus, a risk and uncertainty analysis relates to the risk assessment component of internal control. A risk and uncertainty assessment helps management define objectives and risk tolerances (principle 6), and identify, analyze, and respond to risks (principle 7).

- Chapter 13 explains the importance of step 10, documenting the cost estimate. 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 produces written justification showing how the estimate was developed and aids in updating it as key assumptions change and more information becomes available. Thus, documentation is related to the information and communication component of an internal control system because it helps management use quality information (principle 13) and to communicate internally (principle 14). Case study 30 gives an example of the relationship between inadequate cost estimate documentation and internal control.

Case Study 30: Cost Estimating Documentation and Internal Controls, from *Service Contracts*, GAO-17-398

Independent government cost estimates (IGCE) are the government's best estimate of a contract's potential costs—an important tool for both program and contracting officials to provide information when planning for and awarding contracts. IGCEs are particularly critical for service contracts—accounting for more than $270 billion in government contract spending in fiscal year 2015—to ensure the costs associated with labor are fully understood. GAO was asked to review federal agencies' use of IGCEs. Officials at the departments in GAO's review—Defense, Homeland Security, Health and Human Services, Education, Labor, and Housing and Urban Development—developed independent government cost estimates (IGCE) for 62 of the contracts GAO reviewed.

To maximize the use of the IGCE as a high-quality tool, having information about how it was developed, including sources of data and methodology used, is important. In addition, GAO previously found that documenting an IGCE's methodology and data source in the contract file helped inform future contracting and program officials about the current contract when staff changed. Of the 62 IGCEs GAO reviewed, only 13 included such documentation. In one such case—for a $45 million Army engineering support contract—the IGCE included a statement that the estimate is based on costs from an existing contract and an analysis of labor hours for similar programs. In contrast, the IGCE for another engineering support contract, a $2.8 million award from DHS, lists the number of hours and rates for different labor categories but does not state the source of the information or how it was compiled. In other cases, the IGCEs that were not documented well included some details about their development and methodology in other contract file documents, such as the acquisition plan or price analysis, but this information was generally vague and did not include enough information to provide support for the estimates.

GAO cost estimating guidance and federal internal control standards emphasize the need for documentation, with GAO's cost estimating guidance stating that well-documented cost estimates describe the data sources used, underlying assumptions, and the estimating methodologies used to derive costs. Without supporting documentation, the effectiveness of the IGCE is weakened, as contracting officers either cannot use it or must spend time gathering information they can use.

GAO, *Service Contracts: Agencies Should Take Steps to More Effectively Use Independent Government Cost Estimates*, GAO-17-398 (Washington, D.C.: May 17, 2017).

Table 50 provides examples of how each of the 12 steps of the cost estimating process can be mapped to the five components of internal control. Table 50 is not intended to be definitive or exhaustive; rather, it provides potential relationships between deficiencies in project control and the entity's internal control system.

Table 50: Cost Estimating Steps Mapped to Selected Components and Principles of Internal Controls

		Cost estimating step											
Component	**Principle**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Control environment	(3) Establish structure, responsibility, and authority	X	X								X	X	
	(4) Demonstrate commitment to competence		X										
	(5) Enforce accountability		X										
Risk assessment	(6) Define objectives and risk tolerances	X	X		X			X	X	X			
	(7) Identify, analyze, and respond to risks					X			X	X			
	(9) Identify, analyze, and respond to change									X			X
Control activities	(10) Design control activities												X
Information and communication	(13) Use quality information	X	X	X	X	X	X	X	X	X	X	X	X
	(14) Communicate internally			X	X	X	X	X	X	X	X	X	
	(15) Communicate externally			X	X	X	X			X	X		X
Monitoring	(16) Perform monitoring activities							X					X
	(17) Evaluate issues and remediate deficiencies									X			

Source: GAO | GAO-20-195G

Deficiencies in Design, Implementation, or Operating Effectiveness

As described in *Government Auditing Standards*, auditors may consider different levels of internal control assessment depending on the objectives of the audit. These levels are (1) assessing the design, 2) assessing the design and implementation, or (3) assessing the design, implementation, and operating effectiveness of controls.[3]

- The design of internal control is assessed by determining whether controls individually and in combination are capable of achieving an objective and addressing the related risk. A deficiency in design exists

[3]GAO, *Government Auditing Standards*, GAO-18-568G (Washington, D.C.: July 2018).

when a necessary control is missing or is not properly designed so that even if the control operates as designed, the control objective would not be met. For example, if an agency does not have a documented cost estimating process, or has one that is missing a key best practice such as cost risk and uncertainty analysis, this condition is a deficiency in the design of the control.

- The implementation of internal control is assessed by determining if the control exists and has been placed into operation. A deficiency in implementation exists when a control is properly designed but not implemented correctly in the internal control system. For example, if an agency has a cost estimating policy in place but fails to communicate that policy to its organizations implementing the policy, this condition is a deficiency in the implementation of the control.
- The operating effectiveness of internal control is assessed by determining whether controls were applied at relevant times during the period under evaluation, the consistency with which they were applied, and by whom or by what means they were applied. A deficiency in operating effectiveness exists when a properly designed control does not operate as designed or the person performing the control does not have the necessary competence or authority to perform the control effectively. For example, if the agency has a cost estimating policy in place but cannot develop a robust cost risk and uncertainty analysis because of a lack of trained staff, this condition is a deficiency in the operating effectiveness of the control.

Finally, a control cannot be effectively implemented if it was not effectively designed, and a control cannot be operating effectively if it was not effectively designed and implemented. For example, a cost estimate created in accordance with agency cost estimating policy will not be reliable if that agency's cost estimating policy does not fully address each of the 12 steps of the cost estimating process.

Appendix XIII: GAO Contacts and Staff Acknowledgments

GAO Contact

Timothy M. Persons, Ph.D., Managing Director, Science, Technology Assessment and Analytics (STAA)/Chief Scientist, at (202) 512-6888 or personst@gao.gov

Other Leadership on This Project

Brian Bothwell, Assistant Director, STAA

Jason T. Lee, Assistant Director, STAA

Key Contribcutors

Ellen Arnold-Losey, Senior Visual Communications Analyst
Jehan Chase, Senior Attorney
Juaná Collymore, Senior Cost Analyst
Jennifer Echard, Senior Cost Analyst
Emile Ettedgui, Senior Cost Analyst
Dani Greene, Senior Communications Analyst
Yvette Gutierrez, Senior Analyst
Cristian Ion, Senior Analyst
Anna Irvine, Senior Cost Analyst
Jessica Karnis, Senior Analyst
Jennie Leotta, Assistant Director
Anika McMillon, Visual Communications Analyst
John Ortiz, Senior Analyst
Carol Petersen, Senior Economist
Mary Weiland, Senior Cost Analyst

Glossary

Actual cost of work performed (ACWP)	The costs actually incurred and recorded in the earned value management system for accomplishing the work performed within a given time period.[1] ACWP is also known as Actual Cost (AC).
Affordability analysis	A process that demonstrates whether a program's acquisition strategy has an adequate budget. It also shows if the agency's overall portfolio is affordable or if programs within the portfolio should be cancelled or restructured.
Analogy	A cost estimating method that bases the estimate for the new item on the actual cost of a similar item with adjustments to account for differences between the two items.
Analysis of alternatives (AOA)	A process that assesses potential solutions to mitigate documented capability gaps. Typically performed early in the acquisition cycle, the AOA process examines costs, benefits, schedules, risks, sensitivity, viability, and operational effectiveness for each alternative and the status quo in order to select a preferred alternative that satisfies mission need.
Assumptions	Often grouped together with ground rules, assumptions represent a set of judgments about past, present, or future conditions postulated as true in the absence of positive proof.
Base year dollars	Dollars which are expressed in the value of a specific year and do not include escalation or inflation.[2] Base year dollars are also known as constant dollars.
Benefit-cost analysis	A systematic quantitative method of assessing the desirability of government projects or policies when it is important to take a long view of future effects and a broad view of possible side effects.
Budget year dollars	Dollars that include the effects of inflation and time-phasing.

[1]OD, OUSD A&S (AE/AAP), *Earned Value Management Implementation Guide*, (Washington, D.C.: January 2019).

[2]International Cost Estimating and Analysis Association, Cost Estimating Body of Knowledge, *Module 4 Data Collection and Normalization* (Copyright 2002-2010).

Budgeted cost of work performed (BCWP)	The sum of the budgets for completed work and completed portions of ongoing work within a given time period. BCWP is also known as Earned Value (EV).[3]
Budgeted cost of work scheduled (BCWS)	The sum of the budgets for all work packages and planning packages scheduled to be accomplished within a given time period.[4] BCWS is also known as Planned Value (PV).
Common work breakdown structure elements	In addition to including product-oriented elements, every WBS includes program management as a level 2 element as well as other common elements like integration and assembly, government furnished equipment, and government testing.
Confidence level	In cost estimating, the confidence level represents the probability that the program cost will be equal to or less than the associated cost estimate. Also referred to as percentiles, they are determined from a cumulative probability distribution or S curve derived from a risk and uncertainty analysis.[5]
Contingency	In this *Cost Guide*, contingency 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.
Constant year dollars	See base year dollars.
Correlation	Positive correlation occurs when two WBS elements are both influenced by the same factor and can be expected to vary in the same direction within their own probability distributions in any consistent scenario.

[3]DOD, OUSD A&S (AE/AAP), *Earned Value Management Implementation Guide*, (Washington, D.C.: January 2019).

[4]Ibid.

[5]This definition of confidence level is specific to cost and risk uncertainty analysis. In statistics, confidence level is defined as the percentage of all possible samples that can be expected to include the true population parameter.

Cost accounting	The organized recording and assessment of material, labor, and overhead costs.[6]
Cost analysis	The effort to develop, analyze, and document cost estimates with analytical approaches and techniques; the process of analyzing 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 driver	A system, program characteristic, or cost model input which affects the system or program cost estimate.
Cost estimate	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. The management of a cost estimate involves updating the estimate with actual data as they become available, revising the estimate to reflect program changes, and analyzing differences between estimated and actual costs.
Cost estimating	Collecting and analyzing historical data and applying quantitative models, techniques, tools, and databases to predict a program's future cost. 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, and development teams.
Cost estimating relationship (CER)	A technique used to estimate a cost by using its relationship to an independent variable or combination of variables.
Cost performance index (CPI)	The CPI metric is a measure of cost expended for the work completed. A CPI value greater than 1.0 indicates the work accomplished cost less than planned, while a value less than 1.0 indicates the work accomplished cost more than planned.[7]
Cross-check	An alternate cost estimating methodology used to validate cost estimating results.
Data normalization	

[6]Merriam-Webster, accessed on February 6, 2019, https://www.merriam-webster.com/.

[7]DOD, OUSD A&S (AE/AAP), *Earned Value Management Implementation Guide*, (Washington, D.C.: January 2019).

	Make a given data set consistent with and comparable to other data used in the estimate. Data are normalized in several ways including for cost units, sizing units, key groupings, and technology maturity .
Earned value management (EVM)	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 actual cost of the work accomplished and the value of the work planned in that period. Differences in expectations are measured in both cost and schedule variances.
Engineering build-up	This cost estimating method develops the cost estimate at the lowest level of the WBS, one element at a time, and the sum of the elements comprises the estimate. An engineering build-up estimate consists of labor and materials that have overhead and fee applied to them. This method is normally used during the production phase.
Estimate-at-complete (EAC)	The latest revised estimate of cost at completion including estimated overruns and underruns for all authorized work. It is calculated by adding the forecasted cost of work remaining (budgeted cost for work remaining) to actual costs using an appropriate forecasting method. Contractors are typically required to provide three EACs – a best case, a worst case, and a most likely case.
Expert opinion	A cost estimating method that relies on subject matter experts to give their opinion on what products or efforts within a program should cost. Also known as engineering judgment, it is commonly applied to fill in gaps in a relatively detailed WBS when one or more experts are the only qualified source of information, particularly in matters of specific technology.
Extrapolation from actuals:	A cost estimating method which uses the actual past or current costs of an item to estimate its future costs.
Ground rules	Often grouped together with assumptions, ground rules represent a common set of agreed-to estimating standards that provide guidance and minimize conflicts in definitions.
Independent cost assessment	A non-advocate’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, outside

	source, or required by agency policy, it may be used to determine whether the cost estimate reflects the program of record.
Independent cost estimate	Conducted by an organization outside the acquisition chain, using the same detailed technical information as the program estimate, an ICE serves as a comparison with the program estimate to determine whether it is accurate and realistic.
Independent government cost estimate	Used to analyze contractors' prices or cost proposals for a specific contract, an IGCE only estimates the cost of activities outlined in the statement of work. It excludes all costs not associated with that contract and only reflects costs from a contractor's viewpoint.
Inflation	Growth in the general, economy-wide, average price level.[8]
Integrated baseline review (IBR)	A joint assessment conducted by the government program manager and the contractor, to facilitate and maintain mutual understanding of the scope of the performance measurement baseline; management control processes; program risks associated with technical performance, cost, schedule, and resources; and corrective actions.[9]
Integrated master schedule	A program schedule that includes the entire required scope of effort, including the effort necessary from all government, contractor, and other key parties for a program's successful execution from start to finish. The IMS should consist of logically related activities whose forecasted dates are automatically recalculated when activities change. The IMS includes summary, intermediate, and detail-level schedules.
Learning curve	A measure of the rate of change of hours or dollars as a function of the quantity of items produced. Learning curves assume that as a quantity doubles, the hours or dollars decreases by a constant percentage. Learning curves are a common form of extrapolating from actual costs.
Life cycle cost estimate (LCCE)	A structured accounting of all labor, material, and other efforts required to develop, produce, operate and maintain, and dispose of a program.

[8]Department of Defense, Office of the Secretary of Defense, Cost Assessment and Program Evaluation, *Inflation and Escalation Best Practices for Cost Analysis* (April 2016).

[9]Defense Acquisition University, accessed on February 11, 2019, https://www.dau.edu/acquipedia/Pages/acquipedia.aspx.

Management reserve (MR)	Management reserve funds are for “known unknowns” that are tied to a contract’s scope and managed at the contractor level. Unlike contingency, 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.
Net present value	The discounted value of expected benefits minus the discounted value of expected costs.
Nonrecurring cost	An element of the development and investment costs that generally occurs only once in a system’s life cycle. Includes all the effort required to develop and qualify an item, such as defining its requirements and its allocation, design, analysis, development, qualification, and verification.
Overtarget baseline (OTB)	An OTB may be implemented when it is determined 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 the OTB is to restore management’s control of the remaining effort by providing a more meaningful basis for performance management.
Parametric cost estimating	A cost estimating method that relates cost to one or more technical, performance, cost, or program parameters using a statistical relationship. This method often uses cost estimating relationships to develop estimates.
Performance measurement baseline (PMB)	The PMB represents the cumulative value of planned work over time, taking into account that program activities occur in a sequenced order, based on finite resources, with budgets representing those resources spread over time. It is a resource consumption plan for the program and forms the time-phased baseline against which performance is measured.
Point estimate	The sum of the WBS elements, a point estimate is a single value given as an estimate of program cost. High-quality cost estimates usually fall within a range of possible costs, the point estimate being between the best and worst case extremes.
Primary data	Data obtained from the original source.
Program office estimate (POE)	The responsibility of the program manager, an estimate that covers the entire life of a program and phased by fiscal year for all years from initiation of the program to the disposal phase. POEs are used to prepare

	the resource requirements for translation into programming and budgeting documentation and requests.
Recurring cost	Costs that occur periodically as items are produced or services are performed.
Risk	A potential event that could affect the program positively or negatively. A negative or unfavorable event is a threat or harm, and a positive or favorable event is an opportunity or improvement.
Risk and uncertainty analysis	Uses statistical techniques to predict the probability of successfully executing a program within its budget by capturing the cumulative effect of program risks and uncertainty.
Risk management	A structured and efficient process for identifying risks, assessing their effect, and developing ways to reduce or eliminate risk; a continuous process that constantly monitors a program’s health.
Schedule performance Index (SPI)	The SPI metric is a measure of the amount of work accomplished versus the amount of work planned. An SPI value greater than 1.0 indicates more work was accomplished than planned, while an SPI value less than 1.0 indicates less work was accomplished than planned.[10]
S curve	A cumulative probability distribution particularly useful in portraying the confidence level, or percentile, of a cost estimate.
Secondary data	Data that are derived rather than obtained directly from a primary source. Their quality is lower and less useful than that of primary data. In many cases, secondary data are actual data that have been “sanitized” to obscure their proprietary nature.
Sensitivity analysis	Examination of the effect on program cost of changing one assumption or cost driver at a time while holding all other variables constant.
Technical baseline description	A document or set of documents that describe the program or project’s purpose, system, performance characteristics, and system configuration.
Technology readiness level (TRL)	Describes the maturity of a given technology within its development life-cycle. In general, TRLs are measured along a 1-9 scale, starting with

[10]DOD, OUSD A&S (AE/AAP), *Earned Value Management Implementation Guide*, (Washington, D.C.: January 2019).

level 1 paper studies of the basic concept, moving to laboratory demonstrations around level 4, and ending at level 9, where the technology is tested and proven, integrated into a product, and successfully operated in its intended environment.

Time phase	Spreading a program's expected costs over the years in which they are anticipated to occur.
To complete performance index (TCPI)	Cost performance to be achieved, or TCPI, if the remaining work is to meet the contractor's estimate at completion (EAC). TCPI is an earned value management measure computed by dividing the value of the work remaining by the value of the target cost remaining. The target cost remaining value is tied to some financial goal that management sets. The measure represents cost efficiency from the present time until the end of the contract required to achieve management's target goal.[11]
Variance analysis	Assessment of the differences between ACWP (actual costs) and BCWP (earned value), differences between BCWP (earned value) and BCWS (planned value), and difference between BAC (budget at completion) and EAC (estimate at completion) for WBS elements and the program.
Work breakdown structure	A framework for planning and assigning responsibility for work necessary to accomplish a program's objectives. It deconstructs a program's end product into smaller specific elements that are suitable for management control.

[11]Defense Acquisition University, accessed on February 6, 2019, https://www.dau.edu/acquipedia/Pages/acquipedia.aspx

References

AACEi (Association for the Advancement of Cost Engineering International). *Schedule and Cost Reserves within the Framework of ANSI EIA-748*. Morgantown, WV.: October 24, 2014.

Abba, Wayne. *Contracting for Earned Value Management*. Falls Church, Va.: Abba Consulting, January 13, 2007.

——. "*Earned Value Management from Government Contracts to the Project Management Universe*." Presented at the 19th IPMA World Congress, New Delhi, India, November 13–16, 2005.

———. *Earned Value Management: The Good, the Bad, and the Really Ugly*. Falls Church, Va.: Abba Consulting, December 21, 2004.

———. *How Earned Value Got to Primetime: A Short Look Back and A Glance Ahead*. Reston, Va.: Dekker, 2000.

———. *Understanding Program Resource Management through Earned Value Analysis*. Falls Church, Va.: Abba Consulting, June 2006.

Agrawal, Raj. *Overcoming Software Estimation Challenges*. McLean, Va.: MITRE, May 22, 2007.

Albert, Neil F. *Cost Estimating: The Starting Point of Earned Value Management*. McLean, Va.: MCR, June 2005.

———. *Developing a Work Breakdown Structure*. McLean, Va.: MCR, June 16, 2005.

Anderlohr, George, "*What Production Breaks Cost*," Industrial Engineering. September 1969. 34-36.

Anderson, Mark, and David Nelson. "Developing an Averaged Estimate at Completion (EAC) *Utilizing Program Performance Factors and Maturity*." Arlington, Va.: Tecolote Research, June 14–17, 2005.

Anderson, Timothy P. *"The Trouble with Budgeting to the 80th Percentile."* Washington, DC.: The Aerospace Corporation, November 15, 2006.

Barrett, Bruce E., Jack E. Matson, and Joseph M. Mellichamp. *Software Development Cost Estimation Using Function Points*. Tuscaloosa: University of Alabama, April 1994.

Black, Hollis M. *“Impact of Cost Risk Analysis on Business Decisions.”* Huntsville, Ala.: Boeing, June 14–17, 2005.

Boatwright, Tim. *Earned Value Management System Acceptance and Surveillance*. Booz Allen Hamilton: March 30, 2006.

Boden, Dave, and others. *Interfacing Risk and Earned Value Management.* Buckinghamshire, Eng.: Association for Project Management, 2008.

Bolinger, Paul. “*Schedule Analysis of the Integrated Master Schedule.”* Orange, Cal: Humphreys & Associates, May 2008.

Bone, Lauren, and Val Jonas. *“Interfacing Earned Value and Risk Management.*” PMI-CPM 24th Annual International Conference Proceedings, Clearwater Beach, Fla, May 14–16, 2008.

Book, Stephen A. *Do Not Sum Most Likely Costs*. McLean, Va.: MCR, Apr. 30, 2002.

———. *Issues Associated with Basing Decisions on Schedule Variance in an Earned Value Management System*. McLean, Va.: MCR, 2003.

———. *The Program Schedule Network and Its Critical Path*. McLean, Va.: MCR, August. 26, 2005.

———. *Risks in Costing Software*. McLean, Va.: MCR, August. 26, 2005.

———. “*Schedule Risk Analysis: Why It Is Important and How to Do It*”. McLean, Va.: MCR, June 14–17, 2005.

———. *The Schedule Risk Imperative and How to Deal with It*. McLean, Va.: MCR, August. 26, 2005.

———. *What Is Cost Risk Analysis*. McLean, Va.: MCR, August. 26, 2005.

———. *What Earned Value Data Tells Us about Schedule Progress*. McLean, Va.: MCR, August. 26, 2005.

Brophy, Brian A., and Greg Hogan. *How to Get the Data and Ready It for Analysis*. Chantilly, Va.: Northrop Grumman, The Analytical Sciences Corporation, 2005.

Buchholz, Mark, Shaw Cohe, and Robert Tomasetti. *Earned Value Management: Moving Toward Governmentwide Implementation*. Arlington, Va.: Acquisition Directions Advisory, August 2005.

Cargill, John. *Decision Support for the Program Manager*. Eglin Air Force Base, Fla.: Air Force Cost Analysis Agency, n.d.———. *Forecasting the Future with EVMS*. Eglin Air Force Base, Fla.: Air Force Cost Analysis Agency, n.d.

Carroll, Ed. *Software Estimating Based on Use Case Points*. Beaverton, Ore.: Agilis Solutions, June 2005.

CAIWG (Civilian Agencies and Industry Working Group). *Guide to Earned Value Management Scalability for Non-Major Acquisition Implementations*. Washington, D.C.: March 2015.

Christensen, David S. *The Costs and Benefits of the Earned Value Management Process*. Pensacola: University of West Florida, June 1998.

———. *Determining an Accurate Estimate at Completion*. Cedar City: Southern Utah University, 1993.

———. *Using the Earned Value Cost Management Report to Evaluate the Contractor's Estimate at Completion*. Cedar City: Southern Utah University, 1999.

———, and Carl Templin. *An Analysis of Management Reserve Budget on Defense Acquisition Contracts*. Cedar City: Southern Utah University, 2000.

———, and others. *A Review of the Estimate at Completion Research.* Cedar City: Southern Utah University, 1995.

Chvotkin, Alan, and Harris N. Miller. "Response to FAR Case 2004-019: Earned Value Management Systems, 70 Fed. Reg. 17945 (April 8, 2005)." Washington, D.C.: Information Technology Association of America and Professional Services Council, June 7, 2005.

Coleman, Richard L., and others. *Monte Carlo Techniques for Risk Management*. Chantilly, Va.: Northrop Grumman, The Analytical Sciences Corp., June 2008.

———, and Jessica R. Summerville. *Advanced Cost Risk. Chantilly, Va.: Northrop Grumman*, The Analytical Sciences Corp., June 16, 2005.

———. *Basic Cost Risk*. Chantilly, Va.: Northrop Grumman, The Analytical Sciences Corp., June 15, 2005.

———, and Shishu S. Gupta. *Two Timely Short Topics: Independence and Cost Realism*. Chantilly, Va.: Northrop Grumman, Analytical Sciences Corp., and Intelligence Community Cost Analysis Improvement Group, June 16, 2005.

Comptroller General of the United States. *Government Auditing Standards:* January 2007 Revision, GAO-07-162G. Washington, D.C.: U.S. Government Accountability Office, January 2007.

———. *Theory and Practice of Cost Estimating for Major Acquisitions*, B-163058. Washington, D.C.: U.S. Government Accountability Office, July 24, 1972.

Cooper, L. Sue. *"Basic Schedule Development and Analysis*." Seal Beach, Calif.: Boeing, June 14–17, 2005.

Corrigan, Patricia. *Capital Programming, Earned Value, and the Federal Acquisition Community*. Washington, D.C.: Office of Federal Procurement Policy, Office of Management and Budget, April 2007.

DAU (Defense Acquisition University). Business, *Cost Estimating, and Financial Management Training Requirements*. Fort Belvoir, Va.: n.d.

———. *Cost Estimating Methodologies*. Fort Belvoir, Va.: April 2004.

———. *Defense Acquisition Acronyms and Terms*. Fort Belvoir, Va.: July 2005.

———. *Defense Acquisition Guidebook*. Fort Belvoir, Va.: July 24, 2006.

———. *Introduction to Cost Analysis*. Fort Belvoir, Va.: April 2004.

———. *Unit and Cumulative Average Formulations*. Fort Belvoir, Va.: February. 20, 2004.

DCAA (Defense Contract Audit Agency). *DCAA Contract Audit Manual*. Fort Belvoir, Va.: January 2012.

DCARC (Defense Cost and Resource Center). *Automated Information System Enterprise Resource Planning Work Breakdown Structure.* Arlington, Va.: n.d.

———. *Automated Information System Enterprise Resource Planning Work Breakdown Structure Dictionary*. Arlington, Va.: n.d.

DCMA (Defense Contract Management Agency). *About the Defense Contract Management Agency*. Alexandria, Va.: n.d.

———.*Earned Value Management System Compliance Reviews*, DCMA-INST 208. Washington, D.C.: Change 1, March 7, 2017.

———.*Earned Value Management System Program Support Analysis and Reporting*, DCMA-M 3101-02. Washington, D.C.: November 2017.

———. *Earned Value Management System Standard Surveillance Instruction*. Washington, D.C.: November 2016.

———.*Earned Value Management System Standard Surveillance Operating Manual*. Washington, D.C.: January 2008.

———.*Earned Value Management System Standard Surveillance*, DCMA-INST 210. Washington, D.C.: November 8, 2016.

———. *Earned Value Management System Standard System Surveillance.* Washington, D.C.: May 14, 2008.

———. *Instruction 2303 Surveillance, Contractor Effectiveness Capability.* Washington, D.C.: November 5, 2018.

———. *Software Acquisition Management*. Washington, D.C.: June 2013.

Dean, Joe. *Practical Software and Systems Measurement: Objective Information for Decision Makers.* Boston, Mass.: Tecolote Research, June 2005.

Dechoretz, Jason. *Technical Baselines*. McLean, Va.: MCR, June 2005.

Defense Economic Analysis Council. *Economic Analysis Handbook*. Monterey, Calif.: September 1997.

Dello Russo, Francis M., Paul R. Garvey, and Neal D. Hulkower. *Cost Analysis*. Bedford, Mass.: MITRE, 1998.

DHS (Department of Homeland Security). *Capital Planning and Investment Control*. Washington, D.C.: February. 4, 2016.

———. *Acquisition Management Directive*. Washington, D.C.: July 28, 2015.

DOD (Department of Defense). *Agile and Earned Value Management: A Program Manager's Desk Guide*. Washington, D.C.: April 16, 2018.

———. *Automated Information System Economic Analysis Guide*. Washington, D.C.: May 1, 1995.

———. *Contract Pricing Reference Guide*. Washington, D.C.: 2002.

———. *Contractor Cost and Software Data Reporting*. Washington, D.C.: June 8, 2007.

———. *Cost Analysis Guidance and Procedures*, DOD 5000.4-M. Washington, D.C.: December, 1992.

———. *Cost and Software Data Reporting (CSDR) Manual DOD 5000.04-M-1*. Washington, D.C.: November 4, 2011

.———. *Data Item Description, Contract Performance Report (CPR)*, DI-MGMT-81466A. Washington, D.C.: Approval Date, March 30, 2005.

———. *Data Item Description, Integrated Program Management Report* (IPMR), DI-MGMT-81861A. Washington, D.C.: Approval Date, September 16, 2015

———. Directive 5105.64. Washington, D.C.: January 10, 2013.

———. *Earned Value Management Acquisition, Analytics and Policy*. Washington, D.C.: n.d.

———. *Earned Value Management Glossary of Terms*. Washington, D.C.: n.d.

———. *Earned Value Management Implementation Guide*. Washington, D.C.: January. 18, 2019

———. *Earned Value Management Roles and Responsibilities.* Washington, D.C.: June 15, 2018

———. *Earned Value Management System Interpretation Guide*. Washington, D.C.: February 18, 2015.

———. *Economic Analysis for Decision-making*, DOD 7041.3. Washington, D.C.: October 2, 2017.

———. *Enterprise Resource Planning Information*. Washington, D.C.: April 20, 2006.

———. Inflation and Escalation Best Practices for Cost Analysis. Washington, D.C.: Jan. 2017.

———. *Inflation Handbook 2nd Edition.* Washington, D.C.: June 2011.

———. *Instruction DODI-5000.73*, Washington, D.C: October 2, 2017.

———. *Instructional Systems Development/Systems Approach to Training and Education,* MIL-HDBK-29612-2A. Washington, D.C.: August 31, 2001.

———*. Integrated Master Plan and Integrated Master Schedule Preparation and Use Guide*. Washington, D.C.: October 21, 2005.

———. *Integrated Master Schedule Data Item Description.* Washington, D.C.: March 30, 2005.

———. *Integrated Program Management Report Implementation Guide.* Washington, D.C.: February 5, 2016.

———. *Integrated Project Management/Earned Value Management Handbook*. Washington, D.C.: February 13, 2013.

———. *Operating and Support Cost-Estimating Guide.* Washington, D.C.: March 2014.

———. *Operation of the Defense Acquisition System*, DOD Instruction 5000.02. Washington, D.C.: January 7, 2015.

———. *Operation of the Defense Acquisition System*, DOD Instruction 5000.02T. Washington, D.C.: January 23, 2020.

———. *Over Target Baseline and Over Target Schedule*. Washington, D.C.: December 5, 2012.

———. *The Defense Acquisition System, DOD Directive 5000.01*. Washington, D.C.: Certified Current as of August 31, 2018.

———. *The Program Manager's Guide to the Integrated Baseline Review Process*. Washington, D.C.: June 2003.

———. *Risk Management Guide for DOD Acquisition*, 6th ed., version 1.0. Washington, D.C.: August 2006.

———. "Single Point Adjustments." Memorandum from D. M. Altwegg, Business Management, Missile Defense Agency, to Missile Defense Agency Program Divisions, Washington, D.C., December 8, 2005.

———. "Software Acquisition Gold Practice: Track Earned Value". Washington, D.C.: Data Analysis Center for Software, December. 12, 2002.

———. *Software Resources Data Report Manual*, DOD 5000.4-M-2. Washington, D.C.: February. 2, 2004.

———. *Use of Earned Value Management in DOD*. Washington, D.C. July 3, 2007

———. *Work Breakdown Structures for Defense Materiel Items*, MIL-HDBK-881A. Washington, D.C.: July 30, 2005.

———. *Work Breakdown Structures for Defense Materiel Items*, MIL-HDBK-881D. Washington, D.C.: April 9, 2018.

———, General Services Administration, and National Aeronautics and Space Administration. Federal Acquisition Regulation (FAR) Major System Acquisition, 48 C.F.R. part 34, Earned Value Management System, subpart 34.2, added by Federal Acquisition Circular 2005-11, July 5, 2006, as Item I—Earned Value Management System (EVMS) (FAR Case 2004-019).

DOE (Department of Energy). *Cost Estimating Guide*, DOE G 413.3-21A. Washington, D.C.: June 6, 2018.

———. *Earned Value Interpretation Handbook*. Washington, D.C.: September 30, 2015.

———. *Earned Value Management System*, DOE G 413.3-10A. Washington, D.C.: October 22, 2015.

———. *Earned Value Management System Project Analysis Standard Operating Procedure*. Washington, D.C.: March 12, 2014.

———. *Earned Value Management System Surveillance Standard Operating Procedure*. Washington, D.C.: September 30, 2013.

———. *Program and Project Management for the Acquisitions of Capital Assets*, DOE 413.3B. Washington, D.C.: April 12, 2018.

DON (Department of Navy). *Navy Cost Analysis Division. Cost Analysis 101*. Arlington, Va.: n.d.

———. Navy Cost Analysis Division. *Documentation Guide*. Washington, D.C.: February. 3, 2004.

———. Navy Cost Analysis Division. *Methods and Models for Life-cycle Cost Analysis* in the U.S. Department of Defense. Arlington, Va.: May 25–26, 2004.

———. *SUPSHIP Operations Manual*. Washington, D.C.: March 1, 2016.

———. United States Naval Center for Cost Analysis. *Software Development Estimating Handbook*. Arlington, Va.: February 1998.

Driessnack, John D. *Using Earned Value Data*. Arlington, Va.: MCR, June 2005.

———, and Neal D. Hulkower. *Linking Cost and Earned Value Analysis*. Arlington, Va.: MCR, June 2005.

Department of Infrastructure and Regional Development. *Probabilistic Contingency Estimation*. Canberra, Australia: Australian Government, May 2017.

Druker, Eric, Christina Kanick, and Richard Coleman. *The Challenges of (and Solutions for) Estimating Percentiles of Cost*. Arlington, Va.: Northrop Grumman, August 11, 2008.

FAA (Federal Aviation Administration). *Earned Value Management Guide*. Washington, D.C.: July 2016.

———. *Earned Value Management System Acceptance Guide.* Washington, D.C.: April 2017.

———. *Investment Analysis Standards and Guidelines: FAA Standard Cost Estimation Guidelines*, version 1.0. Washington, D.C.: April 2003.

———. *Program Performance Surveillance Guide*. Washington, D.C.: March 2012.

———. *Program-Level Integrated Baseline Review Guide Performance Version 2.0*. Washington, D.C.: January 2013.

Federal Register. "Rules and Regulations, vol. 73, no. 79". Washington, D.C.: Apr. 23, 2008.

Ferens, Dan. Commercial Software Models. Vienna, Va.: International Society of Parametric Analysis, June 2005.

Fleming, Quentin W. Earned Value Management (EVM) Light . . . But Adequate for All Projects. Tustin, Calif.: Primavera Systems, November 2006.

———, and Joel M. Koppelman. "The Earned Value Body of Knowledge." Presented at the 30th Annual Project Management Institute Symposium, Philadelphia, Pennsylvania, October 10–16, 1999.

———. Performance Based Payments. Tustin, Calif.: Primavera Systems, November 2007.

Flett, Frank. "Organizing and Planning the Estimate". McLean, Va.: MCR, June 12–14, 2005.

Galorath, Daniel D. *Overcoming Cultural Obstacles to Managing Risk*. El Segundo, Calif.: Galorath Inc., 2007.

———. *Software Estimation Handbook*. El Segundo, Calif.: Galorath Inc., n.d.

———. *Software Projects on Time and Within Budget: The Power of Parametrics*. El Segundo, Calif.: Galorath Inc., n.d.

———. *Software Total Ownership Cost Development Is Only Job 1*. El Segundo, Calif.: Galorath Inc., 2008.

GAO. *21st Century Challenges: Reexamining the Base of the Federal Government,* GAO-05-325SP. Washington, D.C.: February 2005.

GAO. *2020 Census: Census Bureau Improved the Quality of Its Cost Estimation but Additional Steps Are Needed to Ensue Reliability,* GAO-18-635. Washington, D.C.: August 17, 2018.

GAO. *2020 Census: Key Challenges Need to Be Addressed to Successful Enable Internet Response,* GAO-15-225. Washington, D.C.: February 5, 2015.

GAO. *2020 Census: Census Bureau Needs to Improve Its Life-Cycle Cost Estimating Process*, GAO-16-628. Washington, D.C.: June 30, 2016.

GAO. *Airborne Laser: Uncertainties Remain Concerning the Airborne Laser's Cost and Military Utility,* GAO-04-643R. Washington, D.C.: March 17, 2004.

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.

GAO. *Amphibious Combat Vehicle: Some Acquisition Activities Demonstrate Best Practices; Attainment of Amphibious Capability to be Determined,* GAO-16-22. Washington, D.C.: October 28, 2015.

GAO. *Assessing the Reliability of Computer-Processed Data,* GAO-09-365G. Washington, D.C.: February 18, 2009.

GAO. *Aviation Security: Systematic Planning Needed to Optimize the Deployment of Checked Baggage Screening Systems,* GAO-05-365. Washington, D.C.: March 15, 2005.

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

GAO. *Best Practices: Better Management of Technology Development Can Improve Weapon System Outcomes,* GAO/NSIAD-99-162. Washington, D.C.: August. 16, 1999.

GAO. *Best Practices: Successful Application to Weapon Acquisitions Requires Changes in DOD's Environment,* GAO/NSIAD-98-56. Washington, D.C.: February 24, 1998.

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.: January. 26, 2007.

GAO. *Coast Guard Acquisitions: Polar Icebreaker Program Needs to Address Risks before Committing Resources*, GAO-18-600. Washington, D.C.: September 4, 2018.

GAO. *Coast Guard: Legacy Vessels' Declining Conditions Reinforce Need for More Realistic Operational Targets*, GAO-12-741. Washington, D.C.: July 31, 2012.

GAO. *Columbia Class Submarine: Overly Optimistic Cost Estimate Will Likely Lead to Budget Increases*, GAO-19-497. Washington, D.C.: April 8, 2019.

GAO. *Columbia Class Submarine: Immature Technologies Present Risks to Achieving Cost, Schedule, and Performance Goals*, GAO-18-158. Washington, D.C.: December 21, 2017.

GAO. *Combat 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.

GAO. *Combat 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.

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.

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

GAO. *Defense Acquisitions: Assessments of Selected Major Weapon Programs,* GAO-06-391. Washington, D.C.: March 31, 2006.

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

GAO. *Defense Acquisitions: Information for Congress on Performance of Major Programs Can Be More Complete, Timely, and Accessible*, GAO-05-182. Washington, D.C.: March 28, 2005.

GAO. *Defense Acquisition: A Knowledge-Based Funding Approach Could Improve Weapon System Program Outcomes,* GAO-08-619. Washington, D.C.: June 2008.

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

GAO. *DOD Systems Modernization: Planned Investment in the Navy Tactical Command Support System Needs to Be Addressed,* GAO-06-215. Washington, D.C.: December 5, 2005.

GAO. *Defense Management: Further Analysis Needed to Identify Guam's Public Infrastructure Requirements and Costs for DOD's Realignment Plan,* GAO-14-82. Washington, D.C.: December 17, 2013.

GAO. *F-35 Sustainment: DOD Needs a Plan to Address Risks Related to Its Central Logistics System,* GAO-16-439. Washington, D.C.: April 14, 2016.

GAO. *Ford-Class Aircraft Carrier: Follow-On Ships Need More Frequent and Accurate Cost Estimates to Avoid Pitfalls of Lead Ship*, GAO-17-575. Washington, D.C.: June 13, 2017.

GAO. *Federal Real Property: DHS and GSA Need to Strengthen the Management of DHS Headquarters Consolidation,* GAO-14-648. Washington, D.C.: September 19, 2014.

GAO. *GAO's High Risk Program*, GAO-06-497T. Washington, D.C.: March 15, 2006.

GAO. *Global Hawk Unit Cost Increases,* GAO-06-222R. Washington, D.C.: December 15, 2005.

GAO*. A Glossary of Terms Used in the Federal Budget Process*, GAO-05-734SP. Washington, D.C.: September 2005.

GAO. *Government Auditing Standards 2018 Revision*, GAO-18-568G. Washington, D.C.: July 2018.

GAO*. Homeland Security: Recommendations to Improve Management of Key Border Security Program Need to Be Implemented,* GAO-06-296. Washington, D.C.: Feb. 14, 2006.

GAO. *Information Technology: Agencies Need to Improve the Accuracy and Reliability of Investment Information,* GAO-06-250. Washington, D.C.: Jan. 12, 2006.

GAO. *Information Technology: HUD Needs to Address Significant Weaknesses in Its Cost Estimating Practices,* GAO-17-281. Washington, D.C.: February 7, 2017.

GAO. *James Webb Telescope, Project on Track but May Benefit from Improved Contractor Data to Better Understand Costs,* GAO-16-112. Washington, D.C.: December 1, 2015.

GAO. *Joint Intelligence Analysis Complex: DOD Needs to Fully Incorporate Best Practices into Future Cost Estimates,* GAO-17-29. Washington, D.C.: November 3, 2016.

GAO. *Joint Strike Fighter: Restructuring Places Program on Firmer Footing, but Progress Still Lags,* GAO-11-325. Washington, D.C.: April 7, 2011.

GAO. *Major Acquisitions: Significant Changes Underway in DOD's Earned Value Management Process,* GAO/NSIAD-97-108. Washington, D.C.: May 5, 1997.

GAO. *Maximizing the Success of Chief Information Officers,* GAO-01-376G. Washington, D.C.: February 1, 2001.

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

GAO. *NASA: Earned Value Management Implementation across Major Spaceflight Projects is Uneven,* GAO-13-22. Washington, D.C.: November 19, 2012.

GAO. *National Airspace System: Better Cost Data Could Improve FAA's Management of the Standard Terminal Automation System*, GAO-03-343. Washington, D.C.: January. 31, 2003.

GAO. *Nuclear Waste Cleanup: DOE Could Improve Program and Project Management by Better Classifying Work and Following Leading Practices,* GAO-19-223. Washington, D.C.: February 19, 2019.

GAO*. Plutonium Disposition Program: DOE Needs to Analyze the Root Causes of Cost Increases and Develop Better Cost Estimates*, GAO-14-231. Washington, D.C.: February 13, 2014.

GAO. *Polar-Orbiting Operational Environmental Satellites: Cost Increases Trigger Review and Place Program's Direction on Hold*, GAO-06-573T. Washington, D.C.: March 30, 2006.

GAO. *Polar-Orbiting Operational Environmental Satellites: Information on Program Cost and Schedule Changes,* GAO-04-1054. Washington, D.C.: September 30, 2004.

GAO. *Project and Program Management: DOE Needs to Revise Requirements and Guidance for Cost Estimating and Related Reviews,* GAO-15-29. Washington, D.C.: November 25, 2014.

GAO. *Schedule Assessment Guide: Best Practices for Project Schedules*, GAO-16-89G. Washington, D.C.: December 22, 2015.

GAO*. Service Contracts: Agencies Should Take Steps to More Effectively Use Independent Government Cost Estimates*, GAO-17-398. Washington, D.C.: May 17, 2017.

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

GAO. *Space Launch System: Management Tools Should Better Track to Cost and Schedule Commitments to Adequately Monitor Increasing Risk*, GAO-15-596. Washington, D.C.: July 16, 2015.

GAO. *Standards for Internal Control in the Federal Government: Exposure Draft,* GAO/AIMD-98-21.3.1. Washington, D.C.: December 1, 1997.

GAO. *Telecommunications: GSA Has Accumulated Adequate Funding for Transition to New Contracts but Needs Cost Estimation* Policy, GAO-07-268. Washington, D.C.: February 23, 2007.

GAO. *Theory and Practice of Cost Estimating for Major Acquisitions*, B-163058. Washington, D.C.: July 24, 1972.

GAO. *Uncertainties Remain Concerning the Airborne Laser's Cost and Military Utility*, GAO-04-643R. Washington, D.C.: May 17, 2004.

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

GAO. *VA Construction: Management of Minor Construction and Non-Recurring Maintenance Programs Could Be Improved*, GAO-18-479. Washington, D.C.: July 31, 2018.

Garvey, Paul R. *Cost Risk Analysis without Statistics*. McLean, Va.: MITRE, February, 2005.

Geiser, Todd A., and David Schaar. "Tackling Cost Challenges of Net Centric Warfare," pp. 4083–92. In 2004 IEEE Aerospace Conference Proceedings, vol. 6. Proceedings of the 2004 IEEE Aerospace Conference, Institute of Electrical and Electronics Engineers. Big Sky, Mt.: March 6–13, 2004.

Gillam, Dale E. "Evaluating Earned Value Management and Earned Value Management Systems Using OMB's Program Assessment Rating Tool (PART)." The Measurable News, Spring 2005, pp. 1–7.

Gordon, Creaghe. "The Importance of Reserves and Budget Distribution in Achieving Budget Requirements." Flying High, 1st Quarter, 2006, pp. 6–8.

———, and George Rosenthal. *Proposal for Combining Risk and Earned Value Management*. Los Gatos, Calif.: n.p., n.d.

Groves, Angela, and Karen McRitchie. *Better Software Estimates Using SEER-SEM*. El Segundo, Calif.: Galorath Associates, n.d.

GSA (General Service Administration). *Project Estimating Requirements.* Washington, D.C.: January 2007.

———. *Public Buildings Service Cost and Schedule Management Policy Requirements.* Washington, D.C.: August 4, 2016.

Harris, Michael D. S., David Herron, and Stasia Iwanicki. T*he Business Value of IT: Managing Risks, Optimizing Performance, and Measuring Results*. Boca Raton, Fla.: Auerbach Publications, 2008.

Haugan, Gregory T. *The Work Breakdown Structure in Government Contracting*. Vienna, Va.: Management Concepts, 2008.

———. Work Breakdown Structures for Projects, Programs, and Enterprises. Vienna, Va.: Management Concepts, 2008.

HHS (Department of Health and Human Services). *DHHS Project Officers' Contracting Handbook*. Washington, D.C.: January 23, 2003.

———. *Acquisition Regulation*. Washington, D.C.: December 18, 2015.

Higdon, Greg, Lew Fichter, and Alfred Smith. *Cost Uncertainty Analysis: Observations from the Field*. Santa Barbara, Calif.: Tecolote Research, April 2008.

Hohmann, Timothy J. *Estimating Software Size: Impact and Methodologies*. El Segundo, Calif.: Galorath Associates, 1997.

Hulett, David T. *Advanced Quantitative Schedule Risk Analysis*. Washington, D.C.: Hulett and Associates, 2007.

———. Considering Corporate Culture in Project Risk Management Maturity Models. Washington, D.C.: Hulett and Associates, 2007.

———. *Corporate Culture in Project Risk Management Maturity*. Washington, D.C.: Hulett and Associates, 2008.

———. *Integrated Cost-Schedule Risk Analysis*. Gower Publishing. Burlington, VT. 2011

———. *Integrated Cost and Schedule Risk Analysis*. Washington, D.C.: Hulett and Associates, 2007.

———. *Integrated Cost and Schedule Risk Analysis Using Risk Drivers*, Washington, D.C.: Hulett and Associates, 2007.

———. *Integrating Cost and Schedule Risk Analysis*. Washington, D.C.: Hulett and Associates, n.d.

———. *The Problem with Dangling Activities*. Washington, D.C.: Hulett and Associates, 2007.

———. *"Using Risk Analysis and Monte Carlo Simulation Techniques in Strategic Decisionmaking"*. Washington, D.C.: Hulett and Associates, May 2–4, 2005.

———, and Waylon Whitehead*. Using the Risk Register in Schedule Risk Analysis with Monte Carlo Simulation*. Washington, D.C.: Hulett and Associates, 2007.

Humphreys, Gary, and Margo Visiticion. *Mastering Program Management Fundamentals Critical for Successful EVM*. Bala Cynwyd, Pa.: Primavera, n.d.

ICEAA (International Cost Estimating and Analysis). Cost Estimating Body of Knowledge. Vienna, Va.: 2013.

Ignemi, Joseph. *Jumpstart Your Val IT™ Process*. Mount Laurel, N.J.: PRICE Systems, August 6, 2008.

Intelligence Community Cost Analysis Improvement Group. *Independent Cost Analysis Checklist*, version 1.0. Washington, D.C.: December 16, 1999.

International Society of Parametric Analysts. *Parametric Estimating Handbook*, 4th ed. Vienna, Va.: 2008.

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

Joint Agency. *Cost Schedule Risk and Uncertainty Handbook*. Washington, D.C.: March 12, 2014.

Jones, Capers. *What Are Function Points?* Hendersonville, N.C.: Software Productivity Research, March 1995.

Kahneman, Daniel, and Dan Lovallo. “Delusions of Success: How Optimism Undermines Executives’ Decisions.” Harvard Business Review, July 2003.

Kratzert, Keith. *Earned Value Management (EVM): The Federal Aviation Administration (FAA) Program Manager’s Flight Plan*. Washington, D.C.: Federal Aviation Administration, January 2006.

Kumley, Alissa C., and others. *Integrating Risk Management and Earned Value Management: A Statistical Analysis of Survey Results.* [Arlington, Va.]: National Defense Industrial Association, Program Management Systems Committee, n.d.

Lavdas, Evaggelos. *Identifying the Characteristics of a Good Cost Estimate: A Survey.* Cranfield, Bedfordshire, Eng.: Cranfield University, June 2006.

Lipke, Walter H. *Independent Estimate at Completion: Another Method.* Tinker Air Force Base, Okla.: October 2004.

Lorell, Mark A., Julia F. Lowell, and Obaid Younossi. *Evolutionary Acquisition Implementation Challenges for Defense Space Programs*. Arlington, Va.: RAND, 2006.

McRitchie, K., and S. Acelar. *A Structured Framework for Estimating IT Projects and IT Support.* Industry Hills, Ca: June 2008.

Majerowicz, Walt. “Schedule Analysis Techniques.” Integrated Performance Management Conference, n.p., November 2005.

Manzer, Frederick. Integrated Baseline Review: *The Link from the Estimate to Project Execution.* Vienna, Va.: Center for Systems Management, June 2005.

Martin, Kevin. *Integrating Schedules and EV Metrics*. KM Systems Group, Arlington, Va.: May 2008.

Melamed, Dan and Robert Loop. *Cost and Schedule Reserves in a Project Baseline, an Owners and Contractor's Perspective*. Department of Energy. Washington, D.C.: 2014.

Minkiewicz, Arlene F. *Estimating Software from Requirements*. Mount Laurel, N.J.: PRICE Systems, n.d.

———. *Measuring Object-Oriented Software with Predictive Object Points*. Mount Laurel, N.J.: PRICE Systems, n.d.

Mislick, Gregory K. and Daniel A. Nussbaum. *Cost Estimating: Methods and Tools*. John Wiley & Sons, Inc. Monterey, CA.: 2015.

NASA (National Aeronautics and Space Administration). *Cost Analysis Data Requirement*. Washington, D.C.: March 22, 2005.

———. *Cost Estimating Handbook*. Washington, D.C.: February 2015.

———. Jet Propulsion Lab. *Handbook for Software Cost Estimation.* Pasadena, Calif.: May 30, 2003.

———. Office of Inspector General. *NASA's Challenges to Meeting Cost, Schedule, and Performance Goals*. Washington, D.C.: September 27, 2012.

———. *Procedural Requirements*, NPR 7120.5C. Washington, D.C.: March 22, 2005.

NAVAIR (Naval Air Systems Command). *AIR 4.2 Life-cycle Cost Estimating Process.* Washington, D.C.: October 1, 1999.

———. *Integrated Project Management Training*. Washington, D.C.: January 2004.

———. *Methods and Models for Life-Cycle Cost Analysis in the U.S. Department of Defense.* Washington, D.C.: May 26, 2004.

———. *NAVAIR Acquisition Guide*. Washington, D.C.: October 1, 2013.

———. *Using Software Metrics and Measurements for Earned Value Toolkit.* Washington, D.C.: October 2004.

NAVSEA (Naval Sea Systems Command). *Cost Estimating Handbook*. Washington, D.C.: 2005.

NDIA (National Defense Industrial Association*). Integrated Program Management Division Guide to the Integrated Baseline Review Rev 2*. Arlington, Va.: February 6, 2015.

———.Integrated Program Management Division. *A Guide to Managing Programs Using Predictive Measures*. Arlington, Va.: September 17, 2014.

———. Integrated Program Management Division. *Earned Value Management System Acceptance Guide Rev 1*. Arlington, Va.: March 24, 2013.

———. Integrated Program Management Division. *Earned Value Management System Application Guide Rev 2*. Arlington, Va.: January 27, 2015.

———. Integrated Program Management Division. *Planning and Scheduling Excellence Guide.* Arlington, Va.: March 9, 2016.

———.*Integrating Risk Management with Earned Value Management*. Arlington, Va.: June 2004.

———. *Program Management Systems Committee. ANSI/EIA-748A Standard for Earned Value Management Systems Intent Guide*. Arlington, Va.: January 2005.

———. *Program Management Systems Committee. EIA-748D Standard for Earned Value Management Systems Intent Guide*. Arlington, Va.: August 2015.

———. *Program Management Systems Committee. Earned Value Management System Application Guide*. Arlington, Va.: March 2007.

———. *Program Management Systems Committee. Surveillance Guide Rev 3*. Arlington, Va.: November 5, 2018.

NIH (National Institutes of Health). *Cost Benefit Analysis Guide for NIH Information Technology Projects*. Bethesda, Md.: April 1999.

NIST (National Institute of Standards and Technology). *Engineering Statistics Handbook.* Washington, D.C.: Department of Commerce, Technology Administration, July 18, 2006.

NSF (National Science Foundation). *Large Facilities Manual*. Washington, D.C.: March 2017.

OMB (Office of Management and Budget). *Capital Programming Guide: Supplement to Circular A-11, Part 3, Overview of the Budget Process.* Washington, D.C.: Executive Office of the President, 2019.

———. *Capital Programming Guide: Supplement to Circular A-11, Part 7, Preparation, Submission, and Execution of the Budget, Version 2.0.* Washington, D.C.: Executive Office of the President, 2019.

———. “Developing and Managing the Acquisition Workforce,” Office of Federal Procurement Policy Letter 05-01, Washington, D.C., April 15, 2005.

———. *Federal Source Code Policy: Achieving Efficiency, Transparency, and Innovation through Reusable and Open Source Software*, memorandum for Chief Information Officers M-16-21, Washington, D.C., August 8, 2016.

———. *FY2007 Exhibit 300 Preparation Checklist*. Washington, D.C.: March 8, 2005.

———. *Guidelines and Discount Rates for Benefit-Cost Analysis of Federal Programs, Circular No. A-94 Revised*. Washington, D.C.: October 29, 1992.

———. *Guidelines for Ensuring and Maximizing the Quality, Objectivity, Utility, and Integrity of Information Disseminated by Federal Agencies*; Notice; Republication. Part IX. Washington, D.C.: February 22, 2002.

———. “Improving Information Technology Project Planning and Execution,” memorandum for Chief Information Officers M 05-23, Washington, D.C., August 4, 2005.

———. *Management of Federal Information Resources*, Circular A-130. Washington, D.C.: July 27, 2016.

———. *Major Systems Acquisitions*, Circular A-109. Washington, D.C.: Apr. 5, 1976.

———. *The President's Management Agenda*. Washington, D.C.: 2002.

Park, Robert E. *Checklists and Criteria for Evaluating the Cost and Schedule Estimating Capabilities of Software Organizations*. Pittsburgh, Pa.: Software Engineering Institute, Carnegie Mellon University, 1995.

Phelan, Pat. *Estimating Time and Cost of Enterprise Resource Planning (ERP) Implementation Projects Is a 10-Step Process*. Stamford, Conn.: Gartner Inc., April 27, 2006.

Performance Management–Civilian Agency/Industry Working Group. *Civilian Agency Reciprocity for Contractors EVMS Acceptance*. n.p.: May 29, 2008.

Project Management Institute, Inc. *A Guide to the Project Management Body of Knowledge (PMBOK® Guide)*, Sixth Edition, 2018. PMBOK is a trademark of Project Management Institute, Inc.

———. *Practice Standard for Work Breakdown Structures*, Second Edition, 2006.

———. *Practice Standard for Earned Value Management*, Second Edition, 2011.

———. "Pulse of the Profession 2018" (2018).

Price, Rick. *The Missing Link: Schedule Margin Management*. n.p.: n.p., May, 2008.

PRICE Systems*. The Promise of Enterprise Resource Planning.* Mount Laurel, N.J.: 2004

RAND. *Impossible Certainty: Cost Risk Analysis for Air Force Systems.* Arlington, Va.: 2006.

———. *Toward a Cost Risk Estimating Policy*. Williamsburg, Va.: February 17, 2005.

Remez, Shereen G., and Daryl W White. *Return on Investment (ROI) and the Value Puzzle*. Washington, D.C.: Capital Planning and Information

Technology Investment Committee, Federal Chief Information Officer Council, April 1999.

Reifer, Donald J. *Poor Man's Guide to Estimating Software Costs*. Torrance, Calif.: Reifer Consultants, June 2005.

SAE International. *Earned Value Management Systems* EIA748D. Warrendale, Pa.: SAE, 2019.

SAVI. "Exponential Growth of System.", AVSI, January 2020.

Scaparro, John. "NAVAIR Integration Project Management Brief to U.S. Government Accountability Office". Pax River, Md.: Naval Air Systems Command, April 19, 2007.

Seaver, David P. *Estimates for Enterprise Resource Planning Systems*, PRICE Systems, Mount Laurel, N.J.: n.d.

SEI. *SEI Research Combats Mounting Acquisition Costs*, SEI. Oaks, PA.: April 9, 2018.

Slater, Derek. "Enterprise Resource Planning (ERP) *Software Packages Promise Great Benefits, but Exactly How Much Will You Have to Pay to Get Them?"* CIO Enterprise Magazine, January 15, 1998, p. 22.

Smith, Alfred. *Examination of Functional Correlation*. Santa Barbara, Calif.: Tecolote Research, June 2007.

———, and Shu-Ping Hu. *Common Errors When Using Risk Simulation Tools*. Santa Barbara, Calif.: Tecolote Research. June 2005.

———. *Cost Risk Analysis Made Simple*. Santa Barbara, Calif.: Tecolote Research, September 2004.

———. *Impact of Correlating CER Risk Distributions on a Realistic Cost Model*. Santa Barbara, Calif.: Tecolote Research. June 2003.

Summerville, Jessica R. Improvement Curves: *How to Account for Cost Improvement*. Chantilly, Va.: Northrop Grumman, The Analytical Sciences Corporation, 2005.

USAF (United States Air Force). *Air Force Handbook of Cost Uncertainty and Risk Analysis*. Arlington, Va.: August 28, 2013.

———, Air Force Cost Analysis Agency. *Cost Risk and Uncertainty Analysis Handbook*. Arlington, Va.: August 28, 2013.

———, Air Force Cost Analysis Agency. *Decision Support for the Program Manager*. Arlington, Va.: n.d.

———, Air Force Cost Analysis Agency. *Pre-Award IBRs*. Arlington, Va.: September 7, 2006.

———, Air Force Cost Analysis Agency. *Raytheon Missile System EVMS Validation Review*. Arlington, Va.: April 18, 2008.

———, Air Force Cost Analysis Agency. *Risk and Estimate Quality Issues*. Arlington, Va.: n.d.

———. Air Force Systems Command. *Cost Estimating Handbook*. Reading, Mass.: 1987.

———. *Condensed GSAM Handbook Checklists*. Hill Air Force Base, Utah: February 2003.

———. *Cost Analysis Guidance and Procedures*, Air Force Instruction 65-508. Washington, D.C.: October 1, 1997.

———. *Cost Risk Analysis: Need-to-Know for Evaluations and Budgetary Decisions*. Arlington, Va.: Government-Industry Space Council, June 2008.

———. *Costing ERP in the Department of Defense*. Washington, D.C.: June 2008.

———. “CrossTalk”. Hill Air Force Base, Utah: June–December 2002.

———. *Economic Analysis,* Air Force Instruction 65-506. Washington, D.C.: November 10, 2004.

———. *Forecasting the Future with EVMS*. Arlington, Va.: n.d.

———. *Guidelines for Successful Acquisition and Management of Software Intensive Systems*. Hill Air Force Base, Utah: February 2003.

———. Myths of EVM. Arlington, Va.: May 11, 2005.

United States Army. Cost Guide *Manual*. Washington, D.C.: May 2002.

———, Environmental Center. *Methodology for Developing Environmental Quality Requirements for a Cost Analysis Requirements* Description. Aberdeen, Md.: November 2001.

VA (Veterans Administration). *Individual VAMC Pricing Guides*. VISN. Washington, D.C.: July 2007.

Visiticion, Margo. *Debunking Commonly Held EVM Myths*. n.p.: n.p., September 2007.

Wideman, Max R. "*A Pragmatic Approach to Using Resource Loading, Production, and Learning Curves on Construction Projects*." Canadian Journal of Civil Engineering 21 (1994): 939–53.

Wiley, David. *Software Cost Estimating: Techniques for Estimating in a Software Development Environment*. Chantilly, Va.: Northrop Grumman and Analytical Sciences Corp., 2005.

Wilkens, Tammo T. *Earned Value Clear and Simple*. Bala Cynwyd, Pa.: Primavera Systems, April 1, 1999.

Wright, R., J. Comer, and Justin Morris. *Enhancing Remediation Project Credibility with Defensible and Documented Cost Estimates*. N.p.: n.d.

Wright, T. P. "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.

Zubrow, Dave. *Earned Value Management: Basic Concepts*. Pittsburgh, Pa.: Carnegie Mellon Software Engineering Institute, 2002.

———. Implementing Earned Value Management to Manage Program Risk. Pittsburgh, Pa.: Carnegie Mellon Software Engineering Institute, 2002.

Zubrow, David, Robert Stoddard, Ipek Ozkaya, William Novak. "SEI *Research Combats Mounting Acquisition Costs*." Software Engineering Institute 2017 Year in Review. 2017: 12.

Image Sources

This section lists credit and copyright information for images and graphics in this product, as appropriate, when that information was not listed adjacent to the image or graphic.

Front cover clockwise (starting from top):

U. S. Capitol building. Source: GAO

Satellite. Source: National Aeronautics and Space Administration

Government Accountability Office Headquarters. Source: GAO

U. S. Navy ship. Source: U. S. Navy