2004 NASA Cost Estimating Handbook

Welcome to the 2004 NASA Cost Estimating Handbook (CEH)

New topics have been added and the document layout updated. To guide you through the changes, the following guide highlights the new and revised areas and provides helpful hints for using the CEH.

Revision Highlights:

- Enhanced introduction to give a more in depth overview of regulations, environment, and cost estimating processes at NASA;
- Cost estimating process tasks identified by life cycle phase; and
- The introduction of the Project Continuous Cost-Risk Management (CCRM) process and how it is integrated with the NASA cost estimating process tasks.

Using the Handbook:

The 2004 NASA CEH is designed to be an electronic resource. Not intended to be read cover-to-cover, this handbook's design helps to facilitate fast topic searches, extractions of specific pages, graphics, or sections as stand alone topical references to use or to share in hard copy or electronically with your colleagues, and provide in depth write ups to describe topics without disturbing the flow of the document for the reader.

A downloadable version of the document in Adobe Acrobat .pdf format is available at **www.ceh.nasa.gov**. This web site also hosts the actual document in HTML format so you can access it even when you are away from your computer. For best viewing results, use Internet Explorer (IE).

The 2004 NASA CEH is not officially available in hard copy. If you would like to print a personal copy of the 2004 NASA CEH, the following printing guidelines should be helpful. The layout of the document has specific margins to allow for online viewing and spiral binding. Following the printing guidelines below will allow the most efficient use of your 2004 NASA CEH.

1. Print the document single sided in color to take advantage of the document's color-coding for easy reference and to make personal notes on the blank side of each page.
2. Reverse the last printed page of the document to provide a back cover.
3. Insert viewgraph sheets in the front and back of the document, providing a protective cover for long-term use.
4. Have the document spiral bound (print departments or copy stores can quickly provide this service.)

Requests or comments - Feedback and/or suggested improvements are welcomed. Information requests can be sent to ceh_info@nasa.gov. Please send your comments and feedback on the CEH to NASA Code BC at ceh_comments@nasa.gov. Please send specific requests on the CEH to NASA Code BC at ceh_request@nasa.gov.

National Aeronautics
and Space Administration
NASA HQ
Washington, DC

This is our first full version of the National Aeronautics and Space Administration's (NASA) Cost Estimating Handbook (CEH). It has been developed as a resource that will be useful to you, the members of the NASA cost estimating community, in performing cost estimating and especially in making the President's Exploration Vision a reality. The CEH is a vital part of the soon to-be approved NASA Procedural Requirement (NPR) 7120.5C, NASA's policy providing the standard for excellence in project management. This first full version represents a significant improvement in clarity of what role cost estimating plays, not only within NASA, but also within the overall Federal resource management process.

The CEH is provided as an educational tool written from a NASA perspective and it covers the fundamental concepts and techniques of cost estimating as applied in NASA. It also contains a very useful new section (Section 4) containing: how to perform a cost estimate from the perspective of each specific phase of the life cycle; a new context for NASA cost management called the Continuous Cost-Risk Management process; an articulation of cost-risk analysis in the 12 Tenets of NASA Cost-Risk; an exciting new vehicle for capturing cost, technical and schedule data, the Cost Analysis Data Requirement (CADRe); and an expanded set of Appendices containing valuable reference materials. These concepts are key to NPR 7120.5C and so it is imperative that that NASA cost community fully understands these critical changes. As before, your comments are strongly welcomed to improve this version and continue to develop it as the official NASA Cost Estimating Handbook. Additionally, this NASA CEH will be available in soft copy on the following website: http://ceh.nasa.gov, where comments can be received and updates posted.

Our Administrator recognizes the importance of cost estimating as a critical NASA competency to support the financial decision-making in the life cycle of programs and projects. NASA's financial goal is to implement programs and projects in a responsible manner to the public who has entrusted us with their valuable resources. Sound cost estimating will be a key foundation to achieving our goals for the exploration vision.

Together, we are pursuing America's space program and represent NASA's greatest strength. Providing this handbook demonstrates NASA's commitment to its cost estimating community. By using this handbook in your day-to-day work, you will have an opportunity to participate in the fulfillment of our Agency's overall goals set forth in the President's Management Agenda and articulated in the NASA Strategic Plan.

Steven J. Isakowitz
NASA Comptroller

NASA cost estimating is undergoing a renaissance.

There is a renewed appreciation within the Agency for the importance of cost estimating as a critical part of project formulation and execution. The evidence for this is abundant. There are newly formed or re-generated cost organizations at NASA Headquarters (in the Office of the Comptroller, in the Independent Program Assessment Office, and in the Enterprises). The field centers cost organizations have been strengthened, reversing a discouraging trend of decline. Agency management, from the Administrator and Comptroller on down, is visibly supportive of the cost estimating function.

NASA projects are soliciting cost estimating services earlier in the life cycle, recognizing that the cost estimating function is an important participant in the overall systems engineering process and that the greatest leverage for cost effectiveness occurs early in the design process. In fact, much attention is being given to integrating separate Agency cost activities into the continuum of cost-risk feedback stages. This includes working more closely with the Integrated Financial Management (IFM), the new financial management system for NASA, Earned Value Management (EVM), procurement, systems engineering, and other functions.

A Cost Analysis Steering Group coordinates the internal NASA cost estimating and analysis community to ensure that best practices are being communicated, trained, and used. Under Headquarters guidance, the steering group is working a number of initiatives to further improve Agency cost estimating. These initiatives include:

- Using cost risk analysis (“S-curves”) and a new Cost Readiness Level (CRL) scale to communicate uncertainty and variability in cost estimates;
- Using a NASA version of a Cost Analysis Requirement Description (CADRe) to document the basis for estimate;
- Improving contract Data Requirements (DRs) to do a better job at capturing and archiving cost and technical data from ongoing projects for use in estimating new projects across One NASA;
- Estimating in full cost; and
- Developing a Cost Estimator’s Career Guide.

The NASA Cost Estimating Handbook itself is one of our more important initiatives. It is has been closely coordinated with the revisions being made to NPG 7120.5B, Program and Project Management Processes and Requirements as NPR 7120.5C (Draft). NPG 7120.5B is the “thou shalt” document for project management, including cost estimating directions. The NASA CEH provides the “how to” for the estimator.

Joe Hamaker

Preface

The NASA CEH has proven to be a dynamic, living document, changing with the many positive developments within the cost estimating community at NASA. In the 2002 edition of the NASA CEH, we stated that our mark of success would be your feedback, dialogue, and finding dog-eared copies on your desks. We thank you all for making the NASA CEH such a success. We heard your overwhelmingly positive and constructive feedback, we engaged each Center in enthusiastic dialogue, and not only did we find dog eared copies on your desks, but on the desks of the NASA Deputy Administrator, NASA Project Managers, engineers, resource analysts, industry, educational institutions and organizations from four continents. Your wisdom, best practices, lessons learned, processes and One NASA cost collaboration estimating knowledge are not only making the NASA cost estimating community a more credible and productive place to be, but also contributing to the cost estimating community at large, at home and abroad.

New NASA Headquarters organizations and directions, new initiatives such as CADRe, including data and model sharing, Data Requirements (DRs) and the ONCE One NASA Cost Estimating (ONCE) database to gather data proactively for future estimates, and the integration of cost risk in the concept of the NASA Project CCRM are just a few of the impressive changes that the One NASA cost estimating community has undertaken to meet today’s challenges. Our goals for the 2002 NASA CEH were to improve communication, to build consistency, and to enhance credibility. You have met these goals through the CEH and other tools and initiatives. By working together and communicating, you shared information and commiserated lessons learned within NASA and beyond. By opening this door to collaboration, you took best practices in NASA and the cost estimating community at large to help increase cost estimating consistency within cost groups, projects, Centers, and to Headquarters, OMB, and Congress. By using the information, presenting it in a consistent manner, and being willing and open to these new ideas and challenges, you have put NASA on the path to recognized, credible cost estimates. You have also caught the attention of the cost estimating community beyond NASA with your new initiatives and creative solutions to long time problems such as data sharing, streamlined technical baselines, and cost risk.

The NASA CEH is a collaborative document developed through hours of interviews, discussion, and correspondence with the NASA cost estimating community. Interviews with the NASA cost estimating community including Headquarters Code B staff, Independent Program Assessment Office (IPAO) staff, and Center Cost Offices were held to research and document cost estimating best practices embraced by NASA, to garner a feel for the environments where NASA cost estimators perform their estimates, and to see, first hand, how the CEH can enhance the cost estimating capability.

In this 2004 CEH edition, Project Managers and resource analysts were also interviewed to determine how the cost community interacts with these critical players and how we can improve. The CEH strikes a balance between documenting processes and providing basic resources for cost estimators from the beginning to the experienced, while providing the detail and “how to” function of NASA Program and Project Management Processes and Requirement (NPR) 7120.5C (Draft). It is supplemented by Center specific examples, best practices, and lessons learned where appropriate.

The NASA CEH brings the fundamental concepts and techniques of cost estimating to NASA cost estimating community personnel in a way that recognizes the nature of NASA systems and the NASA environment. This handbook is a top-level overview of cost estimating as a discipline, not an in-depth examination of each and every aspect of cost estimating. It is called the Cost *Estimating* Handbook so it is not confused as a resource that covers the entire discipline of cost *analysis*. It is a useful reference document, providing many pointers to other sources for details to complement and to enhance the information provided on these pages.

Accurate and defensible estimates are at the core of the future credibility of the NASA cost estimating community. Regardless of whom the estimate is being prepared for, who the decision-maker is, or to whom the estimate is being presented, the estimator must always remember that the ultimate customer is the cost-estimating discipline. Truth and accuracy combined with a defensible and well-documented estimate will always earn the respect of a decision-maker. Cost estimation is part science, part art. There are many well-defined processes within the cost estimating discipline. There is also a subjective element to cost estimating that makes the discipline an art[1]. That is the art form that is learned over time and through experience. Cost estimating is not a "black box" process. The more understanding and credibility we gain with our customers, the more they will understand the disciplined process and tools used in an estimate, so they will understand the structured process that cost estimators follow. An attempt is made to capture the art form as well as the science in this text. The current perception that cost estimating is a "black box" can be demystified by accurate, defensible, well-documented estimates that are consistently presented and can be easily understood. This handbook is a starting point.

This edition of the NASA CEH details the "four letter words" in the NASA cost estimating community. RISK is addressed in a focused manner relevant to NASA. A logical NASA CADRe has been incorporated into the CADRe Project data requirement that takes the "best of" tailored approach from established CADRe processes. Specific templates from CADRes, briefings, and DRs are included. While these are new processes at NASA, we will not try to claim that they were improved. The content of the 2004 NASA CEH and all its described initiatives is still a living document. With your help and constructive feedback, processes will be tested, templates will be used, procedures will be navigated and they will evolve for the better. Speak your mind as you use this information. Check for updates to the CEH on the web site: http://www.ceh.nasa.gov/ and send comments to us at ceh_comments@NASA.gov. We want to hear from you. That's what makes you as a community and the NASA CEH so unique and successful. Leverage your experience. If you are new to NASA, learn and participate. If you are one of the pillars of the NASA cost estimating community, use the CEH to evaluate the new directions, educate your clients, and spread the word and your knowledge.

preface

[1] *We are not referring to the perceived "black box" of cost estimating but rather the art form that is learned over time and through experience.*

The 2002 edition of the CEH was relevant during a time of great growth and positive changes for the NASA cost estimating community. It introduced many to the world of NASA cost estimating. Our measure of success with the 2004 edition is still finding a dog-eared copy on your desk, but also hearing your feedback and your participation through a well-viewed web site. We hope the 2004 edition of the NASA CEH will lead you through a time of continued collaboration, as you use this positive momentum to pioneer new developments in the world of ONE NASA and the universe of cost estimating…as only NASA can.

> From Augustine's Laws…
>
> ...It was also becoming painfully evident that estimating the cost of technologically state-of-the-art projects was an inexact science. The experts, in spite of their mountains of numbers, seemingly used an approach descended from the technique widely used to weigh hogs in Texas. It is alleged that in this process, after catching the hog and tying it to one end of a teeter-totter arrangement, everyone searches for a stone which, when placed on the other end of the apparatus, exactly balances the weight of the hog. When such a stone is eventually found, everyone gathers around and tries to guess the weight of the stone. Such is the science of cost estimating. But then, economics has always been known as the dismal science.
>
> *Brett Watterson*

Acknowledgements

Many people contributed to the achievement of this 2004 edition of the CEH. The NASA Cost Analysis Steering Group (CASG) has proven once again to be the foundation of the CEH, providing hours of discussion, reviews, and hosting us at each Center for interviews. Other thanks go to the Johnson Space Center (JSC) Systems Management Office who administers the Independent Program Assessment Contract (IPAC) where this contract was funded. Dr. James Ortiz and Richard Whitlock were instrumental in making this effort possible on this vehicle. Special thanks goes to Rey Carpio, Richard Whitlock, David Graham, and Joe Hamaker for providing the leadership, direction and contractual means to update the CEH from the first edition of the 2002 NASA CEH to the 2004 NASA CEH evolution.

The 2004 NASA CEH team visited every NASA Center, JPL and HQ to interview the Center Cost Groups, other estimators at each Center, as well as Project Managers as customers of the cost estimate. These interviews were a success because of the CASG members who hosted us during our visits ensured balanced participation. The data that was collected during these interviews formed a foundation for areas that needed to be enhanced, updated, or created in this version of the CEH to keep it a useful document for the estimator and the customer. Genuine thanks and appreciation go to the many people who organized our visits to each Center for interviews and data collection: Richard Whitlock, Steve Creech, Hamid Habib-Agahi, Charlotte (Charli) DiCenzo, Robert (Bob) Sefcik, Glenn Rhodeside, Richard (Rick) Buonfigli, Gigi Hackford, Jack Mechanic, Bill Lawson, Rey Carpio, and Joe Hamaker.

Outside the NASA cost estimating community there were numerous individuals from many organizations that made contributions to this edition of the CEH. The graphics of the moon, mission information and the moons representing each chapter would not have been possible without the generous assistance of the NASA Design and Print Shop, NASA Librarians, and the History Department. Laurette Langlois was invaluable in pulling these talented people together including Andrew Pedrick, Rick Spencer, Jeffrey McLean, Michael Chambers, Larry Hirsch, Steve Johnson, Greg Treese, and Cathy Wilson. NASA HQ Web Master, Scott Glasser with the assistance of Vincent Hurley, Robert Smith, and Bryan McCall provided the support to make ceh.nasa.gov possible.

Many additional NASA personnel and others outside NASA contributed their time to participate in workshops, interviews, and in many cases contributed data for write ups and reviewed drafts of many CEH topics. A complete list of participants in the 2004 NASA CEH can be found in Appendix FF-1. Our thanks go to all participants and we acknowledge your important contribution to this edition of the NASA CEH.

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Introduction

1. INTRODUCTION

Welcome to the updated 2004 National Aeronautics Space Administration (NASA) Cost Estimating Handbook (CEH). This handbook is designed to provide useful information on cost estimating for the entire NASA cost estimating community. Its objective is to be both informative for the new NASA cost estimator and a good reference document for the experienced NASA cost estimator. Helpful to project Continuous Cost-Risk Management (CCRM) participants, who include Project Managers, Headquarters (HQ) staff, the resource community, and the systems engineering community, the information included in this handbook provides NASA-relevant perspectives and NASA-centric data useful in the NASA environment and facilitates the development of reliable, comprehensive, defensible, and well-documented cost estimates.

The NASA cost estimating community should use the 2004 NASA CEH as a starting point:

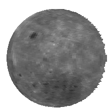
- To **gain** an overview of NASA cost estimating,
- To **find** "specific resources and information in NASA cost estimating, through the topically sorted Appendices of the CEH, and
- To **understand** specific terminology in NASA cost estimating, through the Cost Estimating Glossary.

We hope that you find this handbook informative, useful, and a vital resource in your daily work.

1.1 Scope

This handbook approaches broad cost-estimating topics through general concept discussions and generic processes, techniques, and tool descriptions. It describes cost estimating as it should be applied to NASA projects and provides information on cost estimating and analysis practices. It also identifies practical tips, caveats, and lessons learned.

The 2002 NASA CEH avoided any tone of strict guidance or policy. The 2004 NASA CEH still does not provide actual policy guidance or project requirements, however it does provide details not found in the draft NPR 7120.5C on how one would implement cost estimating requirements found in draft the NPR 7120.5C. The same NASA cost estimating community that helped create the required cost estimating stages found in draft NPR 7120.5C also provided input for the 2004 NASA CEH.

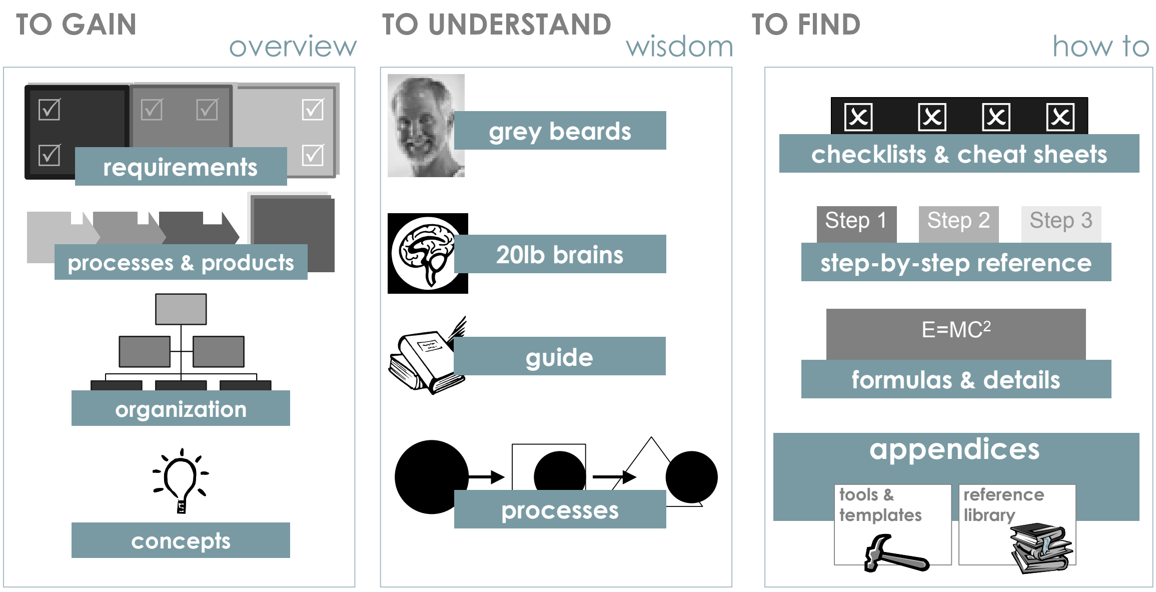


Cost estimating requirements and approaches vary to some extent, based on the NASA Centers' differing missions. However, across NASA, the fundamental cost estimating requirements and approaches are the same. Therefore, this handbook focuses on the fundamentals. Each NASA cost estimating office may choose to supplement these general guidelines, when appropriate, with specific instructions, processes, and procedures that address each Center's unique situations and requirements. Furthermore, each cost estimator is expected to reach beyond this handbook's approaches and methodologies, when they prove inadequate or when circumstances warrant. This departure is the point where art meets science in the field of cost estimating. Both NASA and the NASA cost estimating community are evolving, with some changes already in progress and reflected in this updated version of the CEH. Keep this evolution in mind and remain aware of it when using this CEH.

1.2 Organization

The organization of this handbook has been revamped to reflect how cost estimating is an integral part of life cycle management within NASA.

This handbook is separated into three major parts. The first part can be viewed as an overview, providing the "big picture" of cost estimating within the government and at NASA. It includes this introduction and Chapters 2 and 3, described below:



Chapter 2 introduces the importance of cost estimating by putting it in context of various Federal Government and NASA-specific imperatives that mandate the application of sound cost estimating. This chapter also examines how cost estimates are used to propel the Federal budgeting process and that used within NASA.

Chapter 3 focuses on a cornerstone of One NASA cost estimating, describing the life cycle phases, NASA policy and directives, and the continuous nature of the CCRM. The chapter also describes the cost estimating process and its products that are used by the cost estimating community. In addition to introducing the cost estimating process and Project CCRM, this chapter attempts to pull these pieces together to show how they work in harmony.

The second part of the CEH, entitled The Cost Estimating Process by Major Part: Working Through the Life Cycle Phases, provides the "wisdom" of the document. In narrative, form the twelve tasks in the cost estimating process are described in relationship to each phase of the life cycle. The Project CCRM "connection" to each life cycle phase is detailed as it supports the three major parts of the cost estimating process by keeping a focus on the potential cost impacts due to risks. One can read this section by project life cycle phase, not necessarily from beginning to end.

Chapter 4 provides step-by-step instructions for applying cost estimating and Project CCRM throughout the various life cycle phases. The goal of this section is to provide the cost estimator with specific knowledge as well as an ability to address the objectives and the issues/challenges highlighted in the previous section.

The third part of the CEH entitled Techniques, Tools, and Methods provides hands-on, step-by-step descriptions of the cost estimating process, details of Project CCRM, and the "how-to" of specific methods introduced in previous sections of the CEH. One should use this part of the handbook as a reference guide, choosing a topic of interest and referencing that specific section when needed.

Chapter 5 details the "how to" for each of the 12 steps of the cost estimating process steps.

Chapter 6 describes many of cost estimating techniques used at NASA that support the cost estimating process steps and the CCRM.

Appendices provide supplemental materials as a companion to the text in this handbook and provide useful information for the cost estimator.

The Role of Cost Estimating

2. The Role of Cost Estimating

In this chapter, the handbook describes the importance of cost estimating both within the Government at large and within the NASA community. There are many initiatives underway to improve project management and cost estimating at NASA. Some are described in this handbook. Strictly following the processes outlined in this handbook will bring NASA closer to improved cost estimating and project risk management.

2.1 The Importance of Life Cycle Management and Cost Estimating

An integrated, process-centered, and disciplined approach to life cycle management of projects provides real and tangible benefits to all project stakeholders. Organizations that ask great things from their membership, like NASA, must provide them with the resources necessary to accomplish greatness. This includes the realistic estimates of what those resources will cost. That is why cost estimating is so important at NASA. Through upfront trade studies and cost-risk performance analyses joined with the application of proven software, hardware, and system engineering principles and best practices, risks inherent with the successful delivery of the right product on time and within budget are minimized. Additional inherent results include:

- Early recognition of interoperability requirements and constraints;
- Complete, unambiguous, and documented functional requirements;
- Bounded and clearly defined product functional expectations and acceptance criteria, understood and agreed to by all stakeholders;
- More accurate, credible, and defensible scope, cost, and schedule estimates;
- More complete and timely risk identification, leading to more effective risk mitigation;
- A basis for properly quantifying, evaluating, and controlling the acceptance and timing of changes to requirements (i.e., precluding “scope creep”);
- Final products that deliver better reliability, adaptability, usability, performance, maintainability, supportability, and functionality -- in short, higher quality and value;
- Insight into near, mid and long term technology, design, infrastructure and operational investment needs as they relate to different effects on the phases and trade-offs within the life-cycle;
- Earlier and more consistent visibility to problems (fewer surprises);
- Shorter development cycles and reduced development and O&S costs;
- More efficient project management (management by exception reduces information overload and focuses resources on the most pressing issues);
- Historical data to gauge process improvements and effectiveness; and
- Promotion of organizational credibility and reputation.

This is not an all-inclusive list. Understanding the benefits of life cycle management for a project leads to better understanding of the cost estimate and its role in the project life cycle. Understanding the type of estimate that is required and being conducted is important for the cost estimator to provide a useful estimate to the decision makers.

Cost estimates are key elements of a project plan and project personnel expend considerable effort preparing them. They provide the basis for programming the total requirement and the recommended phasing of budgets. Obtaining accurate cost estimates can be difficult as NASA projects usually involve new technologies and require years to complete. Inaccurate estimates can result from an inability to predict and/or define requirements, technological advancements, task complexity, economic conditions, schedule requirements, support environments, or system employment concepts adequately. Worse, managers sometimes feel pressured to provide optimistic estimates in order to obtain project go-ahead approval. Yet a poor cost estimate can create an unexecutable plan.

A project with an inaccurate cost estimate eventually must deal with the issue.
A poor cost estimate is a destablizer. When the faulty estimate is discovered, a revised plan based on the adjusted cost will be needed if the project is to continue.

QUESTION: WHAT IS A LIFE CYCLE COST ESTIMATE (LCCE)

ANSWER:

- An estimate that includes total cost of ownership over the system life cycle, including all project feasibility, project definition, system definition, preliminary and final design, fabrication and integration, deployment, operations and disposal efforts.
- An LCC estimate provides an exhaustive and structured accounting of all resources necessary to identify all cost elements including development, deployment, operation and support and disposal costs.

QUESTION: WHAT IS A LCCE USED FOR?

ANSWER:

- Budgetary decisions
- System trades and studies
- To support milestone reviews
- To determine a projects viability, appropriate scope, and size

Accurate and reliable cost estimating has a direct, positive impact on NASA. NASA's cost estimating community does not take this responsibility lightly because:

- Overestimating Life Cycle Costs (LCCs) may result in the program being deemed unaffordable and therefore risking not being funded.
- Underestimating LCCs will prevent decision-makers from allocating the proper funding required to support the project.
- Properly estimating cost supports the budgeting and funding profile process.
- Repeatable and documented estimates allows "apples to apples" comparisons to occur, supporting the decision-making process.

2.2 Life Cycle Management and the Role Cost Plays

A project can have numerous goals and objectives, depending on its size, structure, and complexity, but they all intersect when making decisions. This intersection often requires tradeoffs among its objectives and goals. The specific tradeoffs may vary from project to project, but they always return to the concept of the triple constraint – technical requirements, schedule, and cost. This concept is the foundational principle of the Project CCRM, introduced in Section 3 and detailed in Section 4. Following an integrated, process-centered, and disciplined approach to life cycle management will drive results, improve cost and risk performance, and allow NASA to be responsive to Government- wide imperatives.

Exhibit 2-1: The Triple Constraint Concept

2.3 Government Wide Imperatives

Over the past 15 years, Congress has enacted legislation to change the way Federal agencies address common management problems and public opinion that Federal agencies should do their jobs more efficiently and effectively with fewer people and at lower costs. Using cost data to drive decision-making is essential in an era of stiff competition for limited resources. The legislative and policy framework requiring cost accountability include:

Government-Wide Imperatives	
Budget Enforcement Act of 1990	Chief Financial Officers Act of 1990
Government Performance & Results Act (GPRA) of 1993	Federal Acquisition Streamlining Act of 1994 (Title V)
Paperwork Reduction Act of 1995	Federal Financial Management Improvement Act of 1996
Clinger-Cohen Act of 1996 (also known as ITMRA)	Circular A-11, Preparation and Submission of Budget Estimates
Government Paperwork Elimination Act of 1998	Circular A-127, Financial Management Systems
Circular A-123, Management Accountability and Control	OMB memorandum M-97-02, October 25, 1996, Funding Information Systems Investments
Circular A-130, Management of Federal Information Resources	Circular A-76, Competitive Analysis “Performance of Commercial Activities”
OMB memorandum M-00-07, February 28, 2000, Incorporating and Funding Security in Information Systems Investments	

These new "accountability" laws and regulations, especially GPRA, are aimed at improving project performance. This legislative framework tasks government agencies like NASA to:

- Focus on agency mission, strategic goals, performance, and outcomes;
- Make strategic decisions about fiscal investments;
- Get the biggest "bang for the buck;" and
- Deliver results.

For Federal Executive Agencies, the policy imperatives require capital planning and business case analysis and are supported by the guidance and reporting requirements incorporated into the Federal budget process by the Office of Management and Budget (OMB) in Circulars A-11, A-130, and A-94.

THE PRESIDENT'S MANAGEMENT AGENDA

The President's Management Agenda (PMA)[1] identifies five mutually reinforcing Government-wide initiatives. The NASA cost estimating community will have a direct impact on three: Competitive Sourcing, Improved Financial Performance, and Budget and Performance Integration (see Exhibit 2.2 below)

Competitive Sourcing Detailed estimates of full cost government performance to the taxpayer are needed for identifying the most efficient means of accomplishing a task. NASA will convert to Full Cost in GFY 2004 and all NASA cost estimates will have to be full cost.	*The NASA cost estimating community now provides estimates in full cost. We have influence on this initiative by providing estimates to support studies, and conducting trade studies for efficiency.*
Improved Financial Performance Erroneous payments and accounting errors reduce confidence in Government systems. Changes will be made in the budget process to allow "better measure of the real cost and performance of programs." When the Executive Branch Management Scorecard was updated in 2003 NASA dropped in status from yellow to red.	*The NASA cost estimating community can have an impact on this initiative by providing timely and accurate cost estimates that serve as performance baselines and reconciling and updating the estimates frequently.*
Budget and Performance Integration Improvements will have little impact unless they are linked to better results. A budget comparison of procurement funds requested and identified need is not an accurate measure of performance results achieved with previous budgets.	*Realistic and defensible cost estimates, integrated and incorporated, into the NASA IBPDs can have an impact on future requirements and demonstrating results.*

Exhibit 2-2:
NASA and the PMA

1 *For more, see the President's Management Agenda at http://w3.access.gpo.gov/usbudget/fy2002/pdf/mgmt.pdf.*

The 2004 President's Budget for NASA expounds on a new exploration strategy, which calls for a timeframe paced by capabilities and affordability. The cost estimating community will play a central role in determining the latter. Furthermore, the President's Budget specifies "every NASA project and project must … perform successfully against measures." By accurately baselining costs associated with the technical baseline, the cost estimating community can provide PMs with more traceable and defensible estimating products, and an understanding the cost drivers and how to manage them.

THE FEDERAL BUDGET PROCESS

The planning and analysis conducted by individual project teams and agencies is the foundation for the formulation of the President's Budget (see Exhibit 2-3). The Federal budget process involves multiple stakeholders, each working towards the fulfillment of the vision for Government set forth by the Executive Office of the President. The Federal budget process has four phases, involving actions within and between the Executive and Legislative branches. The Federal budget process follows a complex schedule, which at the highest level, involves a flow of information among the Executive Branch departments, the White House's OMB, and Congress.

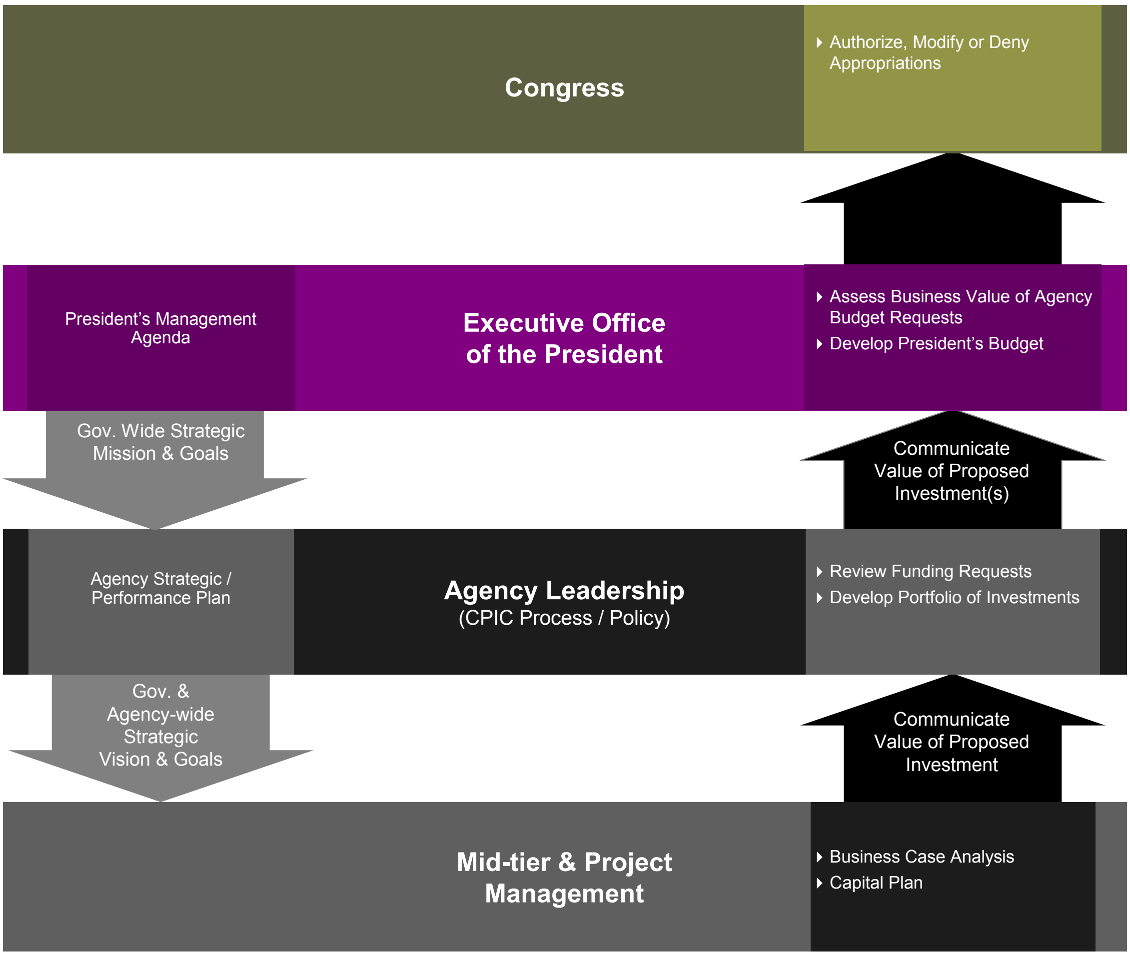


Exhibit 2-3:
Creating the President's Budget

The Federal budget process governs the operation of Federal programs and agencies. To remain in sync with the Federal budgeting process and comply with the requirements for receiving Federal/project funds, continuous, accurate, and forward-focused investment planning and analysis are required. As a current year budget is being executed, the next year's budget must be formulated and planned (see Exhibit 2-4). Development for a given year's budget starts a year and a half before appropriations are enacted. When coupled with the Executive and Legislative requirements for capital planning, the pace can be difficult to maintain. However, by establishing a sound process for capital planning, including a structured approach to cost/benefit/risk analysis, the cycle of deadlines and reporting requirements can be met while the performance of the agency is improved.

	Preparing For FY X	Preparing for FY X +1	Preparing for FY X + 2
January X	OMB prepares FY X budget documentation and forwards it to Congress	Identify Initiatives for FY X + 1	
February		Identify Alternative Solutions for FY + 1	
March	Congress reviews the President's FY X budget, develops its own budget, and approves spending and revenue bills.	Conduct and Document Capital Plan / Business Case (prepare cost estimates) for FY + 1	
April			
May			
June		Internal Review of FY + 1 Budget Requests	
July		Prepare IBPD	
August			
September		FY X + 1 IBPD submitted to OMB	
October	Execute FY X Budget	OMB Review of Budget Requests	
November		OMB Passback	
December		Appeals / Appeals Resolution	
January X + 1		OMB Prepares the President's Budget and forwards it to Congress	Identify Initiatives
February			Identify Alternative Solutions
March		Congress reviews the President's FY X + 1 budget, develops its own budget and approves spending and revenue bills	Conduct & Document Capital Plan / Business Case Analysis (Prepare cost analysis)
April			
May			
June			Internal Review
July			Prepare FY X + 2 IBPD
August			
September			FY X +2 IBPD Submitted to OMB OMB Review of Budget Requests
October - September		Execute FY X + 1 Budget	

Exhibit 2-4:
Continuous Flow of the Federal Budgeting Cycle

2.4 NASA-Specific Imperatives

NASA is constantly striving to deliver maximum results with its limited budget. It is the responsibility of the NASA cost estimating community to revitalize and enhance the current cost estimating infrastructure. This transformation is providing greater information management support, more accurate and timely cost estimates, and more complete cost risk assessments that will increase the credibility of the cost estimates that NASA cost estimating community produces, and in turn, the credibility of NASA as an agency.

The NASA cost estimating community serves to provide decision-makers throughout NASA with accurate, reliable, and defensible cost estimates. These cost estimates are one of the best tools available to meet the stated objectives of three of NASA's four crosscutting processes goals shown in Exhibit 2-5.

	NASA Cost Community Contributions to Each Goal
Manage Strategically Enable the Agency to carry out its responsibilities effectively, efficiently, and safely through sound management decisions and practices	▸ Credible cost estimates are critical to sound management decisions ▸ Collecting, managing and sharing cost data across the entire agency ▸ Protecting data from our projects and our contractors ▸ Cost trade analysis to optimize use of resources ▸ Career development plan for cost estimators
Provide Aerospace Products and Capabilities Enable NASA's Strategic Enterprises and their Centers to deliver products and services to our customers more effectively and efficiently	▸ Credible cost estimates are critical to providing effective and efficient services ▸ Provide cost estimating to technology insertion studies, analyze the economics of commercial partnerships ▸ Work synergistically with NASA's engineering capability ▸ Provide knowledge capture and implementation of cost effective best practices to support continuous improvement
Generate Knowledge Extend the boundaries of knowledge of science and engineering through high-quality research	▸ Support decision making for funding, prioritizing and selecting research projects with credible cost estimates ▸ Archive, maintain and share data ▸ Capture and share lessons learned and best practices

Exhibit 2-5:
NASA's Cross-Cutting Goals

Cost estimating has taken on a greater importance in light of all the new government legislation and guidance directing agencies to be more accountable and responsible stewards of taxpayer dollars. Whereas years ago, cost estimating was used solely as a means of getting project money (i.e., arriving at a number to plug in a budget), now its utility and power cannot be overlooked or denied. Its ability to tie costs with benefits and risks is essential for decision makers as they prepare the necessary project documentation to receive funding [e.g., OMB 300s or the NASA Integrated Budget Performance Document (IBPD)].

BUDGETING AT NASA

Exhibit 2-6 gives an overview of the performance and budgeting planning implementation process at NASA. As referenced in the FY 2004 Budget, under Business Cases for IT Projects:

"NASA has made great strides in refining its plans and processes for monitoring and reporting on its IT investments. However, only two of NASA's 14 IT business cases were judged to be adequate and not "at-risk." NASA and OMB will continue to review its IT portfolio to improve the information that NASA collects and to determine which IT investments require business cases."

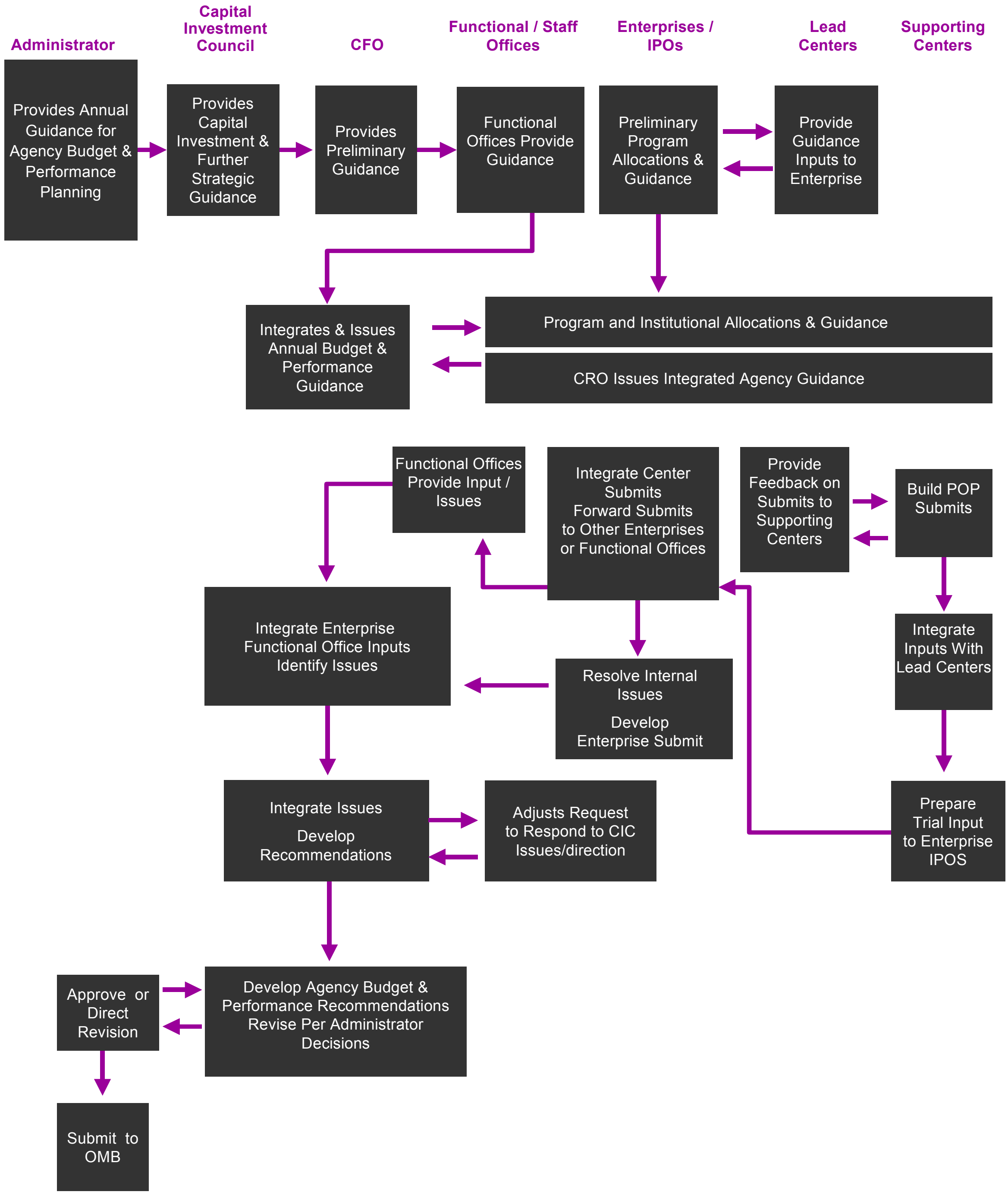


Exhibit 2-6:
NASA's Performance and Budgeting Planning

To improve NASA's performance during OMB reviews and to provide decision makers with the information they need to present projects for approval within NASA, the cost estimator works diligently with project teams to obtain the information they need to understand and estimate project costs, to document the risks and benefits of various technical investment options, and present cost information in a consistent manner.

NASA's Integrated Budget Performance Document

As required by Federal law, NASA consolidates all of its budget inputs into the IBPD, which is a new format for documenting information that is currently found in many separate places. The IBPD supplies:

- Budget information (i.e., the IBPD is the budget format),
- Performance planning and metrics,
- Commitment to proceed to development [i.e., the development sheet captures all the information of a Program Commitment Agreement (PCA)],
- Supplemental project information for OMB (i.e., OMB 300B forms), and
- Congressional submission.

How Cost Estimates Feed Into the NASA Budget

The following steps represent NASA's simplified budget development and execution process, to which cost estimates contribute.

- The Administrator and the Capital Investment Council (CIC) provide strategic guidance for Enterprises, Centers, and staff offices.
- Detailed guidance is then developed by Enterprises and Functional/Staff Offices, working with the PMs and Performing Center Directors (PCDs), and provided to the Chief Financial Officer (CFO).
- The CFO issues a single set of budget guidance annually.
- Once developed, initial budget submissions are prepared by the projects, programs, and Centers and forwarded to both the Program Managers/PCDs and the Program Office (PO).
- Final submissions should be made to the appropriate Associate Administrators (AAs).
- Functional/Staff Offices provide their assessments to the EAAs.

Cost estimating accuracy facilitates requirement submission and advocacy by responsible Enterprise and Functional/Staff Offices to the CFO, the CIC, the Administrator, the OMB, and the Congress. Implementation of final budgetary decisions, both internal and administrative, flows back down to the Performing Centers on the same path that submissions follow.

Exhibit 2-7 provides an overview of the process.

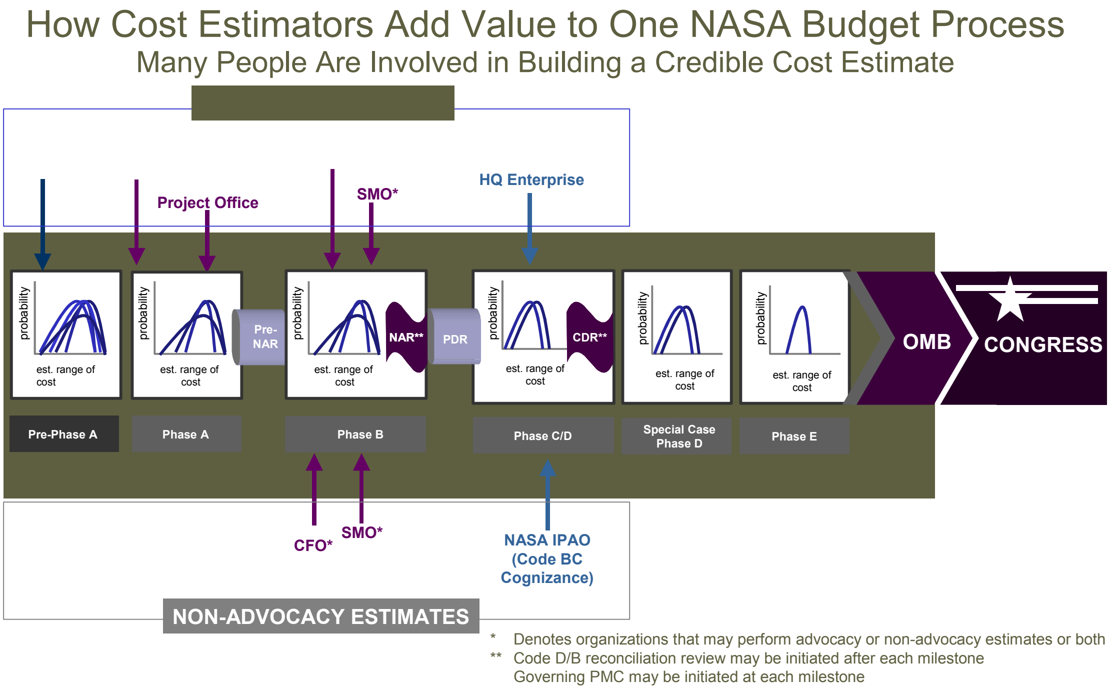


Exhibit 2-7:
The Cost Estimating and Budgeting Connection

2.5 Confidence Levels and Budgeting at NASA

As a general rule, cost estimates at NASA should be presented at the 70% confidence level. As an entire portfolio of Projects, the budget should be presented at the 80% confidence level. A discussion of the rationale behind this philosophy by Tim Anderson of the Aerospace Corporation is provided below.

> "Suppose an acquisition decision-maker desires to budget projects to the 80th percentile of their cost estimates. His goal is to ensure that projects have a reasonably good chance of avoiding cost overruns. However, by budgeting each of the projects at the 80th percentile, the decision-maker constrains the total number of projects he can have, since, if all projects are budgeted in this way, the required total budget will be larger than necessary to achieve success on a portfolio of projects.
>
> Consider a portfolio of *N* projects. Suppose that each project has a cost estimate for a given budget year or sequence of years. Suppose further that each of these cost estimates are mildly correlated and can be represented by lognormal probability distributions. A reasonable question goes as follows: 'If all *N* projects in the portfolio are budgeted at the 80th percentile, at what percentile of the total cost distribution does the sum of these budgets lie?' In general, the answer is not the 80th percentile. In fact, it can be significantly larger, say the 95th percentile or greater. After all, by definition, each project has an 80% chance of costing less than its 80th percentile.
>
> Now the question arises, 'does the decision-maker really want to budget all projects at the 80th percentile, or is it that he wants to ensure an 80% probability that his portfolio budget will not be exceeded?' The latter case seems to be the more sensible alternative. If he budgets all programs at the 80th percentile, then he ends up budgeting far more than necessary for the overall portfolio. On the other hand, if he

> wants to ensure an 80% probability that his portfolio budget will not be exceeded, then he needs to determine that percentile for each individual project, which when summed over all programs, is equivalent to the 80th percentile of the cost of the portfolio. This percentile tends to be substantially lower - near the 70th percentile - depending on the number of projects in the portfolio. That is, for a modestly sized portfolio of projects, say 10 to 20, budgeting each of them at the 70th percentile is roughly equivalent to budgeting the total cost of the portfolio at the 80th percentile. Thus, it is incorrect to budget each individual program to the 80th percentile with the goal of ensuring the total budget is at the 80th percentile.
>
> So, assuming 10 to 20 major projects in the NASA portfolio, each having lognormally distributed cost estimates with mild correlation between them, and assuming the ability to take money from healthy programs and give it to programs that are in trouble, then budgeting each program at the 70th percentile is roughly equivalent to budgeting the entire portfolio at the 80th percentile."

NASA Full Cost Requirement

To be consistent with guidance from the 1990 Chief Financial Officers Act, the 1993 Government Performance and Results Act, the 1995 NASA Zero Base Review, and the 1996 Federal Financial I Management Improvement Act, NASA initiated a full cost concept in 1995 and began budgeting and accounting in Full Cost for FY 2004. While the total of NASA budget will not change, "full cost" will increase the "sticker price" of projects. The full cost of a project is the sum of all direct costs, service costs, and G&A costs associated with the project. A description of how to account for Full Cost in a cost estimate is found in Section 6.15.

The NASA cost estimating community can help decision-makers meet NASA's strategic goals through comprehensive and accurate life cycle cost estimates that address not only costs, but also benefits and risks associated with an investment or on-going project. Using the cost-risk management techniques discussed in this handbook, direct links to an organization's strategic vision, mission, and performance can be made.

Cost Estimating at NASA

3. Cost Estimating at NASA

In the last section, the importance of cost estimating in the context of the government at large and within the NASA community was described. In this section, an overview of cost estimating at NASA is provided: its cost estimating organizations and their roles and responsibilities, its cost estimating requirements, including Project Continuous Cost-Risk Management, the cost estimating process, and the types of estimates or products the NASA cost estimating community provides, and how all of these pieces fit together.

3.1 One NASA Cost Estimating Community

NASA has institutionalized a One NASA concept, which is a fully integrated organizational operating model that encourages everyone to use NASA values in their everyday work in decision making, resource allocation, human resource practices, contractor relationships, etc. A unified approach to cost estimating decisions and processes improves the Agency's cost estimating capability and contributes to the One NASA initiative.

As illustrated in Exhibit 3-1, there are many cost estimating organizations and interfaces at NASA, from the CFO to engineers in projects that provide inputs to cost estimates. However, cost estimating may take place outside of the formal cost estimating organizations described. Some Enterprises have estimators that reside at NASA Headquarters (HQ), and many Centers have teams of estimators and engineers outside of the costing organizations that provide engineering build up estimates and estimates for proposals. Most Centers also have a Project Design Center (PDC) that helps a project develop a mission concept into a proposed mission design, covering all aspects of the project, including cost. Many times cost estimators from the costing organization at each Center are asked to participate in these concept designs. Organizational charts depicting the cost estimating functions within each NASA Center are presented in Appendix D.

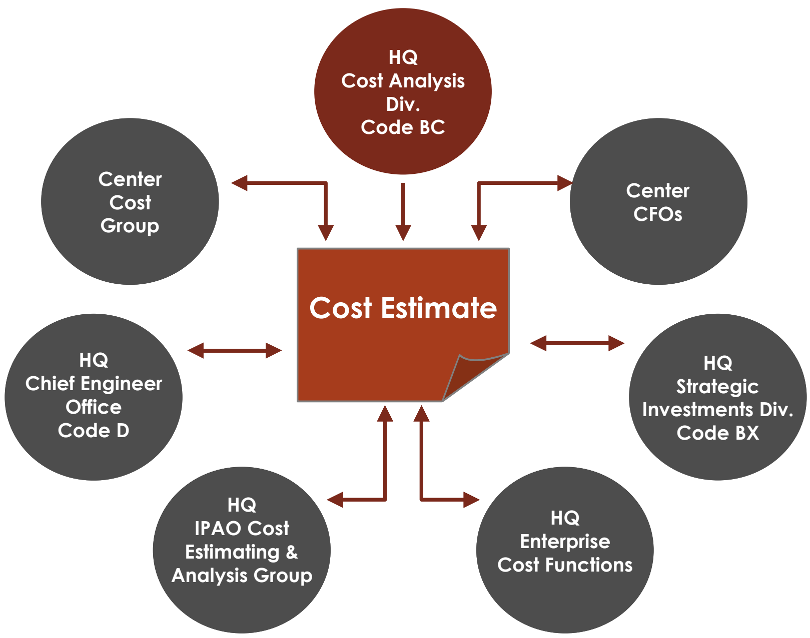


Exhibit 3-1:
NASA Cost Estimating Organizations and Interfaces

Brief descriptions of each of the major cost estimating organizations within NASA and their functions are provided below.

Agency Deputy CFO/Code B
Agency Deputy Chief Financial Officer for Resources (Comptroller)

The NASA CFO at Headquarters (Code B) is responsible for the Deputy CFO for Resources (Comptroller), located in the Office of the CFO. Code B serves as the principal administrative official for Agency funds and resources, and directs, monitors, and approves the structure of budget formulation and execution, including strategic and performance planning, cost estimating and analysis, apportionments and allotments.

Code BC- Cost Analysis Division

The Cost Analysis Division provides the capability for cost estimating and analysis within NASA Headquarters reporting to the Deputy CFO for Resources (Comptroller). This capability is critical to support ongoing budget analysis activities, and to provide leadership, guidance and policy direction for cost estimating and analysis across the agency.

Independent Program Assessment Office (IPAO)

The IPAO is responsible for independent review of NASA programs. In the conduct of the review, independent cost estimates are developed as part of review products. Furthermore, IPAO's role in cost estimating is to provide leadership and strategic planning for the cost estimation core competency by:

- Providing resources for Agency cost estimating research;
- Fostering a "pipeline" of competent NASA cost analysts; and
- Providing independent, non-advocate cost estimates and cost-benefit analyses

Cost Analysis Steering Group (CASG)

The purpose of the CASG is to strengthen NASA's cost estimating standards and practices by focusing on improving tools, processes, and resources (e.g., training, employee development). Membership in this working group is comprised of senior cost estimating analysts from each NASA Center and Headquarters. The working group is also a forum to foster cooperation, communications, and interchange in areas such as sharing models and data across Centers and implementing "lessons learned". The HQ Code BC Director serves as the Chair of the CASG. The CASG charter is located in Appendix E.

The CASG is the governing body for this handbook and provides input into many cost estimating products at NASA, including the NASA Cost Estimator's Career Development Guide (CDG). As part of the One NASA approach, Code BC has sponsored the development of a Cost Estimator's CDG with defined job categories, associated technical competencies and a core curriculum of courses by job category/career stage. For a detailed description of the Career Development Guide, see Appendix F.

NASA Center Cost Offices

Center cost offices (also called cost engineering or analysis offices) are charged with implementing Agency and Center cost estimating policy and guidance; providing tools, models, training, and other resources for more effective cost estimating at the Center. In many cases Center cost offices perform both advocacy and independent cost estimates, proposal estimates and analyses of projects at the Center level and may also support Agency level cost estimating exercises and NARs. Centers using a PDC have a cost chair where a Center cost office representative usually participates. At NASA HQ the Center cost office equivalent is the enterprise cost office.

Cost Estimating Customers

The entire NASA team and many external organizations are users of the cost estimating process described in this handbook. Their needs vary over time and among different stakeholders. Therefore, the cost estimating process must be adaptable and flexible while holding firm to the principles, objectives, and practices of cost estimating. In addition to the NASA organizations already mentioned, the following groups are involved with cost estimating:

- Enterprise Leaders have the responsibility for assessing and allocating the full cost of each project including personnel and facilities. This requires cost estimates that are consistent across the Enterprise.
- PMs require valid cost estimates on competing concept alternatives in order to support their selection between the alternatives.

- To obtain OMB and Congressional support for NASA projects, credible budget inputs are key. The POP process requires development of a five-year projection of cost as a key input to the budget process. OMB, in Circular A-11, details requirements for ensuring that performance is measured against established metrics. To support the objectives of that circular, a reasonable estimate of resources required to support each goal is essential.

The table below describes NASA cost estimating customers and their use of NASA cost estimating products.

Customer	Uses
General Accounting Office (GAO)	Oversight
Congress	Appropriations
NASA HQ (CFO/CIC)	Approval and Balancing Strategy
Enterprise Leaders	Program Cost Allocation and Assessment
Program Manager	Selection Alternatives/Meeting Commitment
Scientist/Engineer	Selecting Alternatives/Design Influence
Logistician	Logistic Planning/Design Influence
Cost Analysts	Comparing Program Cost and Analysis
Other Programs	Benchmarking Costs
IPAO	Cost Evaluation
Inspector General (IG)	Oversight

3.2 NASA Procedures and Requirements (NPRs)

Guidance provided in NASA Procedures and Requirements (NPRs) (formerly called NASA Procedures and Guidance (NPGs) shapes cost estimating at NASA. NASA project life cycle management includes six phases as shown in Exhibit 3-2. Effective life cycle management begins at Pre-Phase A, Conceptual Definition and carries through to Phase E, Operations, Support and Disposal. Early emphasis on cost estimating is critical to successful life cycle management, especially in the early pre-acquisition and acquisition phases (Pre-Phase A, Phase A, and Phase B).

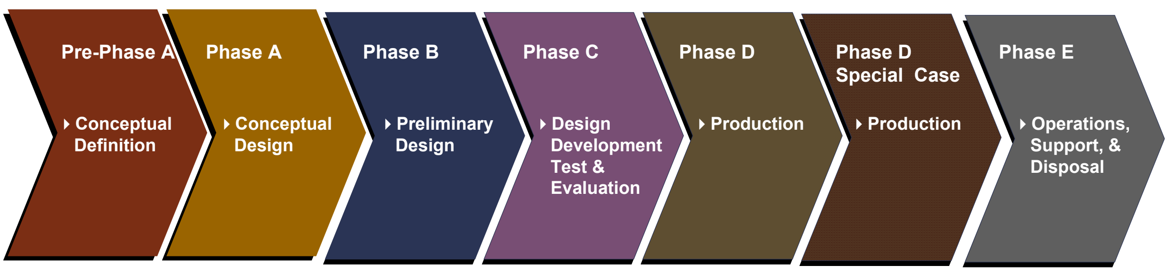


Exhibit 3-2:
The Life Cycle Project Phase

NASA Program and Project Management Processes and Requirements (NPR) 7120.5B

NASA Program and Project Management Processes and Requirements (NPR 7120.5B) covers project management guidance at NASA. NASA NPR 7120.5B establishes the management system for processes, requirements, and responsibilities for implementing NASA Policy Directive (NPD) 7120.4, Program/Project Management. This management system governs the formulation, approval, implementation, and evaluation of all Agency projects established to Provide Aerospace Products and Capabilities (PAPAC). It supports the safe accomplishment of the NASA projects, consistent with established Agency strategic planning, on schedule, and within budget, while satisfying the success criteria and requirements of multiple stakeholders and customers. As related specifically to cost estimating, this policy requires that:

- The LCC shall be developed to establish a project commitment, assessed at major reviews, and updated for each budget submission.
- The LCC shall be determined using currently available full cost accounting guidance.
- All cost estimates shall be summarized according to the current WBS and time phased by government Fiscal Year (FY).
- The LCC effects shall be projected for all major changes and submitted as a part of any formal change control request.
- Project baselines are to incorporate project management flexibility, including financial reserves, schedule margins, and technical performance margins to enable the management of risks. Financial reserves shall be established and maintained commensurate with programmatic, technical, cost, and schedule risks. These reserves include the following:
    1. <u>Allowance for Program Adjustment (APA).</u> These reserves are available for approved changes in project objectives or scope, the resolution of unforeseen major problems, project stretch-outs from Agency funding shortfalls, and similar fiscal difficulties.
    2. <u>Contingency.</u> Sufficient reserves are allocated to and managed by the PM for the resolution of problems normally encountered while ensuring compliance to the specified project scope.

NPR 7120.5B also requires that costs be fully accounted for and that the cost over the life cycle of the project are minimized. NPR 7120.5B further requires that Information Technology (IT) project investments shall be separately planned for, evaluated in terms of return on investment (ROI), budgeted, and managed.

NPR 7120.5C (Draft)

As of the publication date of the 2004 NASA CEH, NPR 7120.5C is in draft form. Please check for the most current version of NPG 7120 for guidance. The cost estimating community is participating in the development of this version and has recommended enhancements to policies and processes associated with NASA cost estimating and management. Three of the major improvements to the cost estimating process are the introduction of the Cost Readiness Level (CRL) and the Project CCRM:

- NASA CADRe provides a mechanism for capturing project cost and technical data.
- Modeled after the NASA Technical Readiness Level (TRL) scale, CRLs are designed to communicate the quality of the cost estimate by designating an associated CRL for each cost estimate to be funded in the POP (see Section 6.1 for the CRL scale and description).
- Traditionally discrete cost activities are transformed into a continuum of activities linked together by risk.

Feedback is the essential element transforming cost management into a dynamic, continually reacting system where focused reporting of high-risk drivers and metrics alert the PM that a negative cost trend has been identified and requires action. Project CCRM is presented in three main stages as captured in Exhibit 3-3. Below the exhibit, a high-level roadmap describes the Project CCRM activities and participants. Each of these activities is explained in greater detail in Section 4.

Traditionally, NASA cost estimating focused on deterministic estimates, sometimes without incorporating the cost impacts due to risks. Cost-risk estimation is the quantification of cost impacts due to risk. Although the discipline of cost-risk estimation has been at times incorporated into producing cost estimates, the concept of setting up, getting, and using cost-risk feedback throughout the continuum of costing activities has not been institutionalized.

Exhibit 3-3: Project CCRM

The focus of Project CCRM is the process of using cost-risk feedback for improved project management. It involves first setting up a cost-risk baseline. Next, potential system developers have to know what, how often, and in what form to provide cost-risk feedback, so directions must be provided in the Request for Proposals (RFPs) and project plans. Finally, the cost estimating staff supporting the government PM produces quantified projections of potential final outcomes of contract and project costs. Through data generated by Project CCRM, the PM has an improved capability to make more fully informed risk management decisions. By increasing the frequency of cost-risk feedback analysis and evaluation, the PM can maximize corrective recovery actions in keeping the project's costs on track.

Presented below are the 12 generally held tenets of NASA cost-risk. These tenets are intended to convey what the NASA cost estimating community fundamentally believes about cost-risk assessment and underpins its implementation.

THE 12 GENERAL TENETS OF NASA COST-RISK

1. **NASA cost-risk assessment, a subset of cost estimating, supports cost management for optimum project management;**
2. **NASA cost-risk assessment is based on a common set of risk and uncertainty definitions;**
3. **NASA cost-risk assessment is a joint activity between engineers and cost analysts;**
4. **NASA cost-risk assessment is composed of cost estimating relationship (CER) and technical risk assessment plus cost element correlation assessment;**
5. **NASA technical cost-risk assessment combines both probabilistic and discrete technical risk assessments;**
6. **NASA cost-risk probability distributions are justifiable and correlation levels are based on actual cost history to the maximum extent possible;**
7. **NASA cost-risk assessment ensures cost estimates are "likely-to-be" vice "as specified" for optimum credibility;**
8. **NASA cost-risk assessments account for all known variance sources and include provisions for unknown sources;**
9. **NASA cost-risk can be an input to every cost estimate's CRL;**
10. **NASA cost-risk integrates the quantification of cost-risk and schedule risk;**
11. **NASA decision makers need to know:**
    a. How much money is in the estimate to cover risk events;
    b. To which WBS elements are the risks allocated; and,
    c. The likelihood of an overrun.
12. **NASA project cost-risk data, collected as a function of government and contractor project estimates, contract negotiations, and contract data requirements descriptions (DRDs), is compiled into the One NASA cost estimating (ONCE) data base.**

Exhibit 3-4 illustrates the relationship of CCRM to the NASA life cycle phases. In Pre-Phase A, all activities are associated with the steps in the Set Up stage of Project CCRM and gradually move to the getting and using stages in the remaining phases. The steps in the Set Up stage identify the risks on which data collection and production is focused for use in the second and third stages of the Project CCRM.

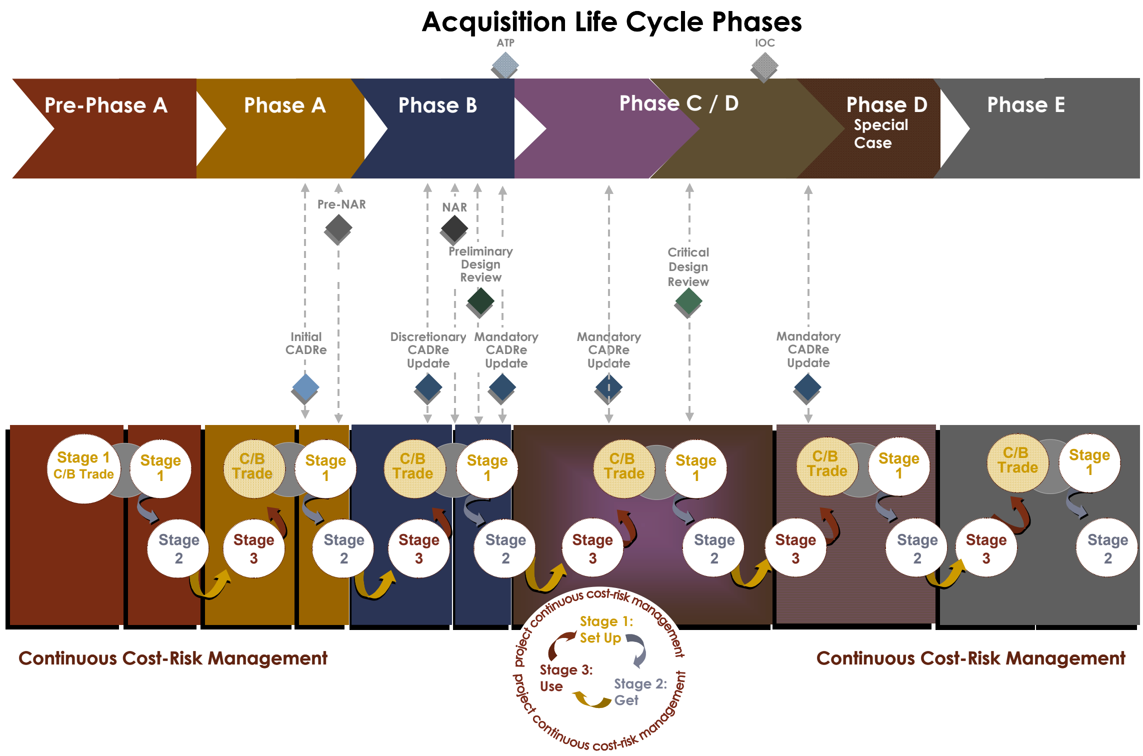


Exhibit 3-4:
Pulling it Together

The following is a high-level description of the activities and participants of Project CCRM. Section 4 provides greater detail for each of these activities.

Stage 1: Set Up
The overarching goal of Stage 1 is to establish the baseline and mechanisms required to manage and control project costs and risks.

Steps: There are five primary steps associated with this Stage:

1. Perform cost/benefit trade studies [e.g., Cost as an Independent Variable (CAIV), etc.].
2. Build requirements/ function/ WBS matrix [i.e., creating the NASA Cost Analysis Requirements Description (CADRe)].
3. Develop a reference point cost and schedule estimate.
4. Assess WBS element risk.
5. Translate risk into cost/schedule impacts.

Participants: Participants in this stage are mainly cost estimators, project engineers, and PMs.

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Stage 2: Get
During Stage 2, NASA personnel must work to ensure that:

- Cost performance data will be via standard reporting mechanisms to manage risk and cost-risk at the source level of risk-regardless of where in the WBS element structure the risk is located.
- Related reports (e.g., risk management, technical performance measures, etc.,) are consistent with cost performance data and that LCCs are updated at least annually.

Steps: There are three primary steps associated with this stage:

6. Develop EVM, LCCE, Risk and CADRe RFP DRD's.
7. Review cost proposal during source selection.
8. Participate in post-contract award meeting. This is a key bridging event in the process.

Participants: Participants in getting cost-risk feedback are the PMs, cost estimators, project engineers, procurement analysts, and EVM specialists.

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Stage 3: Use
During Stage 3, the information requirements established in Stage 2 are used to manage risks and cost-risks. For example, the cost-risk feedback received from the cost performance measurement system may indicate trends in a WBS element that had been identified as a risk source in Stage 2 above and drive the need for a follow on cost/performance trade study as conducted in Stage 1 of CCRM.

Steps: There are four primary steps associated with this stage:

9. Manage the project using cost-risk feedback data (e.g., EVM Cost Performance Reports (CPRs), S-curve, Technical Performance Measures (TPMs), Schedule risk and critical path analysis, etc.)
10. Update LCCE (CADRe) and Cost / Schedule Risk Assessment.
11. Compile end-of-contract cost-risk data for evaluation and analysis.
12. Assess data for model and database updates (CADRe and ONCE).

Participants: PMs, project engineers, and EVM specialist are the primary users of cost-risk feedback. Cost estimators remain involved during this Stage to update total project estimates, "S"-curves, databases and/or cost models, or to re-visit cost/performance trade studies.

CCRM does not end with project handover to the customer or operator. Throughout Stages 1, 2 and 3, an emphasis exists on balancing and managing the cost-risks, including operational risks. Feedback in Project CCRM is especially effective when it shapes near-term, up-front decisions that have an impact on what may be decade's long operational consequences.

The cornerstone of CCRM is the cost estimating discipline. The focus of this document now shifts to the cost estimating process with CCRM "connections" being made only to emphasize how risk and cost-risk relates to the cost estimating process.

3.3 The Cost Estimating Process

Exhibit 3-5 depicts the NASA cost estimating process as a wheel, illustrating that the entire process is continuous and iterative throughout the life cycle phases and Project CCRM. During any process, it is easy to fall into the trap of performing each stage sequentially: ignoring or avoiding critical insights that may require a re-examination of an earlier stage, cutting off a stage prematurely, or not taking advantage of conducting stages in parallel. The 12 tasks of the cost estimating process have been grouped into three parts: Project Definition, Cost Methodology, and Estimate. Each of these parts is explained as they manifest themselves in each of the life cycle phases in greater detail in Section 5. Presented below Exhibit 3-5 is a high-level roadmap of the cost estimating process tasks.

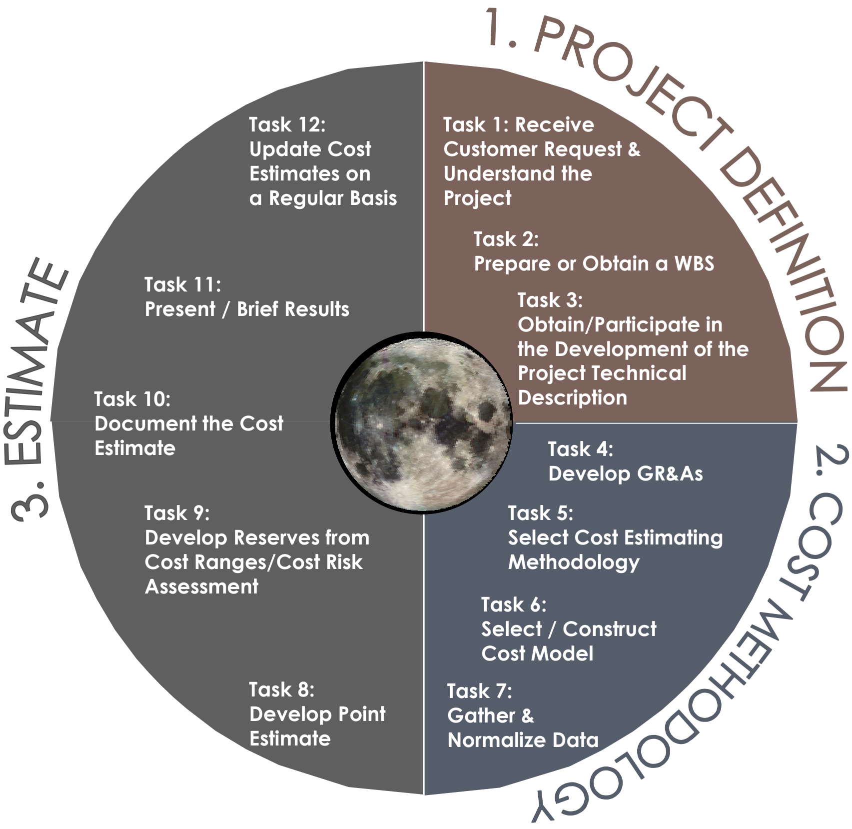


Exhibit 3-5:
The Cost Estimating Process

Cost Estimating Process Tasks

Task 1: Receive Customer Request and Understand the Project

The goal of this task is to interface sufficiently with the customer to gather enough project information to generate an accurate estimate.

Activities: There are three activities associated with understanding the project.

1. Gather all relevant project data for evaluation. Discuss schedule, data, expectations, and resource requirements with the requesting customer. If an estimate has been conducted for this product before, review and incorporate lessons learned from the last effort.
2. Evaluate the project's mission needs, objectives, and goals and assess the operating environment and life cycle phase for the project within the context of the NASA enterprise architecture.
3. Review all related project documentation, including an existing technical baseline or CADRe, previous estimates, budget data and programmatic data such as schedules.

Participants: Participants in this task are mainly cost estimators, PMs, and project engineers. Other participants that provide data could include budget analysts and acquisition specialists.

Task 2: Prepare or Obtain a Work Breakdown Structure (WBS)

The objective of this task is to provide a consistent structure that includes all elements of the project the cost estimate will cover.

Activities: There are three activities associated with preparing or obtaining a WBS:

1. Determine if a WBS exists or work with the project to create.
2. Create a WBS Dictionary to define the WBS elements.
3. Ensure that the cost estimating WBS is consistent between functions such as budgeting, weight statements, EVM, project plan, System Engineering Master Plan (SEMP), contracts, Integrated Financial Management (IFM), etc., to enable improved cost estimation, future data collection, and performance measurement and management.

Participants: Participants in this task are mainly cost estimators, engineers, and the PM.

Task 3: Obtain or Participate in the Development of the Project Technical Description

The objective of this task is to establish a common baseline document used by the project team to develop its estimates.

Activities: There are two activities associated with developing or obtaining a project technical description:

1. Describe the level two or lower system characteristics, configuration, quality factors, security, its operational concept, and the risks associated with the system for use by the cost estimator.
2. Describe the system's (or the project's) milestones, schedule, management strategy, implementation/deployment plan, test strategy, security considerations, and acquisition strategy.

Participants: Participants in this task are project engineers, PM, and the cost estimator.

Task 4: Develop Ground Rules and Assumptions (GR&A)

The objective of developing GR&A is to communicate the context/environment within which the estimate is being developed.

Activities: There are three activities associated with developing the GR&A:

1. Establish a set of programmatic, technical, and schedule GR&A to define the scope of the estimate (i.e., what costs are being included and what cost are excluded).
2. Achieve consensus on the GR&A with stakeholders, vendors, end users, etc., to ensure their applicability
3. Fully document the GR&A.

Participants: Participants in this task are the NASA PM and his/her staff, stakeholders, and the cost estimator.

Task 5: Cost Estimating Methodology

The goal of this task is to select the best cost estimating methodology (or combination of methodologies) for the data available to develop the most accurate cost estimate possible.

Activities: There are four activities associated with selecting the cost estimating methodology:

1. Determine the type of system being estimated.
2. Determine the life cycle phase of the project.
3. Determine the availability of data.
4. Select the methodology(ies).

Participants: The participants for this task are the NASA or contractor cost estimators.

Task 6: Select/ Construct Cost Model

The objective of this task is to select the most appropriate tool/model or to create a model to estimate the cost. Factors that influence the selection process include data and resource availability, schedule, and cost.

Activities: There are three activities associated with selecting or constructing a model.

1. Review available choices and make a selection. If no suitable alternatives exist, explore the option of creating a model.
2. Be prepared to defend the choice.
3. Ensure that the model is full cost compliant.

Participants: For this task, NASA cost estimators and/or contractors are the participants.

Task 7: Gather and Normalize Data

Data collection is one of the most difficult, time-consuming, and costly activities within the cost estimating discipline. The objective of this task is to arm the cost estimator with as much information as possible so that he/she can develop the most accurate and justifable cost estimate.

Activities: There are four activities associated with gathering and normalizing data.

1. Identify data needed and potential data sources.
2. Review, interview, and/or survey data sources to obtain data.
3. Conduct project schedule analysis.
4. Normalize data.

Participants: The participants for this task are the NASA cost estimators, stakeholders, the PM, schedule analysts, and members of the technical team.

Task 8: Develop Point Estimate

The goal of this task is to create an accurate LCC point estimate to be used in conjunction with the cost risk assessment to develop the final estimate.

Activities: There are eight activities associated with developing a point estimate.

1. Populate model with the normalized data collected.
2. Verify the GR&As.
3. Ensure the estimate is full cost compliant.
4. Run the model to calculate cost.
5. Time phase the estimate.
6. Adjust for inflation.
7. Conduct any cross check estimate or estimate reconcilation.
8. Develop or update cost track to previous or independent estimate.

Participants: The participant for this task is the NASA cost estimator.

Task 9: Conduct Develop Reserves from Cost Ranges/Cost Risk Assessment

The objective of this task is to produce a credible project cost "S"-curve - that is, the CDF for the range of costs of the project. This task also allows the cost estimator to document risks in a manner that accommodates proactive management of project costs.

Activities: There are six activities associated with conducting the cost risk assessment.

1. Determine the project's cost drivers with input from the PM and staff.
2. Develop probability distributions for the cost model uncertainty.
3. Develop probability distributions for the technical and schedule cost drivers.
4. Run Risk Model.
5. Identify the probability that the actual cost is less than or equal to the point estimate.
6. Recommend sufficient reserves to achieve the 70% confidence level.

Participants: The participants for this task are the NASA cost estimator, the PM, and staff.

Task 10: Document the Cost Estimate

The objective of this task is to capture, in a continuous fashion, from project initiation through completion, the LCC results of the cost estimating process and the CCRM, and all of its by products (confidence levels, CRL, risk reserves).

Activities: There are three activities associated with documenting the cost estimate.

1. Document the LCC.
2. Determine the quality of the cost estimate, its fitness for use and its CRL (see Section 6.1).
3. Conduct peer review.

Participants: The participants for this task is the NASA cost estimator.

Task 11: Present / Brief Results

While it may not be realistic to standardize the content and format of the cost estimating briefing charts across all NASA Centers for all estimate types, an objective of this task is to promote the quality of the cost estimating and analysis documentation by advocating consistency across and in Centers.

Activities: There are three activities associated with presenting/briefing results.

1. Create briefing materials and supporting documentation to be used for internal and external presentations as appropriate. (See Appendix I).
2. Present and defend the estimate.
3. Gather from customers and provide feedback to capture improvements for the next estimate.

Participants: The participants for this task are the NASA cost estimator, the PM, project stakeholders, and decision-makers.

Task 12: Update Cost Estimate on a Regular Basis

The purpose of updating the cost estimate is to defend the estimate over time, to reduce updated estimate turn-around time, and to give decision-makers a clearer picture for major decisions or "what if" drills.

Activities: There are three activities associated with updating the cost estimate on a regular basis.

1. Obtain and assess customer feedback and conduct a lessons learned analysis upon estimate completion and incorporate this feedback into the next version of the estimate.
2. Update estimate when project content changes and as the project moves through its life cycle phases/milestone reviews.
3. Use and update the estimate for feedback into the budget and Earned Value Management System (EVMS) and capture the estimate data for future estimates.

Participants: The participants for this task are the NASA cost estimator and the PM.

3.4 Cost Estimating Products

So far, this chapter has described who at NASA is responsible for cost estimating, what guidance exists within NASA for the cost estimator, including the activities and participants associated with Project CCRM, and the cost estimating process that is followed. The following section details the types of estimates conducted at NASA and NASA cost estimating products generated in support of this function.

Project Life Cycle Cost Estimate (LCCEs)

A Project LCCE is developed to ensure that costs are fully accounted for and that each project's LCC is minimized. The life cycle of a project equals its total life, beginning with mission feasibility and extending through operation and disposal or conclusion of the project. The Project LCCE should be comprehensive and structured to identify all cost elements. As members of the product or project design team, cost estimators prepare a project LCCE by translating the technical and design parameter characteristics and schedules into cost estimates using established cost estimating methodologies. Iterative and on-going reviews are conducted with the technical team during the design process until the cost estimator and the project management team is confident that the cost estimate credibly reflects the baseline project's design requirements, technical capabilities, management structure, and operational scenarios. Then, the project LCCE becomes the basis for the project's budget baseline.

What is a Project LCCE?

A full cost accounting of all resources necessary to design, develop, deploy, field, operate, maintain, and dispose of a systems over its lifetime.

Independent Cost Estimates (ICEs)

The ICE is based on the same project definition documentation (technical baseline or CADRe) as used for the Project LCCE --including life cycle, WBS, and phase. However, this estimate, including the data sources and cost estimating approaches, is intentionally independent from the LCCE. NPR 7120.5C identifies the types, purpose, and frequency of these independent reviews. The independent review team develops an ICE to provide an alternative assessment of the project's LCCs.

What is an ICE?

ICEs are LCCEs prepared as a result of an independent review of a project.

Non-Advocate Review (NAR)

The approval sub process for selected projects must include a NAR. A team, led by the IPAO, comprised of individuals outside of the project's advocacy chain, conducts a NAR. A Pre-NAR is conducted when the project is moving from Phase A to Phase B. A NAR is conducted when a project is moving from Phase B to Phase C.

What is a NAR?

A NAR is an independent verification of a candidate project's plans, LCC status, and readiness to proceed to the next phase of the life cycle.

Independent Annual Review (IAR)

An IAR provides:

- An assessment of progress/milestone achievement against original baseline,
- A review and evaluation of the cost, schedule, and technical content of the project over its entire life cycle,
- An assessment of technical progress, risks remaining, and mitigation plans, and
- An identification of any project deficiencies that will result in revised projections exceeding predetermined thresholds.

What is an IAR?

An IAR validates conformance to the Program Commitment Agreement (PCA) and provides the status and performance of the project to the NASA Program Management Council (PMC).

Cost Estimate Reconciliation

During the cost estimate reconciliation process, estimators examine estimates for completeness, analyze similarities and differences, and resolve problems of duplication or omission. Estimate reconciliation may results in a synthesized cost estimate or leave two estimates at different values with a documented set of differences. If the estimate cannot be synthesized, the estimates are brought forward for higher-level adjudication.

What is a cost estimate reconciliation?

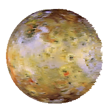
A cost estimate reconciliation is a comparison or reconciliation of competing estimates (e.g., a project LCCE and an ICE) that are based on the same NASA CADRe

Announcement of Opportunity (AO) and NASA Research Announcement (NRA) Proposal Estimates

Selections through proposals can, involve multi-million dollar budgets for the largest projects. These proposals are usually are awarded through contracts, to Centers, industry, non-profit organizations, and occasionally through grants. Many NASA Centers have developed proposal tools and templates to help expedite the development of an AO proposal estimate for these quick turnaround efforts, with the contractor supplying much of the data needed to support a proposal estimate.

What are AO and NRA proposal estimates?

An AO and a NRA proposal estimate responds to unique research investigation opportunities.



AO Proposal Estimates

RFPs are used to procure an item competitively, at almost any level of cost from a few thousand dollars to many millions. AOs are generally used for medium cost projects that are less well defined or more experimental than items procured with RFP, and price of the proposal is an important criteria. These procurements are also usually used to buy science, not necessarily a spacecraft. The goal in NASA source selection is to determine which proposal offers the "best" science for the least risk. AOs are usually cost-capped missions, so price is not a consideration, as long as it's below the cap. NASA owns the spacecraft/instruments developed, and the science data obtained, which is always made available to the public. NASA ICEs of each AO give a measure of risk and chance of success to assist in the proposal evaluation process.

NRA Proposal Estimates

NRAs are low cost investigations and generally of three types: (1) incremental advancement of technology (AITP, AIST, IIP programs) (2) sub-orbital programs, where science instruments are built and installed in one of our research aircraft to obtain specific science data (TRACE-P) or (3) science research in which scientists are provided funds to develop algorithms which will analyze data that is in our DAAC archives (data from TERRA, AQUA, JASON, TRMM, etc.), and develop models to better understand and predict events such as weather, tornado development, etc. NRAs are usually treated as grants, and the money is usually spent on the scientist's time, and high-powered computer equipment. NRAs in general have no required deliverable; a report is usually provided, papers are written, etc. NASA ICEs of each NRA give a measure of risk and return on investment to assist in the evaluation process.

Other NASA Cost Estimates

Other analysts at NASA such as resource, budget and EVM analysts also provide cost estimates. These estimates may employ different approaches and procedures than outlined in this CEH. Generally these estimates do not appear in the products listed above. These estimates are generally conducted in support of a budget, contract negotiations, or engineering change proposals (ECPs).

Independent Government Cost Estimate (IGCE) Considerations

The preparation of an IGCE in support of a NASA procurement should proceed like any other well prepared independent cost estimate (ICE). However, there are some key differences. These differences are driven by the unique nature of the government procurement process. To assist the estimator in preparing the IGCE, the following is a list of some of the key differences in an IGCE.

The IGCE is a product of the Source Evaluation Board (SEB). They are not only the customers, they are the owners. Therefore, the cost estimator has to do what they tell him or her.

The IGCE is used to judge the validity of the proposer's estimates. Therefore, much attention will be given as to how the estimate will align with the proposer's estimate and the adequacy of the models for estimating the work to be proposed.

The IGCE can only address the work outlined in the RFP's Statement of Work (SOW). Anything that is not specifically asked for in the SOW cannot be included in the IGCE. This means that the estimator must fight their natural tendency to capture all of the costs associated with a program or project.

The IGCE must be estimated from the proposer's (contractor's) point of view. The contractor's point of view will be that no changes will be made to the work as described in the SOW. Also, the proposer will assume that all technical challenges will be met and overcome as outlined in their proposal. This means that the estimator cannot account for design problems or contingencies (if not specifically address by the proposer).

3.5 Project Category Overviews

This section briefly describes how NASA determines Programs and Projects categorizations. Project Category (I-III) determines the governing PMC body and the review thresholds at NASA. Project Categorization Schema are shown below.

		Cost		
		C < \$100M	\$100ms C > \$250M	C ≥ \$250M
	High			
	Moderate			
	Low			

For Project development activities, C = life cycle costs. For Project activities in which LCC is not appropriate, C = total expected investment (or 5 year investment for activities running more than 5 years.) All values reflect full costs.

CATEGORY DEFINITIONS/PROJECT CATEGORIES:

Categorization	Definition / Characteristics	Governing PMC
Category 1 (Cat. 1) MAJOR PROJECT	▸ Projects with LCC >$250M that are considered high or moderate risk. ▸ Projects with $100M < or LCC< $250M that are considered high risk. ▸ Projects with $100M < total investment or < $250M that are considered high risk.	Agency PMC
Category 2 (Cat. 2) MODERATE PROJECT	▸ Projects with total investment > $250M that are considered low risk. ▸ Projects with $100M < total investment or < $250M that are considered moderate risk. ▸ Projects with total investment < $100M that are considered high risk.	Enterprise PMC
Category 3 (Cat. 3) SMALL PROJECT	▸ $100M < total investment or < $250M that are considered low risk. ▸ Total investment < $100M that are considered moderate or low risk.	EPMC, may delegate to Center PMC

Cost Estimating Process Tasks and Project CCRM by LCC Phase

4. Cost Estimating Process Tasks and Project CCRM Stages by Life Cycle Phase

In this section, the twelve tasks in the cost estimating process are described in relationship to each of the six phases of the project life cycle. This section focuses on high-level information in the context of the process. Details about how to conduct each task within the cost estimating process are provided in Section 5. Exhibit 4-1 illustrates that the life cycle phase influences the type of estimate required, which organizations get involved, and the exit criteria. In this section, the overall objectives, issues and challenges, roles and responsibilities, and exit criteria for each of the six NASA life cycle phases are described as well as the Project CCRM's "connection" to each life cycle phase in regards to how the CCRM Stages support the three major parts of the cost estimating process. The Project CCRM has been created to ensure that the links between phases and the data gathered in each phase are used to make the project stronger in the next phase. As shown in the Exhibit, the CRL can be influenced by the project life cycle phase.

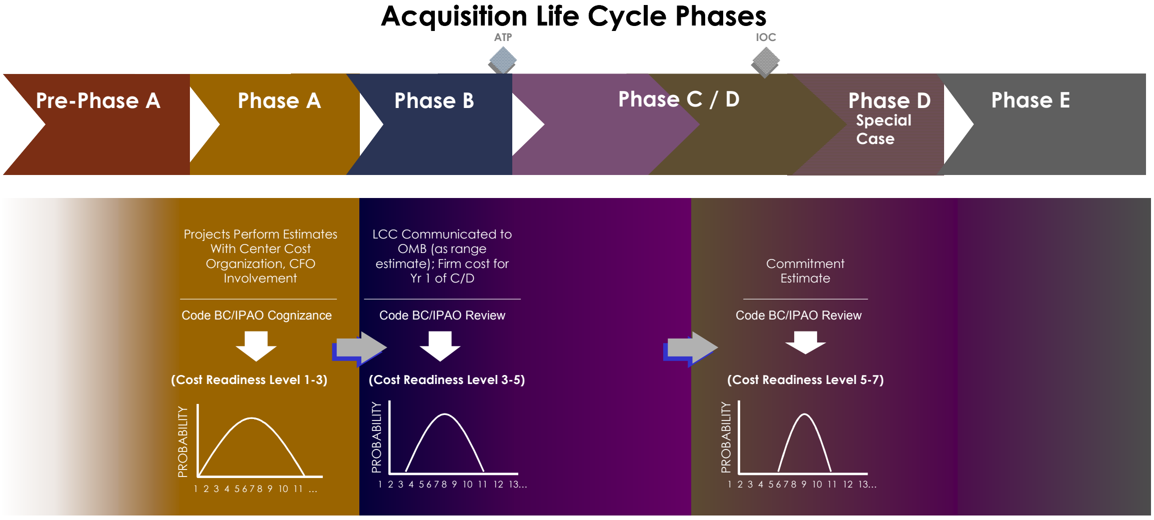
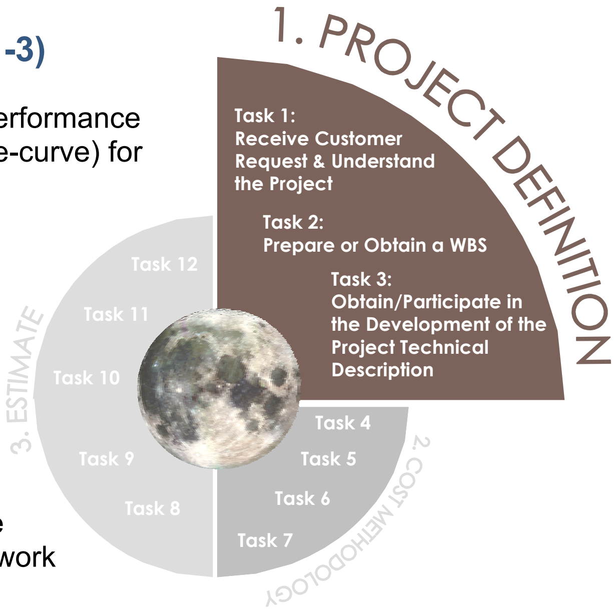


Exhibit 4-1: Life Cycle Influence

This section does not have to be read from beginning to end. Instead it can be approached by reading about the life cycle phase in which you find your project for which you are conducting your estimate. This section is the "wisdom" of the handbook that should help give you an overview and answer questions from the perspective of a seasoned cost estimator. The "how to" details of each step can be found in Section 5.

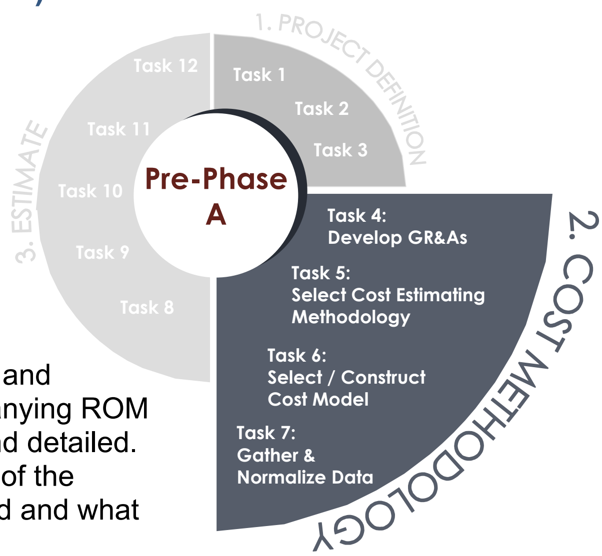
4.1 Pre Phase A: Conceptual Definition

PROJECT DEFINITION (COST ESTIMATING PROCESS TASKS 1-3)



Determining the optimum combination of performance levels and cost (i.e., finding the "knee-in-the-curve) for each conceptual alternative will allow comparison between them for alternative selection and entry into Phase A. While conducting rough order of magnitude (ROM) estimates, the estimator is gaining an *understanding of the project concept*, building a very high level *WBS* to estimate to, and collecting any technical requirements into a high level *technical baseline* for each concept. At this point, however, a formal NASA CADRe is not required but using the CADRe framework is recommended.

COST METHODOLOGY (COST ESTIMATING PROCESS TASKS 4-7)



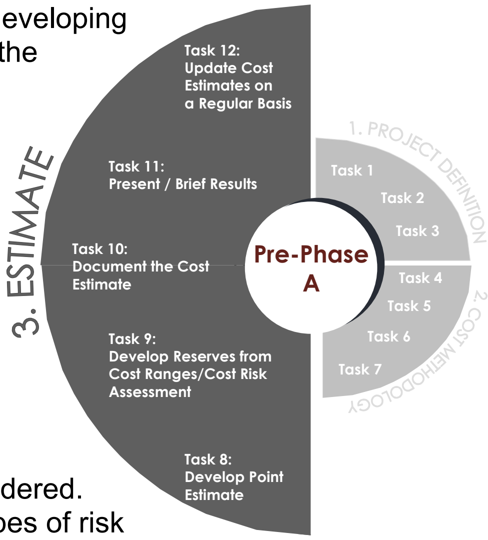
These Pre-Phase A ROM estimates, which explore different concepts, are generally very high level and quick turnaround. While conducting each of these ROM estimates, the estimator needs to be sure to *document the GR&A*, *select the cost estimating methodology*, *select or construct the model*, and *gather and normalize data*.

In Pre-Phase A, there are many unknowns and therefore, the list of *GR&A* for the accompanying ROM LCCE is critical and expected to be long and detailed. These GR&A are used to define the scope of the estimate (i.e., what costs are being included and what cost are excluded).

In Pre-Phase A, it is most probably too early in the project to have actual cost or performance data; therefore data from similar projects must be used to predict the cost. Keeping this in mind when a *cost methodology* is selected, the most effective cost estimating methodology is either a parametric or analogy cost methodology. Once an estimating methodology has been selected, a *model should be selected or constructed* to conduct the estimate. A model used in Pre Phase A should facilitate the high-level, quick turn-around estimates and should support multiple estimates and "what-if" drills. The tools selected for estimate development in Pre-Phase A can include parametric cost models and the use of spreadsheets. For more information on selecting a model and information on existing models and tools, see Appendices L through U.

In Pre-Phase A, the *data gathering* exercise is limited by the availability of data, time, and resources. Given the conceptual nature of the system under study and likely use of analogous or parametric methodologies, cost estimators should focus on utilizing existing parametric models (e.g., PRICE, SEER, NAFCOM, USCM, etc.,) and obtaining the technical input variables these models require.

THE ESTIMATE (COST ESTIMATING PROCESS TASKS 8-12)



Generating a point estimate is just the beginning of developing the estimate (tasks 8 through 12). Once generated, the point estimate needs to be allocated across the appropriate time period (i.e., properly time phased), taking into account the planned execution schedule. See Section 5.8 for details.

Even as early as Pre-Phase A, it is important to capture risk in cost estimates, especially technical, schedule, and risk data. It may be too early to conduct an in-depth risk analysis, but there are many risks that can and should be identified and addressed in a high-level *cost risk assessment*. Cost estimating uncertainty, technical input variable uncertainty, and correlation risks all need to be considered. Schedule risk can be handled outside these three types of risk by applying probabilistic activity duration risk to the critical path analysis (CPA). Most scheduling software has this capability in which discrete durations used for CPA are transformed into duration distributions by which a CPA produces the proportion of time activities that appear on the critical path. This procedure produces a more realistic picture of the true critical path. This time-based schedule information can then be translated into cost estimates for comparison with the cost-risk results above. Once data is captured during interviews with project engineers, a commercially available risk analysis tool is the best way to conduct a risk assessment during Pre-Phase A.

Documenting this total time phased, risk adjusted, full cost estimate is a challenge in this early phase but is essential to the success of the project. The nature of these multiple ROM estimates generally do not call for volumes of documentation, however; it is important that the GR&A, data sources, methodology, CRL, and the risk assessment are documented to increase credibility and facilitate information sharing, and to make these estimates usable in the future. During this Phase, documentation may include activities such as adding notes to an Excel spreadsheet to increase the repeatability of the estimate in the future or providing a write up to a decision maker to help them understand the ROM estimate details from the multiple "what-if" scenarios you provided. Historically, some of the most informal estimates have ended up being used in the most formal budget formulation documents.

The cost estimator should be prepared to *present and defend the estimate*. Using the front-end briefing template that can be found in Appendix I also provides the decision maker with a familiar format with clearly defined key factors, even in the early Pre-Phase A estimates. Especially during Pre-Phase A when the project is evolving and changing frequently, it is important to *update the cost estimate* often. Keeping the estimate and its documentation up- to-date helps to defend the estimate, reduce updated estimate turn-around time, and gives the decision-maker a clearer picture for "what if" drills and major decision making.

Pre-Phase A Conceptual Definition

Pre-Phase A activities uncover, invent, create, concoct and/or devise a broad spectrum of ideas and alternatives for missions from which new projects (programs) can be selected. This phase consists of loosely structured examinations of new ideas, usually without central control and mostly oriented toward small studies. Its major product is a stream of suggested projects, based on the identification of needs and the discovery of opportunities that are potentially consistent with NASA's mission, capabilities, priorities, and resources.[1] In this phase, the system or product configuration is generally in concept development and therefore, Pre-Phase A is characterized by intense early cost/performance trade analyses between requirements and costs. Pre-Phase A is also a time of early project definition of multiple options, with the development of the initial WBS and project technical description.

Pre-Phase A Overall Objectives

Investments need to contribute directly to an organization successfully meeting its mission. Working closely with the project technical staff to examine the costs, benefits, and risks associated with making an investment, the overall objectives in Pre-Phase A are to determine the best solution to meet NASA's mission, goals, and objectives within its cost, technical performance, and risk tolerance baselines. This is done by conducting and analyzing ROM LCC estimates, by establishing performance metrics, and by analyzing benefits and risks. At this phase, a ROM estimate(s) should be sufficient for planning purposes, including budgeting, and more responsive to the PM, who does not have the resources or time to develop a precise estimate that might not even be possible given the number of assumptions and uncertainties associated with this phase. The cost estimator must also work with the PM to establish the cost risk margin(s) that are broad enough in range to account for the level of uncertainty and to ensure that the CRL reflects this uncertainty. Establishing the estimate's CRL during this period is critical in communicating the maturity of the estimate to decision makers.

Pre-Phase A Roles and Responsibilities

The role for the cost estimator in Pre-Phase A is to understand the key engineering performance parameters (KEPPs)[1] so as to develop ROM cost estimates (ranges preferred) for different levels of KEPP expectations. The concept developer, ordinarily within a Performing Center, begins developing a concept using a core team including designated cost personnel from Supporting Centers as required. The resulting concept will be submitted to the NASA Enterprise Office for review. Funding estimates are generated parametrically, using aircraft and historical space data, and tools such as NAFCOM, PRICE, and SEER[2]. The funding estimate often will be part of a submission of a technology or idea that supports the space launch portion of the NASA Strategic Plan. If acceptable to the NASA EAA and CFO, a NASA project is initiated using a Program Formulation Agreement (PFA). The PFA establishes, among other things, resource estimates, cost risks, contingency reserves, and related relevant requirements. The funding estimates become part of the 5-year budget cycle, and identify program-funding levels for the budget year two years out.

The cost team working with the project is responsible for preliminary cost estimates and cost support for conceptual design activities. The Enterprise, IPAO, and Code BC will primarily maintain cognizance in Pre-Phase A with Code BC providing strategic guidance for cost estimating processes to include assessment of risk for cost impacts.

The following list describes some of the issues and challenges faced by NASA cost estimator during this life cycle phase:

- Variable and early definition of requirements.
- Project content not fully captured and reflected in cost estimate (e.g., ground systems, software, etc.)
- Optimism in schedule, technology and acquisition strategy planning.
- Not fully accounting for the risks.
- Over-optimism in hardware/software reuse.
- Going external with cost too early or without a correctly specified CRL.

Pre-Phase A Exit Criteria

The decision to proceed into Phase A will be made on the basis of technical feasibility, desirability, and affordability of the ideas derived from these early concept definition trade studies and cost estimates. In-house estimate reviews are conducted at the discretion of the Project Office, and may include review of prime hardware contractor input. Each major concept update requires an acceptance decision. Each review of data prior to a NAR requires PM acceptance of cost as part of the whole concept. The PM must take into account overall budget constraints, cost, schedule, and technical risk, and cost realism, reviewed as one requirement of the overall design requirements. These PM reviews are the key to successful concept selection and success at the NAR/project approval reviews

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1 *The Technology Puzzle: Quantitative Methods for Developing Advanced Aerospace Technology", by Liam Sarsfield; RAND, National Security Research Division, 2001.*

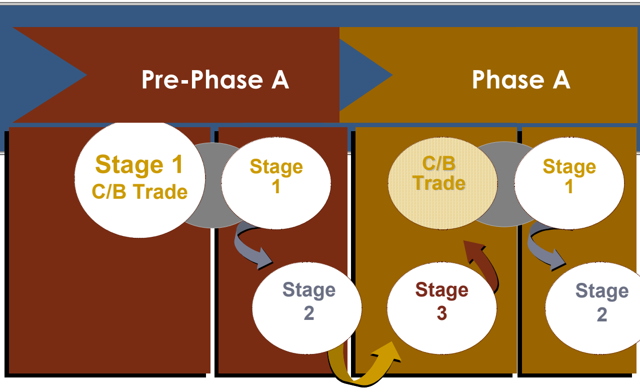
2 *Information about NAFCOM can be found in Appendix N. Information about PRICE can be found in Appendix Q, and information about SEER in Appendix P. Other tool information can be founding Appendices L through U.*

The Project CCRM Connection
Risk Considerations

Project Definition (Cost Estimating Process Tasks 1-3)
In Pre-Phase A, due to the lack of a stable system configuration, the Project CCRM Set Up Stage's Steps may not all be applied. The Field Center Cost Organization, CFOs, and cost groups are responsible for preliminary cost estimates and cost support in Pre-Phase A Conceptual Definition activities to include cost/performance trades and possibly CAIV studies. The Enterprise, IPAO, and Code BC will primarily maintain cognizance in Pre-Phase A with Code BC providing strategic guidance for cost estimating processes to include assessment of risk for cost impacts. Pre-Phase A can involve intense early cost/performance trade-off analyses between requirements (e.g., KEPPs) and cost in CAIV trades (see Section 6.2). Through quantifying the effectiveness brought to the potential missions (e.g., science expectations) by varying the levels of project requirements (e.g., threshold, objectives and levels in between) and costing out each level, an incremental effectiveness/cost "knee-in-the-curve" analysis can be performed[3] (see Section 6.2). A comparison of each project alternative's effectiveness/cost curve is then made to find the best value project alternative. The costing of each level of the requirements will include the cost-risk impacts due to the risk threads that are first recognized during Pre-Phase A and will stay with the project throughout its life cycle. The analysis identifies the point on the curve where little effectiveness is gained for more expenditure of funds. If this point does not achieve the minimum measure of effectiveness necessary to move into Phase A, more study is necessary to spiral up to that point. The decision to proceed into Phase A is made on the basis of technical feasibility, desirability, and affordability of the ideas derived from these early cost/performance and CAIV trades.
Cost Methodology (Cost Estimating Process Tasks 4-7)
The GR&As should be scrutinized to ensure that any risks that could be treated as "known unknown" risks and small unfunded "unknown unknown" risks are included explicitly as cost-driving risks in the estimate, and large "unknown unknown" risks are treated as assumptions with regard to occurring (e.g., launch failure, requirements growth, budget cuts, etc.). The cost estimating methodology should include cost-risk to the extent possible at this early phase. Any cost estimating models contain inherent uncertainty and the risks posed to the cost estimate by that uncertainty has to be quantified. Additionally, cost impacts due to technical risk and risks introduced by correlation between major elements of the system should be considered in arriving at the ROM estimates used in the cost/performance trades (see Section 6.2).
The Estimate (Cost Estimating Process Tasks 8-12)
Ensure that the model calculating the cost accounts for cost estimating uncertainty, technical input variable uncertainty, and correlation risk. Justifying the risk reserve level is a function of the detail specification of cost estimating, technical, and correlation risks that drive the cost risk range. A risk reserve that adds, for example, 30% additional cost to the reference point estimate has to be defensible. That defense comes from a cost-risk methodology that justifies the endpoints of individual WBS element cost-risk distributions, standard errors of the estimating regression line, and solid correlation coefficients (as good as can be captured in Pre-Phase A).

[3] *"Knee-in-the-Curve Supporting CAIV Analysis," Graham, David R. Aerospace Corporation 2001.*

Project CCRM Transition Activities Pre-Phase A To Phase A

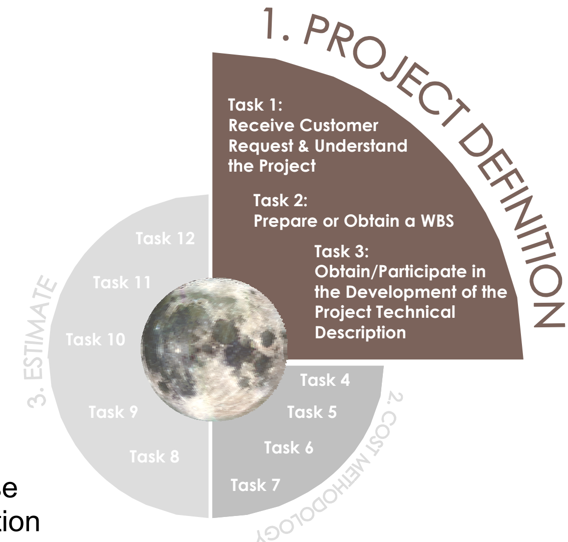


The transition from Pre-Phase A into Phase A represents the first time Project CCRM can be fully implemented. First, the Pre-Phase A Stage 1 CCRM Steps 1 and 2, Cost/Performance Trades and Requirements-to-Functions-to-WBS Allocation are updated. Next, Stage 1 CCRM Steps 3-5, Develop the Reference Point Estimate, Assess WBS Element Risk, and Translate Risk into Cost Impacts are performed as best they can at the end of Pre-Phase A to develop a risk-based estimate.

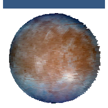
This is followed by Stage 2 CCRM Step 6 of the CCRM, Developing RFP EVM, CADRe, and Other Related DRDs. If EVM will be a requirement on the Phase A contract, the cost estimator passes these high and medium risk WBS element information to the EVM analysts writing the EVM reporting DRD for the Phase A RFP. The RFP for transition from Pre-Phase A to Phase A will also contain solicitation direction to potential bidders on other cost-risk related areas through DRDs focusing on the cost-risk management interrelationships between the following: CADRe development and updates, Probabilistic Risk Assessment (PRA) Plans and Reports, Financial Management Reports (533 M&Q), Integrated Master Schedule/Integrated Master Plans (IMS/IMP) and Reports, Technical Performance Measure Plans and Reports and Risk Management Plans and Reports. Check ceh.nasa.gov for the most recent downloadable DRD templates. When proposals come into the Project Office for source selection evaluation (Stage 2 CCRM Step 7) the contract award would go to the bidder who, in part, addressed these cost-risk management contract data requirements best. In Stage 2 CCRM Step 8, a post-contract award meeting, also called an Integrated Baseline Review (IBR) if EVM is part of the contract requirements, should be held with the winner to ensure that these data requirements are understood. If EVM is not a requirement during Phase A, some scaled-down version of all these data requirements should be made a part of the solicitation.

4.2 Phase A: Conceptual Design

PROJECT DEFINITION (COST ESTIMATING PROCESS TASKS 1-3)



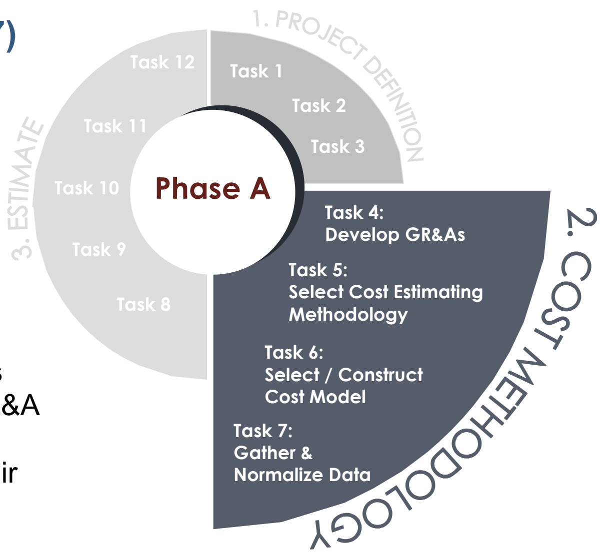
During Phase A, the transition is made from roughly sketched concepts to conceptual designs where the alternative projects develop more definition in system requirements, engineering detail, top-level system architecture, and operations concepts. Technical risks are identified in more detail and technology development needs become focused in the requirements and KEPPs. These advancements, in addition to more documentation being available such as system engineering master plans (SEMPs), specifications, and drawings, allow the estimator to understand the Project in more detail to provide a more detailed estimate.



Using the basic format prescribed for the NASA CADRe to *develop the project technical description* for a project in Phase A is encouraged. It will help in the eventual development of the preliminary or full NASA CADRe in later life cycle phases if required. The information the cost estimator is looking for to develop the project's cost estimate is the information used to establish the cost, technical, performance, and schedule baselines that should be located in the NASA CADRe. The NASA CADRe also requires recording of final technical parameter values (e.g., KEPPs) and actual costs at the end of the contract for storage into the One NASA Cost Estimating (ONCE) database.

There must be a preliminary *WBS developed* during the Conceptual Design phase for each of the options. To the extent possible, this WBS should also be consistent with the WBSs contained in the cost models used at NASA (e.g., NAFCOM, PRICE, SEER, etc.). The NASA Systems Engineering Handbook sets forth policies and processes for preparing WBSs and some examples of WBSs used at NASA are listed in Appendix G.

Cost Methodology (Cost Estimating Process Tasks 4-7)



During Phase A, as the conceptual design is beginning to take form, the Part II tasks of the Cost Estimating Process become refined to reflect the specific requirements of the project. For example, the GR&A are refined, reduced in number but those that remain become more detailed, there are more options in selecting a cost estimating methodology, and if the same methodology is chosen estimates are further refined. Any GR&A changes should be discussed with the project team to ensure their buy-in.

To ensure accuracy and acceptance, it is also recommended that the cost estimator coordinate the GR&A with stakeholders, vendors, etc. Project detail can be added into existing models to revise estimates or new models can be created now that more detail is available. As data becomes available in Phase A, it is important for the cost estimator to have a method to capture this information, normalize it, and maintain the data for future Project estimates. It is important to begin to refine the detail available to ensure credibility for the Project estimate as the Pre-NAR and the ICE, which are conducted in Phase A.

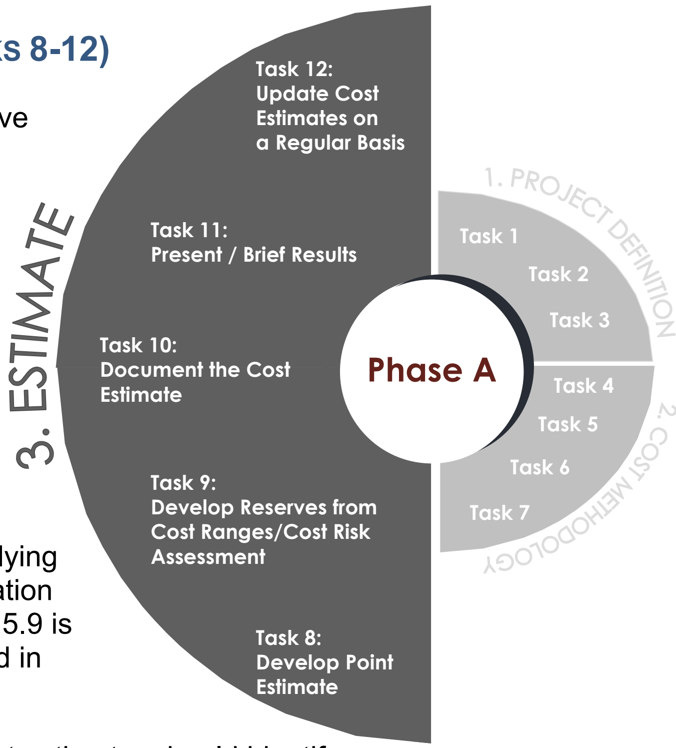
As in Pre-Phase A, the *selection of a cost estimating methodology* is largely dependent upon the depth and breadth of information availability (e.g., actual cost data, granularity of project definition). It is recommended that cost estimating activities during Phase A be guided by either the parametric or analogous system cost estimating approach. For detailed information on estimating methodologies please refer to Section 5.5.

In Phase A, the type of data available will influence the *constructing or selecting model* decision. At this point, there still may not be much detailed data past the third WBS level and there may still be many assumptions. If this is the case, it is most likely that the same model that was used for a Pre-Phase A estimate, such as a parametric tool like SEER-H or PRICE-H, would be used to update the Phase A estimate. If the quality of the data has increased since Pre-Phase A and there is more detail in the data that can be found at lower WBS levels, then in many cases it may still be best to use a parametric model, but it may also be possible to construct your own model using the more specific data and engineering build up estimates from the project participants.

At this phase of the project as in all phases, it is important to *gather data* from as many sources as possible and to allot time for data collection. Replace assumptions with real project data wherever possible. In Phase A, a more detailed understanding of project and technical requirements as documented in the WBS and CADRe may be used to begin to solicit input from the vendor community. Once data is collected it must be *normalized* or adjusted to standardize costs across previous projects for unit conversion, key groupings, inflation, etc. The normalization process includes accounting for content, quantity, and inflation within the raw data collected. A simple example is one in which length of cable is hypothesized to be the driver in cable cost and there is data on cable cost by the foot and by the meter. The cost estimator decides on the preferred system of measurement and then normalizes the data by converting meters to feet, for example. The final part of the data normalization process is adjusting the data for inflation. Commonly, historical cost data needs to be normalized for inflation to be used in generating an estimate. For information about inflation, see Sections 5.7 and 6.7.

The Estimate (Cost Estimating Process tasks 8-12)

All of the assumptions and data that have been collected to this point become the basis for the *point estimate.* Yet, this is not the entire answer – a cost estimate is not complete without a *cost-risk assessment* that takes into account cost, schedule, and technical risks that are then factored back into the estimate. Even though most science projects at NASA are selected on the basis of the science package ratings, cost is considered as a risk element and proposals can be lost if cost is not properly justified. Applying the comprehensive cost and risk estimation approach described in detail in Section 5.9 is the kind of justification for cost expected in proposals submitted.



Working with project office staff, the cost estimator should identify cost-risk drivers and vary the operating scenarios and input parameters through the conduct of a comprehensive probabilistic and deterministic cost-risk and sensitivity analyses (see section 5.9). It is the job of the cost estimator to estimate the effects of identifying, assessing, and analyzing cost-risk drivers (e.g., probabilistic cost-risk analysis) and varying cost drivers (e.g., deterministic cost-risk) and to revise the LCC estimates reflecting the selected variations, pointing out the relationship between the LCC and the key technical and/or operational parameters. Additionally, the cost estimator should identify the investment areas with the greatest and least return [see Section 6.9 for information on calculating the return on investment (ROI)].

As a project moves through this conceptual design phase, the range of feasible alternatives decrease and the definition of those alternatives increase. However, there is still a critical need to identify pertinent cost issues early to correct them before correction costs become prohibitive. Issues and cost drivers must still be identified to build successful options. By accomplishing a cost estimate on proposed project alternatives, the Project Office can determine the cost impact of the alternatives. These cost drivers feed into an increasingly detailed cost-risk assessment that takes into account cost, technical, and schedule risks for the estimate. The point estimate and the risk assessment work together to create the total LCC estimate.

Once the LCC estimate is complete, *final documentation* should be prepared. Phase A is generally the first opportunity for full up documentation for an estimate. It is important to keep in mind that the best way to create estimate documentation is to record your sources, methodologies, CERs, and other estimate documentation as you are conducting the estimate. Waiting until the end increases the chances for overlooking important information and not having a replicable estimate, which can lead to credibility problems. Cost estimates must be *updated* whenever project content changes because a project estimate must be continuous over the project's life, and must continue to provide useful insights. It is essential that all the documentation is in place for traceability and so that updates can occur in follow-on phases.

It is recommended that each Center maintain as much consistency internally with respect to the LCC content and format as possible. The benefit of a well-documented estimate is that the differences with other cost estimating efforts for the same project should be easily reconcilable from the documented information. The value of the documentation and analysis is in providing an understanding of the cost elements so that decision-makers can make informed decisions.

Once the estimate is documented, it should be *presented to the decision makers* using the familiar front-end briefing format. A template for this briefing format can be found in Appendix I. After the estimate has been conducted and presented it should be updated on a regular basis with any new information found during Phase A.

Phase A Conceptual Design

Phase A further examines the feasibility and desirability of a suggested new major system or project before seeking significant funding. NASA personnel must work to ensure that data required will be available to *manage* to the estimate that supports the budget, keeping in mind that the CRL calculated-regardless of the risk reserve established through the cost risk assessment. During this phase, these risk reserves should be revisited and potentially the ranges refined (i.e., narrowed). This Phase is where the Project is beginning to identify cost drivers in terms of risk ranges. Therefore, Phase A is he first phase where Project CCRM may be implemented in its entirety. The final cost/performance trade studies from the end of Pre-Phase A represent the beginning of its full implementation. Phase A continues to be a time of intense design formalization and documentation.

Phase A Overall Objectives

Phase A estimates are conducted for many purposes. A Pre-NAR and an ICE are required and a project estimate is used not only as the baseline project estimate, but also as the basis of estimate for the project's budget. Project Managers use cost estimates as baseline rationale to develop budget submissions for Presidential and Congressional approval. As a budget is partly subjective; to increase the validity of requested dollars, a project that uses a valid cost estimate greatly improves the defensibility of a budget request. This is because with a detailed cost estimate, there is little room for hiding money or for asking for too much. Similarly, a detailed cost estimate will show impacts to the project if allocated too little money. Quality, risk, and sensitivity analyses along with thorough documentation and a consistent briefing format are all important factors when defending an estimate.

An overall objective in this phase is to secure funding for the project, which requires an understanding of the project's business drivers and sound business decision-making. To do this, the cost estimator must re-examine the cost, risk, and performance parameters established in the set up phase of Project CCRM to ensure that they accurately reflect the system as it is being designed.

The cost estimator will work closely with project staff, especially acquisition specialists, to execute the three primary activities associated with the second phase of Project CCRM (getting the feedback). While most RFP and contract work is an activity in Phase B, some of this data may be available in Phase A to begin.

Phase A Roles and Responsibilities

During Phase A, Centers define an affordable concept and expand the goals and objectives into a set of requirements and implementation options, available technology, risks, budget, and schedule are identified and investigated. In this phase, cost estimators examine cost feasibility, uncertainty, and constraints. Later in this phase, feasible concepts are studied and trade studies are performed to determine an optimal concept. After alternative concepts have been analyzed, the project is defined, approval received from the governing PMC, and 1-2 primary concepts are chosen for further development and project planning.

If a CADRe is required for the Project, the contractor and/or NASA project engineers, assisted by cost estimators, construct the NASA Project CADRe. A NASA CADRe is required for all projects. An abbreviated NASA CADRe may be appropriate for lower category or early phase estimates. The Project CADRe provides the technical basis for the LCCE and, for Category I projects, supports the Congressional requirement for an ICE prior to entry into Phase B. Code BC and the IPAO will coordinate on this ICE, which will be communicated as preliminary and presented as a range of possible costs that are clearly subject to change. A full NASA CADRe is required for entry into Phase C to support the Phase C ICE and project LCCE, whose cost ranges should be greatly reduced from the Phase B ICE and project LCCE.

Phase A Issues/Challenges

The following list describes some of the issues and challenges that the NASA cost estimator faces during this life cycle phase:

- Inadequate understanding of reserve needs; lack of cost/schedule/technical risk knowledge.
- Untenable schedules.
- Over-optimism in project and contractor capabilities, technology, and execution plans.
- Over-subscription to management reforms or new ways of doing business.
- Tendency to influence or accept contractor buy- in.
- Lack of independent validation of costs/schedules.

Enterprises identify ICE applicable projects early in a FY (e.g., >$ 150M). An ICE is integrated into Code D/IPAO reviews and during the process, Code BC assigns a cost team drawn as appropriate from Code BC, IPAO, and the Center. The team may also draw upon Center cost organizations, support contractors, Federally Funded Research and Development Centers (FFRDCs), and consultants. The review team reports to the governing PMC and then Code BC works with Code L to draft the Congressional report. For Category I projects, the Project LCCE, based on the technical requirements defined in the NASA CADRe, is first developed by the project and coordinated between the project and the Center SMO or Center cost group near the end of Phase A. In some cases a separate, and additional estimate is developed by the Enterprise as a crosscheck that also becomes part of the coordination. At the same time, the IPAO develops an ICE, based on the same Project CADRe, with Code BC cognizance. A coordination meeting, chaired by Code BC/Code D, presents the Project/SMO/Enterprise LCCE and the IPAO ICE to coordinate on the two positions. A period of 30 days is allotted for full coordination/reconciliation between both cost positions. In the unlikely event of irreconcilable differences between the estimates, a pre-Agency PMC (APMC) reconciliation review is held, chaired by Code D/Code B to formulate a recommended cost position to the APMC.

Phase A Exit Criteria

There are two primary categories of cost review during conceptual design. The first type is an internal PM review of the contractor and in-house (or advocate) estimates. The second type of review is the external pre-NAR or at some Centers, an Independent Assessment (IA). For the space launch programs, one NAR occurs early in formulation on advanced concept review. This is done after basic program documents such as the project plan and a draft Systems Concept Document are developed. This pre-NAR is part of the preliminary program approval review performed by the PMC.

The PM's estimate is reviewed externally against an ICE, developed outside the project by the IPAO using the same CADRe as a technical baseline. The focus, or criteria, for the review is the thoroughness and realism of the cost estimate including estimated reserve requirements. Exit criteria include:

- All cost estimates done in full cost.
- A minimum of a preliminary CADRe exists in late Phase A for any category project.
  - All WBS items are costed (no TBDs).
- A preliminary Code BC/IPAO ICE at end of Phase A for projects with expected LCC>$250M.
  - OMB-provided first year of implementation funding; out years as ranges;
  - CRLs calculated, documented, and clearly communicated;
  - Probabilistic cost/schedule risk range across multiple configurations/design solutions;
    - Outyear cost expressed in ranges are desired, but in many cases it will only be possible to provide discrete values.
  - At Confirmation Reviews and Authority to Proceed (ATP) decision point, the cost estimate must include an appropriately chosen level of reserves.

The PM must correct estimating problems, questions, and issues identified by the NAR team and the PMC. If the cost estimate must be revised, the iterative cost/design process, discussed in the estimate refinement section, is used and the updated estimate provided to the Project Office and the PMC. In Phase A, the PM should review estimates for approval/disapproval based as a minimum on the following criteria:

- Affordability: Ensure that the cost estimate indicates that the candidate system is affordable based on the affordability estimate and preliminary budget data from NASA. To determine this, the PM must review the estimate to ensure it is compatible with the budget. An estimate/budget reconciliation and an understanding of any disconnects is helpful at this stage. The PM should be aware that a primary difficulty in cost estimation in this early stage is decision-maker demand for unrealistic precision that is above the state-of-the-art given concept definition fidelity. Clearly defining the decision criteria and demonstrating that the precision available supports those criteria may mitigate this difficulty.
- Realism: The probability that the cost estimate is within a realistic range. This requires that the level of precision be such that the cost estimates are representative of the expected value and consistent relative to other options. A high-level cost risk assessment is also important at this point, based on the technical risk assessment already documented in the technical baseline or the

Phase A CADRe, schedule analysis, and cost risks. Ensure that the 'typical' cost drivers are identified as well as the magnitude of the risk that they represent. This will allow the PM to identify estimates that are unrealistically optimistic in areas such as technology assessment, schedule, or general support requirements. At this point it is also recommended that a cross check estimate be conducted, either using a different estimating methodology, or at a minimum, using a different cost model to help reveal any issues or items that may have been overlooked or not fully understood in the estimate.

- Sufficient Detail: Ensure the cost estimate is completed at the level and precision needed to influence the current stage of the design. Has the estimate identified the cost drivers in the system, and does the estimate adequately address these drivers? Early estimates should reflect the nature of decisions being made at an early stage, and need only distinguish between early level alternatives.

The Project CCRM Connection

Risk Considerations

During Phase A, the implementation of CCRM Step 9, Do EVM, "S" Curve, Schedule Risk, and CPA, focuses analysis of the EVM cost-risk reporting on high/medium risk WBS elements. This analysis is used to indicate the need to re-address cost/performance trade studies to help the PM decide whether to continue with a new design or fall back to a proven design, to assist cost estimators interested in current cost performance on previously estimated cost and/or cost-risk impacts due to medium and high risk WBS elements, to help update cost and cost-risk models, and to update the NASA CADRe with reasons for cost growth in support of the pre-NAR. CCRM Step 10 requires updates to the initial Phase A Project LCCE cost-risk "S"-curve distribution based on a CADRe at significant contract milestones and/or at least annually in support of the President's Budget submission as part of the NASA CADRe requirement. CCRM Steps 11 and 12 involves end-of-Phase A contract data analysis and population of the ONCE database for cost estimating and cost-risk methodology updating.
Project Definition (Cost Estimating Process Tasks 1-3)
The Project's Phase A Stage 1 CCRM Steps 1 and 2 are engaged during the annual refinement of the project definition leading to the pre-NAR NASA CADRe and LCCE. Cost organizations assist in developing the pre-NAR CADRe, but it is owned and signed by the PM. The risk section of the pre-NAR CADRe documents and updates the risk threads first identified in the Pre-Phase A cost/performance trade studies. Contracts may have been awarded to assist in Phase A to readdress and firm up the mission concept and ensure that the project justification and practicality are sufficient to warrant a place in NASA's budget.

Cost Methodology (Cost Estimating Process Tasks 4-7)

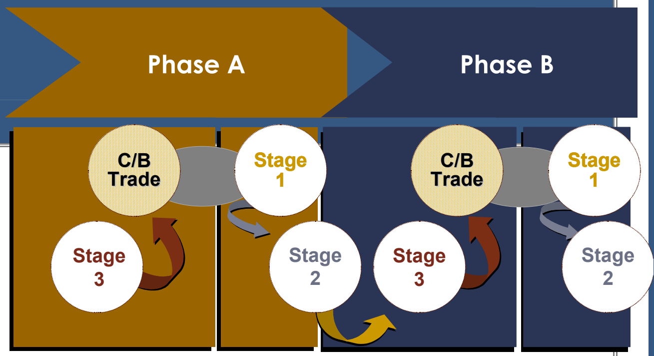
Part of the Phase A Project CCRM Set Up Stage Step 3 involves the refinement of the cost methodology. During the selection of a cost methodology, a way for accounting for cost estimating, technical, and correlation risk must be identified. There are methodologies available to the cost estimator, one outlined as part of the 12 Tenets of NASA Cost-Risk in Section 6.18. When using any risk assessment and cost-risk determination methodology, the estimator should always be sure the outputs from the methodology are defensible before they are used as inputs into the cost-risk Monte Carlo simulation or analytic cost-risk models.

The Estimate (Cost Estimating Process Tasks 8-12)

The Project Stage 1 CCRM's Steps 4 and 5 of the Set Up Stage involve assessing risk and translating that risk into cost impacts for the Phase A pre-NAR LCCE. Since all cost estimating methodologies contain inherent uncertainty, the risks posed to the cost estimate by that uncertainty has to be quantified. This risk quantification results in a cost range around a reference point estimate that enables an identification of confidence for the estimate. The first uncertainty that can cause cost-risk is the cost estimating model. For example, a CER regression line has inherent uncertainty around any point on the line that must be taken into account in the estimate. The second uncertainty concerns the range of possible technical parameter values that will be entered into a cost estimating model or methodology. Since a random variable has a range of possible values, it is the range of data that must be entered into the cost estimating model and not just one value within the range. This data variability will further add to the range produced just from the cost estimating model's or methodology's inherent risk, in effect widening the resulting cost probability distribution (i.e., increasing its variance), that enables an identification of confidence for the estimate. The final influence is the correlation between the WBS elements that make up the system being estimated. All the well-known Monte Carlo simulation models and analytic cost-risk models allow for correlation risk (e.g., NAFCOM, ACEIT). The estimator should also make some allowance for a range of values for the Full Cost Accounting factor used even if it is a subjective-based range. Once all known-unknown risks have been accounted for in the development of the pre-NAR LCCE's CDF "S"-curve, the 70th percentile LCCE value can be determined. It is this value that is the recommended value that should be used for planning the project's budget.

Near the end of Phase A, in preparation for entering into Phase B and for budgetary purposes, the Field Center, Enterprise, and IPAO will reconcile to one probabilistic estimate in a meeting co-chaired by Deputy Code D and Code BC, for a recommended cost position to the APMC. Along with the pre-NAR LCCE and ICE, Code BC will verify the project's CRL, a measure of the readiness of the cost estimate dependent on analysis of the cost-risk in the estimate, of the recommended estimate (see Section 6.1 for a detailed explanation of CRLs).

***Post* Phase A**
Estimate Project CCRM Activities

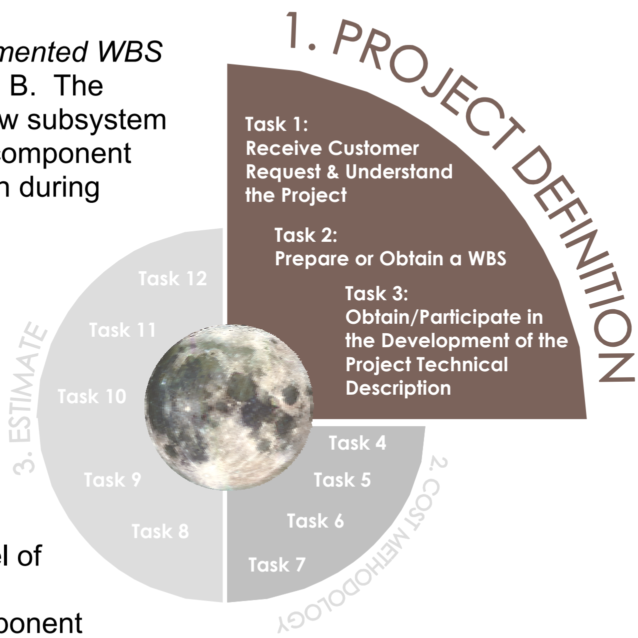


During the development of the end-of-Phase A estimate, WBS elements with high and medium risk should be identified. These high and medium risk WBS elements are then identified for project and/or contractor tracking and analysis during the performance of the Phase B effort via DRDs in the solicitation's RFP. This activity is captured in Step 6 of Project CCRM Stage 1 as the first part of the get stage for acquiring cost-risk feedback. If EVM will be a requirement on the Phase B contract, the cost estimator passes this high and medium risk WBS element information to the EVM analysts writing the EVM reporting DRD for the Phase B RFP. This activity is captured in Step 6 of Project CCRM Stage 2 and repeats the Phase A RFP cost-risk feedback DRD development process. Additionally, probabilistic cost/schedule risk analysis for the pre-NAR Project LCCE and ICE should be improved by Risk Management reports, PRA-identified risks plus programmatic and management risks delivered as a result of Phase A contract data requirements. Steps 7 and 8 of the CCRM Stage 2 then repeat just as for entering into Phase A. The project is now ready to enter into Phase B.

4.3 Phase B: Preliminary Design

Project Definition (Cost Estimating Tasks 1-3)

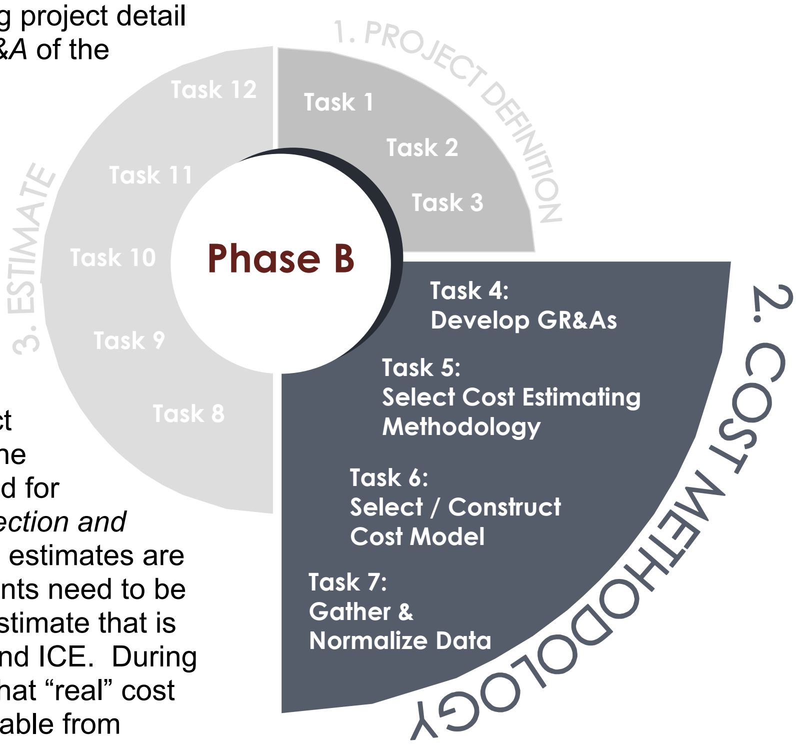
At no time is a well-structured and *documented WBS* more important than at the end of Phase B. The Phase B WBS should be defined at below subsystem levels down to the component and sub-component levels due the evolution of system design during this Preliminary Design phase.



Using the same basic table of contents for the *technical baseline or NASA CADRe* in late Phase A, the Phase B CADRe evolves from a streamlined, preliminary version to a full NASA CADRe. This means that where, for example, the lowest level of definition in the CADRe in the late Phase A time period was the subsystem level, the level of definition in the late Phase B time period should be at the component or sub-component levels.

COST METHODOLOGY
(COST ESTIMATING TASKS 4-7)

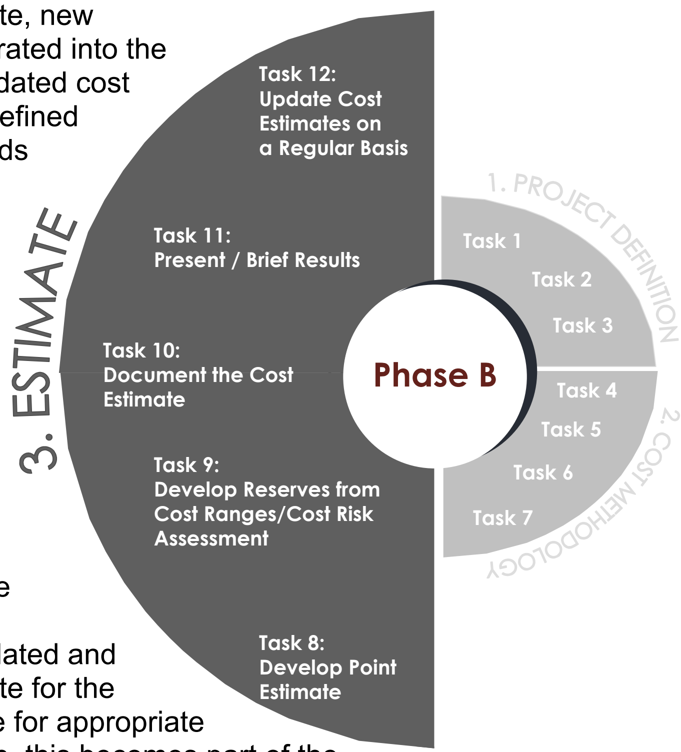
During Phase B, the increasing project detail should be captured in the *GR&A* of the estimate. *Estimating methodologies* start to move away from parametric and analogy methodologies used when little information is available, and move toward more detailed parametric estimates or engineering build up estimates supported by technical subject matter experts. Project detail also starts to influence the *model that is chosen* or created for the estimate and the *data collection and normalization process*. As the estimates are further refined, these refinements need to be incorporated into the project estimate that is used in the NAR and the second ICE. During this phase, it is also possible that "real" cost data (i.e., actuals) will be available from contractors hired to work with NASA to define and develop the project. These contractors, through DRDs, should be required to provide the PM with EVM (or like) data that can be used to validate or update previously prepared estimates. This EVM information may provide status on the retirement (or not) of risk and cost-risk valuable in updating the cost-risk assessment for the NAR Project LCCE and IPAO ICE. When actual data is available, the preferred cost methodology is engineering buildup. The engineering build up methodology rolls up individual estimates for each element into the overall estimate.



As definition increases, cost estimators should *migrate to tools* that relate specific design characteristics of the new system to the cost of elements of the system. In many cases by this phase, a specific tool has been chosen that the project uses for all primary cost estimates. This allows for quick updates to the next cost estimate excursions and for easy comparison to provide thorough cost track analysis in the estimate documentation.

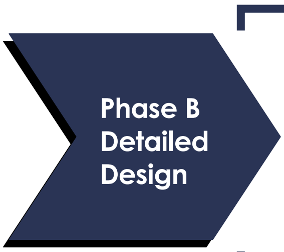
The Estimate (Cost Estimating Tasks 8-12)

When conducting the Phase B estimate, new information collected must be incorporated into the current cost models to ensure that updated cost estimates accurately reflect "new" or refined requirements and data. This data feeds back into the *point estimate* and the *risk assessment* for a more detailed project estimate. This data is also used in the NAR and the second ICE that are conducted for the project.

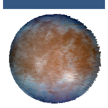


For each suggested change in the requirements, design, use, or support arrangement, there must be an assessment made of the impact of the change on cost. This cost assessment accompanies the suggested change through the change review process. When the change is approved, the cost assessment is updated and incorporated in the formal cost estimate for the system by modifying the cost estimate for appropriate cost elements. During implementation, this becomes part of the formal configuration control process.

Keeping the estimate up-to-date with these changes and having a full cost risk assessment helps to defend the estimate, reduce updated estimate turn-around time, and gives the decision-maker a clearer picture for "what if" drills or major decisions. Phase B activities demand a well-documented estimate that is defensible and replicable. *Thorough documentation* increases estimate credibility and also makes it easier to *present and defend* the estimate through the various Phase B milestones.



Phase B is used to define the project in enough detail to establish an initial baseline capable of meeting mission needs. Initial concepts are down-selected to a manageable number in Phase B and then are provided to the internal NASA design teams, through the Project Office, to develop an optimal architecture. During this Phase, there should be a single selected design approach, with possibly several lower level optional characteristics.



Phase B Overall Objectives

During this phase, an objective for the cost estimator is to refine the point estimate's accuracy by scrutinizing the assumptions, the cost drivers, risks, and conducting periodic PRAs. During this phase, more specific data is available to develop a solid technical baseline or NASA CADRe, conduct a full LCCE, and reconcile it with a NAR. Estimates should be based on preliminary design review (PDR) or near PDR quality definition. The maturity of the data and the better-defined project should also help improve the CRL for each of the estimates. In Phase B, the numbers of concepts are down-selected to a manageable number from which the internal NASA design teams, through the Program Office, develop an optimal architecture. During this Phase, there should be a single selected approach possibly with several lower level optional characteristics.

Cost/schedule risk analysis should be driven by PRA-identified risks plus programmatic and management risks. A contractor estimate(s) is often developed separately and the various estimates compared for completeness, standardized GR&A, and reasonableness. At this Phase, a CADRe is required and there is also a NAR reviewed and adjusted cost estimate.

Phase B Roles and Responsibilities

The role of the cost estimator during this phase is critical. It is important to understand the basis of the estimate, from the technical baseline to the cost risk assessment and to be able to document and present the results of these efforts to the decision makers. Findings during this phase for cost, performance trades, and risks influence the acquisition of a system and the execution of the project. It is the cost estimator's responsibility to test, understand, and validate the knowledge base used to derive estimates. It is also the responsibility of the cost estimator to ensure the best possible LCCE with recommended reserves based on updated cost risk assessments in Phase B. These estimates will support budget formulation as well as source selection support in the transition from Phase B to Phase C/D. The cost estimator ensures that the NASA CADRe used as the basis for the estimate is as complete and accurate as possible and that it is the same version that the project LCC team and the NAR team uses to build their estimates. In this phase, another critical responsibility of the cost estimator is to work with the PM and acquisition team to ensure that solid WBS reporting structures and data collection mechanisms for the execution of the project are in place.

Phase B Issues/Challenges

The following list describes some of the issues and challenges that the NASA cost estimator faces during this life cycle phase:

- Trying to overcome the lack of cost/schedule/technical risk knowledge, to be able to defend reserves as demonstrated by the evolving nature of Project CCRM.
- Unrealistic schedule constraints due to corporate or contractor commitments.
- Over-optimism in project and contractor capabilities, technology, and execution plans.
- Over-subscription to management reforms or new ways of doing business.
- Tendency to influence or accept contractor buy- in as RFP release approaches.
- Independent validation of costs/schedules may lead to new issues to be reconciled and resolved before proceeding according to schedule.

Making this process more efficient, NASA has established a program of cooperative engineering centers called PDCs. At these centers, the engineers and cost analysts determine the relative benefit of specific technologies or mission concepts to improve space transportation or the mission using individual workstations and the variety of analysis tools. Center and visiting/teleconferenced experts analyze all aspects of a space project, from the technical aspects of flight operations to a business model to determine the ROI. The PDCs enable cost personnel to rapidly estimate costs for a variety of concepts. As the program or project matures during the formulation sub-process, concept definition designs are refined and their number reduced, with more detail being added to the cost estimate. The earlier concept definition tools are generally phased out and engineering expertise and actual data are used more frequently.

The office responsible for building these concept cost estimates, particularly the Design Development (DD) estimate, is the cognizant cost office at the performing Center, using tools like NAFCOM, the PRICE estimating suite, and SEER. Operations and Support (O&S) estimates are generated using a different set of tools such as MESSOC, SOCM, RMAT, COMET/OCM, GEM-FLO for cycle time, and Architectural Assessment Tools-enhanced (AATe)[4]. Supporting NASA centers provide cost data input in such areas as spaceport operations (Kennedy Space Center), mission operations and data analysis (Goddard Space Flight Center and Jet Propulsion Laboratory), and airframes (Langley Research Center). Together, these cost analysts work to build a concept architecture. In some cases, they study the impact of infusing new technology into a reference vehicle and its impact on cost. In many cases, they study concepts initially generated by contractors, then selected by the PM for cost, schedule, and technical merit.

Phase B Exit Criteria

Throughout the process, cost personnel support a variety of reviews. PMs may specify internal reviews, in addition to the required NAR required to move a project into the implementation process. These reviews ensure the concept being developed meets NASA resourcing goals and objectives for the project, among other requirements. Towards the end of project design phases (Pre-Phase A, A, and B), as system requirements are sufficiently developed, the project prepares for a Project Approval Review by the Center PMC, usually in concert with the NAR. Part of this review includes an ICE, performed by a cost estimation office outside of the performing Center. The Phase A independent LCC estimate is reviewed, including funding resource requirements, reserve allocations, workforce and infrastructure requirements, and partnering efforts. Contractor estimates and the ICE are reviewed, differences analyzed, and potentially reconciled, by the cost office. Subsequently, one, or a combination of the cost estimates, is presented by the PM during the project approval process to the assigned PMC. If costs are accepted, the estimates become part of the overall approval process to move the system to implementation. If estimates are not satisfactory, they are returned to the cost office for additional estimation and analysis.

[4] *Appendices L through U provide details about many of the cost models and tools available to NASA cost estimators.*

The PM should review estimates for approval/disapproval and reconciliation based as a minimum on the following criteria:

- Ensure the cost estimate is comparable to other estimates, notably the ICE, and between the various contractor estimates. The reason for major differences between estimates should be clearly understood and explained as part of the reconciliation and review.
- Ensure the cost estimate has a detailed cost risk assessment that is documented in the estimate documentation and supporting risk data is detailed in the CADRe. At this point, the areas of cost risk addressed earlier should have been mitigated or reduced to a manageable level, and this reduction documented and reflected in the estimate. This does not mean that the cost estimator has ignored cost realism and removed or minimized the risks and their impact. It means that the cost estimator has worked with the technical team to identify, understand, and document trade studies, alternatives, and risk mitigation strategies and this risk mitigation is realistically reflected in the cost estimate.
- Verify the full cost aspects of the estimate.
- Ensure the estimate meets NAR requirements, to include funding resource requirements, reserve allocations, workforce, and infrastructure requirements, risk assessment, and external contributions such as partnering.

A successful late Phase B review moves the project, including its associated cost estimate, into the Detailed Design and Development Phase C/D, and out of the Preliminary Design Phase B. Exit criteria guidelines include:

- NASA CADRe or abbreviated CADRe in late Phase B depending on project category.
- IPAO/Code BC ICE based on increased detail (eventually major assembly, component level).
- Probabilistic cost/schedule risk analysis (tied to PRA identified risks) plus programmatic and management risks.
- Updated cost/performance trade/CAIV study (ies).
- Field Center, Enterprise and Code BC reconcile to one probabilistic estimate for PMC.

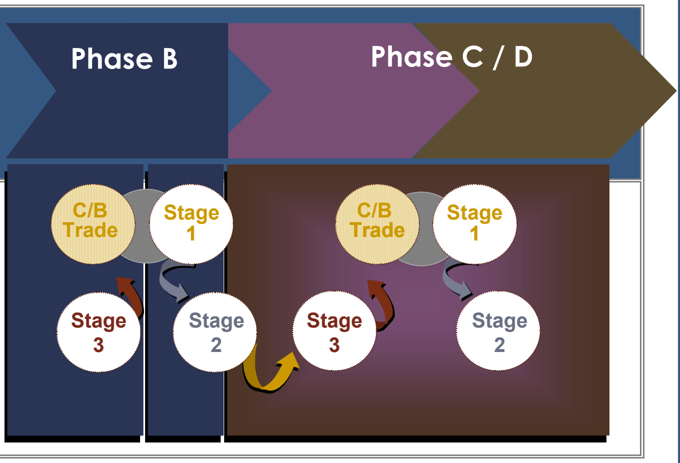
The Project CCRM Connection

Risk Considerations

During Phase B, the implementation of Stage 3 CCRM Steps 9-12 repeats exactly as in Phase A except with Phase B cost-risk feedback information used in preparation for the NAR. The sources of cost-risk feedback data on the Phase B contract (required by DRDs) should be producing valuable cost-risk information for the Phase B contractor and for project cost estimators to use in updating the LCCE for the NAR and helping the PMs manage project cost. If EVM performance measurement feedback on high or medium risk WBS elements is showing overrun tendencies, mitigation efforts should be instituted or cost/performance trade studies should be repeated to keep costs under control. Just as in the Phase A pre-NAR LCCE, the Phase B NAR LCCE should also account for cost estimating, technical, and correlation risks in the development of the CDF "S"-curve updates. The cost-risk feedback data available through these sources should help bring extra credibility to the cost impacts due to risk for the NAR LCCE. EVM report information used in generating the Phase B NAR LCCE also can be useful in updating cost models. The 70th percentile cost estimate value should have shifted to a somewhat lower value as cost-risk feedback has enabled the PM to control and retire risks.
Project Definition (Cost Estimating Process Tasks 1-3)
Phase B is the second phase where the Project CCRM can be fully implemented as begins with a reassessment of the requirements within the context of cost/performance or more formal CAIV trade studies. During The Project's Phase B Stage 1 CCRM Steps 1 and 2 also repeat exactly as in Phase A except with Phase B trade and project definition updates in preparation for the NAR. As these cost/performance trade studies are updated, they form the basis for an update to the systems engineering evolutionary requirements-to-functions allocation process (Step 2). In like manner, the rest of the Setting Up for cost-risk feedback Stage of CCRM is updated, that is, the CADRe, reference point estimate, risk assessment and cost-risk impacts due to risk.
Cost Methodology (Cost Estimating Process Tasks 4-7)
The Project's Phase B Stage 1 CCRM Step 3, involving the further refinement of the cost methodology, also repeats exactly as in Phase A except with Phase B cost methodology updates in preparation for the NAR. Stage 1 CCRM Step 3's cost methodology activities are focused on updating what was accomplished in previous phases relative to annual CADRe updates to the reference point estimate, risk assessment, and cost-risk impacts due to risk as they relate to the NAR LCCE. Analogy and parametric estimating methodologies can now be augmented with actual cost information from Phase B providing more credibility to the estimate and the cost-risk assessments for the NAR LCCE.
The Estimate (Cost Estimating Process Tasks 8-12)
The Project's Phase translation into cost impacts, also repeats exactly as in Phase A except with Phase B risk and cost impact updates in preparation for the NAR. The Project's Phase B Stage 2 CCRM Steps 6-8, involving the writing of cost-risk feedback RFP DRDs, review of bidder cost proposals and post-contract award NASA/contractor meeting (e.g., IBR), also repeats exactly as in Phase A except with Phase B medium and high risk WBS element updates. The project is now ready to enter into Phase C/D.

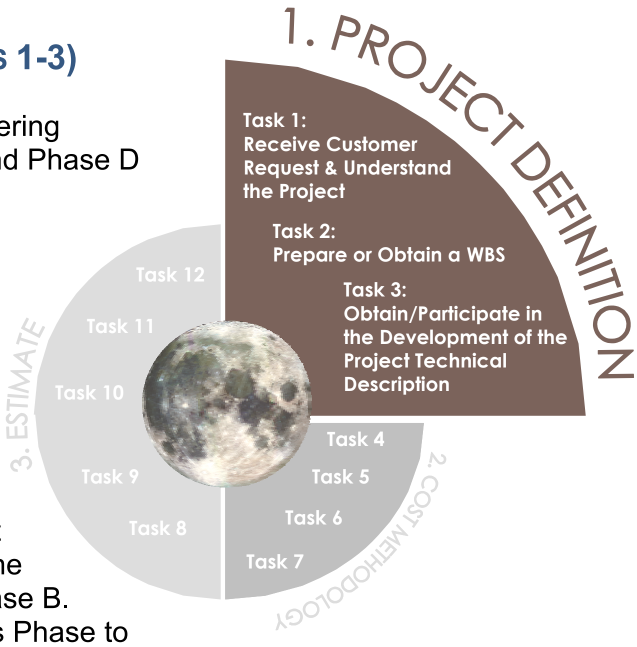
***Post* Phase B**
Estimate Project CCRM Activities

The Project's Phase B CCRM Stage 2's Steps 6-8, involving the writing of cost-risk feedback RFP DRDs, review of bidder cost proposals and post-contract award NASA/contractor meeting (e.g., IBR), also repeats exactly as in Phase A except with Phase B medium and high risk WBS element updates.



4.4 Phase C/D: (Design, Development, Test and Evaluation - DDT&E/Production)

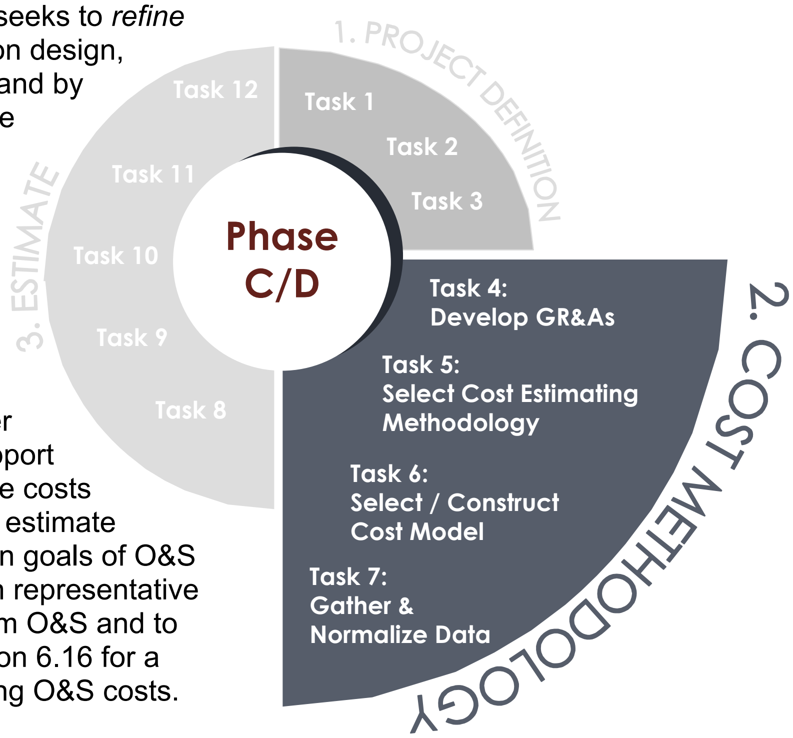
Project Definition (Cost Estimating Process Tasks 1-3)



Even though the NASA Systems Engineering Handbook calls out Phase C (Design) and Phase D (Development) as separate and distinct acquisition phases, in practice, NASA merges them together. The implication for the cost estimator is simply that entry from Phase B into Phase C/D is of much greater significance than if Phase B was transitioning into Phase C alone. Entry into a design phase would not be such a major commitment of funds as compared with entry into a full system development phase, hence the major significance of the ICE as part of the NAR at the end of Phase B. Cost estimates are conducted during this Phase to support PDRs and Critical Design Reviews (CDRs) that are used to commit the project funds. These estimates should not be taken lightly.

During this Phase, there are many sources that the estimator can turn to for a better *understanding of the project*, including the CADRe, which is a particularly good source of information for any new participant in the project at this time as it has been refined from Phase A and contains summarized information on all areas of the project, including costs. As the system design is finalized for entry into Development, the *WBS is also updated* to reflect the final subsystem, component, and sub-component element configuration. The *CADRe is also updated* to reflect any changes to requirements and system element performance changes and expectations.

COST METHODOLOGY (COST ESTIMATING PROCESS TASKS 4-7)

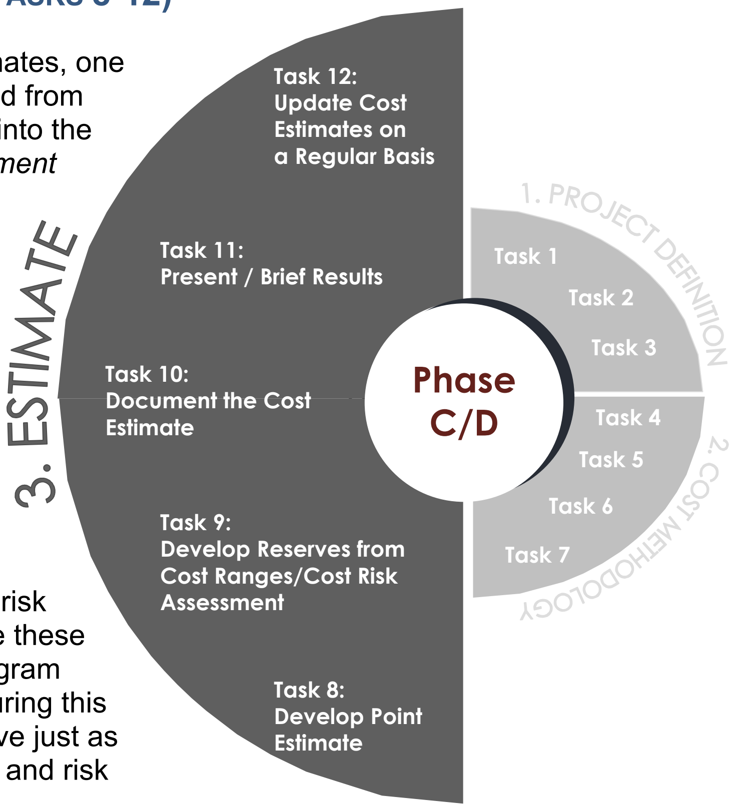


Cost estimating in Phase C/D seeks to *refine project estimates* by focusing on design, development and testing data and by focusing on defining the relative cost of operating and supporting the project. Cost estimates at this phase also focus on determining the relative importance of contributing factors on cost drivers. One cost driver that should have been, but may have been overlooked in earlier phases, is Operations and Support (O&S) costs. Historically, these costs are difficult for the estimator to estimate in a credible manner. The main goals of O&S cost estimating are to establish representative cost estimates of launch system O&S and to identify cost drivers. See Section 6.16 for a detailed discussion of estimating O&S costs.

During Phase C/D, the *GR&A* should be clearly outlined, the *estimating methodology* or combination of methodologies should be well understood and easily defensible. The *model construct* will be much more stable and should include detailed data that has been gathered through previous estimating efforts or from current data that is captured in the model and the estimates.

In Phase C/D, when actual data is available, the *preferred cost methodology* is engineering buildup. This costing methodology involves computing the cost of a WBS element by estimating at the lowest level of detail (often referred to as the “work package” level) wherein the resources to accomplish the work effort are readily distinguishable and discernable. Often the labor requirements are estimated separately from material requirements. Overhead factors for cost elements such as ODCs, G&A expenses, materials burden, and fee are generally applied to the labor and materials costs to complete the estimate.

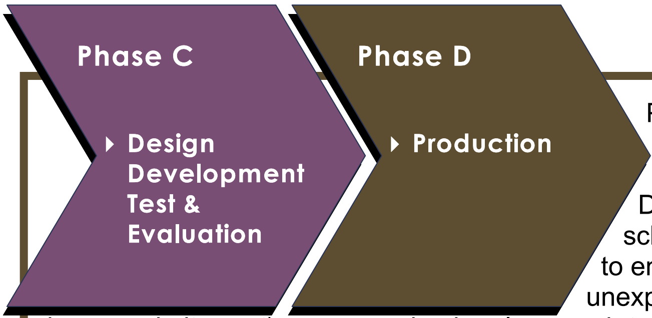
The Estimate
(Cost Estimating Process Tasks 8-12)



When conducting Phase C/D estimates, one must feed new information collected from contractor sources and tests back into the *point estimate* and the *risk assessment* creating a more detailed project estimate. During this phase, the cost-risk assessment should be very detailed, not only including any changes in requirements or project design, but other details provided by project technical experts such as testing and schedule impacts. While the product is being designed, developed, and tested, there are many little items that can change which impact the estimate and the risk assessment. It is critical to capture these changes to maintain a realistic program estimate now and in the future. During this phase, programmatic data may have just as much of an impact on the estimate and risk assessment as technical data.

Keeping the *estimate up-to-date* with these changes and having a full cost risk assessment helps to defend the estimate. Phase C/D activities demand an estimate that is *defensible* and replicable. By this phase, the estimators and the decision makers should be familiar and comfortable with the briefing template (see Appendix I) used for cost presentations, allowing the audience to focus more on the estimate results rather than understanding the layout of the charts.

Once the estimate has been conducted, documented and presented, it is important to keep it up-to-date with any program changes during Phase C/D activities and milestones.



Phase C establishes a complete design ("build-to" baseline) that is ready to fabricate (or code), integrate, and verify. During this phase, technical parameters, schedules, and budgets are closely tracked to ensure that undesirable trends (such as an unexpected growth in spacecraft mass or increase in its cost) are recognized early enough to take corrective action. Phase C/D is also the third phase where Project CCRM can be fully implemented and it repeats the *setting up, getting,* and *using* stages of Project CCRM just as in Phase B. As the project proceeds through design, development, and test and evaluation, the project technical description/NASA CADRe is updated as necessary to reflect major engineering and requirements changes. Updates to the reference point estimate, risk assessment, and cost-risk impacts, and CRL are made and reflected in new cost-risk distributions.

Cost trend data captured in the EVMS is an input to these LCCE updates since there is much to be gained from exploiting the cost, risk, and cost-risk knowledge captured via EVM and possibly IFM during development for improving cost and cost-risk databases, cost models and, ultimately, estimates on future projects.

Phase D builds and verifies the system designed in the previous phase, deploys it, and prepares for operations. Subsystems (including the operations system) are built and integrated to create the system. Phase D is the fourth phase where Project CCRM can be fully implemented employing the *setting up, getting* and *using* stages of Project CCRM just as in Phases B and C. As the project completes design, development, test and evaluation and proceeds to production, the project technical description/NASA CADRe is updated as necessary to reflect final engineering decisions along with associated updates to the reference point estimate (in conjunction with the EVM specialists tracking the cost trends in the Cost Performance Reports (CPRs), risk assessments, and cost-risk impacts. Since the end of Phase D represents the completion of project development, this is the most critical phase to capture the cost, risk, and cost-risk knowledge captured via EVM, possibly IFM and actual cost data along with final development phase technical parameters in the CADRe. This documentation will help improve cost and cost-risk databases, cost models and, ultimately, future project estimates.

Design changes continue to be an iterative process in this Phase, with cost estimates analyzed for affordability and effectiveness at each design change. Estimates are based on CDR/ near CDR quality definition and new estimates include estimates of major engineering changes. These should be integrated with EVMS by this Phase and processes for capturing cost analysis knowledge should also be in place to improve cost model accuracy. Some of these processes are contractor cost data collection requirements integrated into EVM, civil service cost data collection requirements integrated into IFM, and prime contractor special cost analysis DRs still required for other cost data requirements such as heritage of parts/software and other information.

Phase C/D Design, Development Test and Evaluation (DDT&E)

Phase C/D Overall Objectives

The connection between the Definition and the Design phases of an investment's life cycle is critical to maintain in order to realize estimated benefits and stay within estimated costs. Cost/performance trade studies are ongoing in this phase and updated periodically. In addition to creating the foundation for certain plans, the benefits and their definitions should be considered THE performance metrics and targets for the on-going evaluation of the investment. It is only logical that the criteria against which the investment was assessed would be the same as the criteria against which the performance of that investment is tracked and assessed through test and evaluation. The cost estimator, in developing the costs for these trades, plays a key role in this crucial assessment.

The following list describes some of the issues and challenges that the NASA cost estimator faces during this life cycle phase:

- Basic requirements changes.
- Make-it-work changes.
- Inadequate risk mitigation.
- Integration and test difficulties.
- Reluctance to reduce headcounts after peak.
- Inadequate insight/oversight.
- Lack of understanding or poor use of EVM and schedule analysis as an effective early warning capability.
- De-scoping science and/or operability features to reduce nonrecurring cost:
    - Contract and design changes between the Development and Operations phases;
    - Reassessing cost estimates and cost phasing due to funding instability and stretch outs; and
    - Development difficulties.
- Manufacturing breaks.

Phase C/D Roles and Responsibilities

The cost estimator's role in Phase C/D is to review the engineering build up estimate for reasonableness, completeness, and consistency with the project's GR&A. It is also the cost estimator's responsibility to test, understand, and validate the knowledge base used to derive engineering build up estimates. It is important for the estimator to understand his/her role in supporting the cost management phase of a project and how his/her updated estimates, actual cost data, and documentation can assist the PM. It is also important for the cost estimator to recognize his/her responsibility in capturing data from this phase of the Project to benefit future efforts. If actual cost data is captured and documented in a methodical manner, data collection after the program ends and during its execution is much easier and ensures that the data is more reliable.

While it is not as common for the estimator to be involved in Phase D estimates, it is becoming increasingly important. Costs and risks from the early phases of a project should have been captured and documented as actuals in the estimate to date. At this point in the project lifecycle, Project CCRM has been fully employed and is generating risk and cost-risk data that is being captured and used. It is important for the cost estimator to ensure this data is reflected in the program LCCE. It is important to capture the data for the immediate project estimates and as data for estimating the costs of future projects.

Phase C/D Exit Criteria

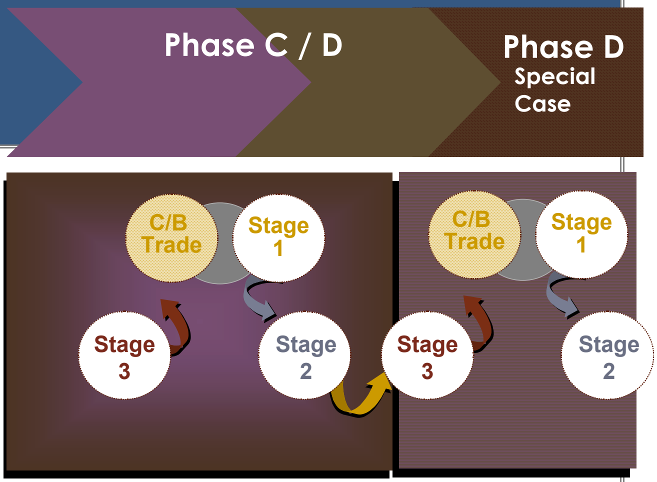
Reviews at this Phase with Code D/BC involvement and the governing PMCs are designed to minimize duplication with other reports and organizations involved. These reviews ensure the concept being tested and deployed meets NASA re-sourcing goals and objectives for the project, among other requirements. Phase C/D estimates involve project surveillance and estimates of any new or modified concepts. If costs are accepted, the estimates become part of the overall approval process to move the system to operations. If estimates are not satisfactory, they are returned to the cost office for additional estimation and analysis. Exit criteria include:

- Estimates of major engineering changes (in cooperation with EVM community).
- Estimates if project re-baselines.
- Improved processes for capturing cost estimating knowledge for future cost models.
- Using NASA CADRe and augment via EVM and possibly IFM.

The Project CCRM Connection | Risk Considerations

During Phase C/D, the implementation of Stage 3 CCRM Steps 9-12 repeats exactly as in Phase B except with Phase C/D cost-risk feedback information in preparation for the CDR LCCE update.
Project Definition (Cost Estimating Process Tasks 1-3)
The Project's Phase C/D Stage 1 CCRM Steps 1 and 2, involving updates to the cost/performance trades studies and refinements to project definition, also repeat exactly as in Phase B except with Phase C/D trade studies and project definition updates in preparation for the CDR LCCE.
Cost Methodology (Cost Estimating Process Tasks 4-7)
The Project's Phase C/D Stage 1 CCRM Step 3, involving the further refinement of the cost methodology, also repeats exactly as in Phase B except with Phase C/D cost methodology updates in preparation for the CDR LCCE.
The Estimate (Cost Estimating Process Tasks 8-12)
The Project's Phase C/D Stage 2 CCRM Steps 6-8, involving the writing of cost-risk feedback RFP DRDs, review of bidder cost proposals and post-contract award NASA/contractor meeting (e.g., IBR), also repeats exactly as in Phase B except with Phase C/D medium and high risk WBS element updates. These are the post estimate CCRM steps.

Post **Phase C / D**
Estimate Project CCRM Activities

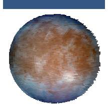


The Project's Phase C/D CCRM Stage 2's Steps 6-8, involving the writing of cost-risk feedback RFP DRDs, review of bidder cost proposals and post-contract award NASA/contractor meeting (e.g., IBR), also repeats exactly as in Phase B except with Phase C/D medium and high risk WBS element updates. The project is now ready to enter into Special Case Phase D (Production).

4.5 Special Case: Phase D (Production)

In the unusual case at NASA that more than one unit of a system is produced (e.g., reusable launch vehicles, multiple TDRSs, etc.), the Project enters Special Case Phase D. For the most part, the tasks followed in Phase C/D should also be followed in Special Case Phase D, Production. For example, both the *WBS and CADRe* should be *updated* to prepare for *updates to the reference point cost estimate, risk assessment,* and "S"-curve. Also, the CRL should be updated in the *cost estimate documentation*.

Cost estimates in Phase D still focus on major engineering changes (in cooperation with EVM community) and estimates if project re-baselines. Reviews and cross check estimates are conducted at the end of Phase D to evaluate production costs and readiness to move to operations and support in Phase E. During special case Phase D, it is important for the estimator to focus on using improved processes for capturing cost estimating knowledge for future cost models as production runs at NASA are not common on all Projects. Using the NASA CADRe data and augmenting it with EVM and possibly IFM data is important for collecting actuals for future Projects.



The Project CCRM Connection | Risk Considerations

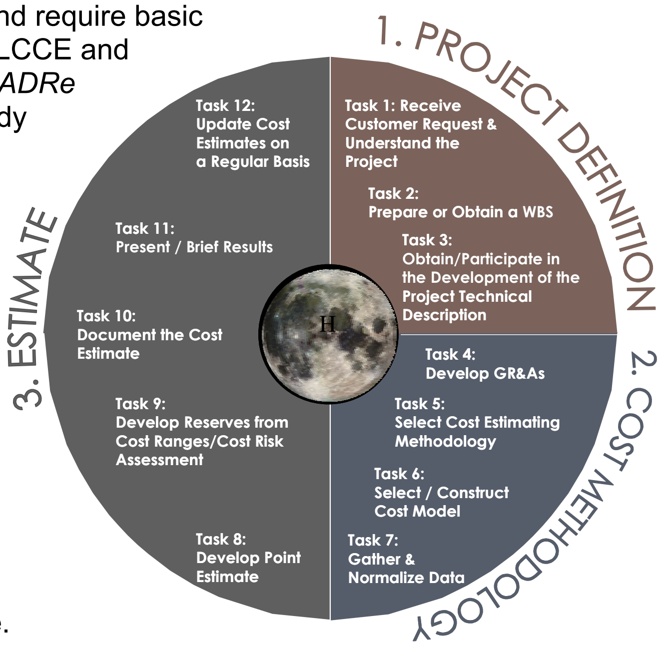
Most risk should have been retired by the time multiple copies of a system are being produced, unless requirements have changed and/or enhanced performance is desired, which must be reflected in the updated WBS and CADRe. If actual cost and cost risk data has not been ported over for use in cost estimating and cost risk models/methodologies and databases, it should be done at this time. If changes are made to the system, updates to the CADRe, reference point estimate, cost risks, and LCCE "S" curve should be made.

During Special Case Phase D, the implementation of CCRM Steps 9-12 repeats exactly as in Phase C/D except with Special Case Phase D cost risk feedback information in producing LCCE updates.

4.6 Phase E: Operations, Support & Disposal

PROJECT DEFINITION/COST METHODOLOGY/THE ESTIMATE (TASKS 1-12)

Phase E estimates should be mature and require basic updates to ensure an accurate Project LCCE and future data collection. The *WBS and CADRe* for O&S should be essentially at a steady state with any changes requiring updates being a function of significant requirements and/or major system element performance changes. Since disposal costs can be as innocuous as letting a satellite's orbit deteriorate in a structured, safe sequence, or as significant as launching a newly developed external propulsion module for boosting the space vehicle into the sun or into a controlled, safe but self-destructive, earth re-entry orbit, the disposal part of Phase E deserves an update to the system WBS and CADRe.



If estimates are conducted during this Phase, the *GR&A* are generally more concise and refined. The appropriate *cost methodology* at this time is usually the use of actual project costs and models containing this information are usually the same models used in Phase C/D and earlier.

Phase E

- Operations , Support, & Disposal

Phase E is the final phase of a Project and of Project CCRM. As a Project proceeds to the Operations, Support & Disposal phase, the project technical description or CADRe is updated as necessary to reflect final engineering decisions along with associated updates to the reference point estimate (in conjunction with the EVM specialists tracking the cost trends in the CPRs), risk assessments, and cost-risk impacts.

The connection between the DDT&E and the Operations, Support & Disposal phases of an investment's life cycle is critical to maintain to realize estimated benefits and capture actual data during operations. This is the stage where the benefits of CCRM are realized. Actual cost data can also benefit future projects by using the performance metrics and targets from the current project evaluation and cost growth lessons learned. Collecting and sharing O&S data is helpful as there is very little O&S data available to estimators.

Phase E Overall Objectives

The overall objective of Phase E is to support, maintain, and at the appropriate time, dispose of the system. Cost estimators may be asked to conduct Estimates at Completion (EACs) at the beginning of this Phase and should be available to the Project team for analyzing project cost data for use in follow on projects. Costs and risks from the early phases of a project should have been captured and documented as actuals in the estimate to date. The costs of O&S are often overlooked when capturing actuals for comparisons to estimates.

Phase E Roles and Responsibilities

This is an excellent time for the estimator to reconcile previous estimates to the current actuals and calibrate estimating methods from the initial estimates. At this point in the project life cycle, Project CCRM has been fully employed and is generating useful data. It is important for the cost estimator to ensure this data is accurately captured and reflected in the program LCCE and stored for future projects in ONCE. If the actual cost data is captured and documented in a methodical manner during O&S, it makes the effort of data collection after the project ends much easier and ensures that the data is reliable.

Phase E Issues/Challenges

The following list describes some of the issues and challenges that the NASA cost estimator faces during this life cycle phase:

- Little involvement in the project due to minimal requirements for estimate updates.
- Limited access to data for future use.
- Important phase for data capture for use on future programs to reflect accurate O&S costs and an overview of the entire Project costs.

Phase E Exit Criteria

Exit criteria for a Project from Phase E leads to Project closure. This exit criteria is not based on a cost estimate, but rather a measure of success for the Project objectives, cost data captured, cleanup, and disposal. For a cost estimator, the most important criteria is estimate reconciliation and archiving actual data for future estimates. Some of the key criteria for Project exit from Phase E include:

- Project has been fully operational and supported through its expected life.
- Project is disposed of as planned.
- All actual data and cost estimating knowledge is captured for future cost models.
- The project and the cost estimating team reconcile estimates at completion (EAC) with cost/performance data and document lessons learned.

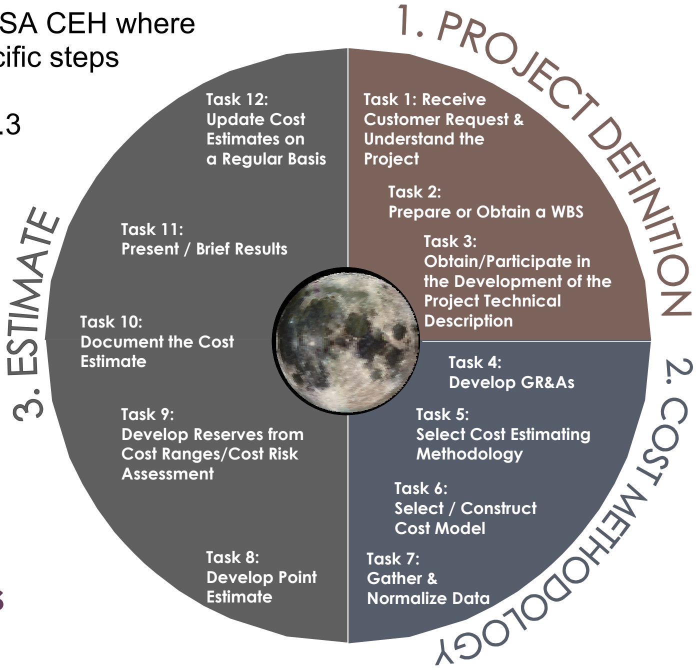
The Project CCRM Connection | Risk Considerations

As Phase E is the final phase of the project and the CCRM, estimates should be detailed. The project has completed the major phases of the life cycle, previous estimates have been refined, and detailed data has been captured and documented in a form that may assist as analogies for future programs. Most risk should have been retired by time the O&S portion of Phase E occurs, unless requirements have changed and/or enhanced performance is desired. These changes, as well as any new risks must be reflected in an updated WBS and CADRe. Additionally, if any new risk is introduced due to disposal requirements, it should also be included in the Phase E WBS, CADRe, and corresponding updates to the reference point estimate, cost-risk, and LCCE "S"-curve.

5 Cost Estimating Application

5. Cost Estimating Application

This section is the "how to" of the NASA CEH where details on how to do accomplish specific steps of the cost estimating process are described. As described in section 3.3 and shown in the graphic to the right, there are three main parts to the NASA 12 step cost estimating process. In this section, each of the 12 tasks within each of the three parts are described in greater detail.



5.1. Project Definition Tasks

The first three tasks in the cost estimating process relate to defining the project. The tasks associated with defining the project help to establish the framework from which the estimate can be conducted.

Task 1: Receive Customer Request and Understand the Project

The goal of this task is to interface sufficiently with the customer to gather enough project information to generate an accurate estimate.

There are three activities associated with understanding the project.

1. Gather all relevant project data for evaluation. Discuss schedule, data, expectations, and resource requirements with the requesting customer. If an estimate has been conducted for this product before, review and incorporate lessons learned and customer feedback from the last effort.

2. Evaluate the project's mission needs, objectives, and goals and assess the operating environment and life cycle phase for the project within the context of the NASA enterprise architecture.
3. Review all related project documentation, including an existing technical baseline or CADRe, previous estimates, budget data and programmatic data such as schedules.

When a request for a cost estimate is received, the supervisor of the cost group must ascertain if he/she has the resources to accept the assignment based upon his/her understanding of the expectations of the estimate. The estimator then determines the magnitude of the workload required, i.e., the type of estimate, the due date(s), and relative priority of the request. If the request is accepted, the supervisor will notify the requester of this fact and will assign an estimator (or estimators) to the task. As illustrated in Exhibit 5-1, there are four critical elements to any estimate that need to be understood and agreed upon between the cost estimator and the decision-maker before a methodology can be chosen and an estimate can be developed. These four elements are resources, data, schedule and expectations.

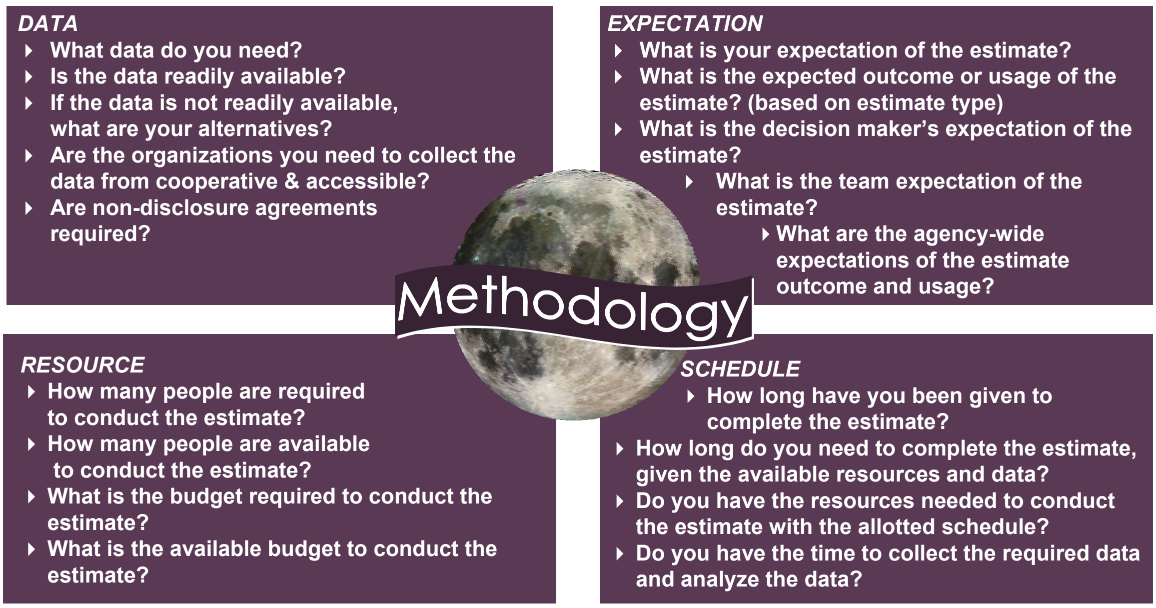


Exhibit 5-1:
The Four Critical Elements of a Cost Estimate

While the methodology selected will be influenced by these four elements, the estimating process itself does not vary greatly between the different types of estimates.

It is essential that the cost estimating process begins on the right footing, which is why this first task is important. In early life cycle phases, there will be many unknowns. It is the role of the cost estimator to ask insightful questions that help the Project Management staff make decisions regarding key aspects not normally considered in an early stage (e.g., maintenance concept, testing strategy, etc.,) and to address issues such as manpower, schedule, technologies, and cost drivers that can have a major impact on risk.

Determining the four critical elements of a cost estimate along with understanding the initial need and the desired outcome of the estimate are essential to starting an estimate off on a solid foundation. This initial communication and understanding will provide the estimate with adequate resources, funding and support for a successful outcome.

Task 2: Build or Obtain a WBS

The objective of this task is to provide a consistent structure that includes all elements of the project the cost estimate will cover.

There are three activities associated with preparing or obtaining a WBS:

1. Determine if a WBS exists or work with the project to create.
2. Create a WBS Dictionary to define the WBS elements.
3. Ensure that the cost estimating WBS is consistent between functions such as budgeting, weight statements, EVM, project plan, System Engineering Master Plan (SEMP), contracts, Integrated Financial Management (IFM), etc., to enable improved cost estimation, future data collection, and performance measurement and management.

According to NPR 7120.5B, the WBS "serves as the structure for project technical planning, scheduling, cost estimating and budgeting, contract scope definition, documentation, product development, and status reporting and assessment (including integrated cost/schedule performance measurement)." The WBS is a critical project management tool used throughout the project's life cycle to structure the project, to manage acquisitions, to capture all costs, and to communicate scope among review authorities and stakeholders. It provides a structure that includes all elements of the project the cost estimate will cover.

In Pre-Phase A, the cost estimator will either obtain a high-level Project WBS(s) from the project staff or work with them to develop one. A Project WBS is the comprehensive WBS including all life cycle phases and items including the hardware for the product, and other items such as training, SE&I, I&T, system test, and project management. Additionally, a companion high-level WBS dictionary that describes the overall structure and content of each major element of the WBS must be developed. The WBS dictionary communicates the contents of each major WBS element to avoid duplication and to ensure full coverage.

A good WBS has a strong product focus with a project life cycle orientation, and generally includes hardware, software, and supporting services. It establishes a hierarchical structure or product oriented "family tree" of elements. It is used to organize, define and graphically display all the work items or work packages to be done to accomplish the project's objectives, including:

- Project and technical planning and scheduling;
- Cost estimation and budget formulation (in particular, costs collected in a product-based WBS can be compared to historical data collected against the same products);
- Defining the scope of statements of work and specifications for contract efforts;

- Project status reporting, including schedule, cost, workforce, technical performance, and integrated cost/schedule data [such as EVM and estimated cost at completion (EAC)]; and
- Plans such as the SEMP and other documentation products such as specifications and drawings.

It is desirous that WBSs be standard and consistent throughout NASA and during Pre-Phase A and Phase A is the right time to begin creating this standard structure. This means that WBS elements for similar projects within each NASA organizational Code will have standard and consistent labels and definitions (i.e., content) and be standard and consistent across different cost disciplines (e.g., cost estimating, EVM, cost databases, etc.). This consistency will enable improved cost estimation, performance measurement, and project management. To the extent possible, these WBSs should also be consistent with the WBSs contained in the cost models used at NASA (e.g., NAFCOM, PRICE, SEER, etc.). The NASA Systems Engineering Handbook sets forth policies and processes for preparing WBSs and some standard examples of WBSs used at NASA are listed in Appendix G.

TIPS

- MIL HDBK 881B (http://www.kolacki.com/MIL-HDBK-881.htm) is the DOD's guide to WBSs
- The OSD CAIG (http://www.dtic.mil/pae/paeosg04.html) provides guidelines for the development and definition of standard elements for O&S cost estimates.
- A WBS may also be called a Cost Estimating Structure (CES), Cost Element Structure (CES), or Cost Breakdown Structure (CBS).
- The WBS you create might not necessarily map to the estimating structures found in commercial tools used in the estimating community. Know the tool you plan to use before you begin and be prepared to provide a map of your WBS back to the project WBS if there are differences.
- Examples of standard WBS's used at NASA can be found in Appendix G.

Task 3: Build or Obtain a Project Technical Description or CADRe

The objective of this task is to establish a common baseline document used by the project team and independent estimators to develop their estimate(s).

There are two activities associated with developing or obtaining a project technical description:

1. Describe the level two or lower system characteristics, configuration, quality factors, security, its operational concept, and the risks associated with the system for use by the cost estimator.
2. Describe the system's (or the project's) milestones, schedule, management strategy, implementation/deployment plan, test strategy, security considerations, and acquisition strategy.

Every estimate regardless of size needs to define what is being estimated. The NASA organization sponsoring a project will prepare, as a basis for life-cycle cost estimates, a description of features pertinent to costing the system being developed and acquired. The type of document used to record this project technical description depends on the time available to conduct the estimate, the size of the project, technical information available, including the requirements' thresholds and goals (objectives), and the phase of the life cycle in which it exists. Projects that are smaller in size or earlier in their project lives may only require a simple data sheet with technical requirements provided by the project to support developing a ROM cost estimate.

The project technical description defines and provides quantitative and qualitative descriptions of the project characteristics from which cost estimates will be derived. As such, the project technical description ensures that cost projections jointly developed by the Project Offices and the independent review organizations are based on a common definition of the system and project. The project technical description also should identify any area or issue that could have a major cost impact (e.g., risks) and, therefore, must be addressed by the cost estimator. A further benefit derived from the CADRe is its built-in requirement for end-of-contract actual costs and technical parameters (by WBS element) used to update NASA cost models. These values (e.g., KEPPs) and actual costs at the end of the contract are ported into the ONCE database.

TIPS

Many times, in Pre-Phase A, a formal CADRe is not required. However, following the basic format for the NASA CADRe in developing the project technical description for these projects in Pre-Phase A is encouraged. It will help in the eventual development of the CADRe in later life cycle phases when required.

The CADRe is a hybrid requirement that is unique within NASA that combines key elements of two previously used DRDs - the Cost Analysis Requirements Description (CARD) and LCCE into a single, coordinated document. The CADRe, like the CARD, is "owned" by the PM, although populating most of its content can be a contractual requirement. While it does not incorporate the WBS DRD, the information contained in the CADRe DRD must conform to the approved project WBS in order to ensure that each and every element of the entire project is included. See Appendix H for information about the CADRe DRD. Templates for the NASA CADRe are still in development as of the date of publication for the NASA CEH. When they are available for release, they will be posted on ceh.nasa.gov.

QUESTION: Why Use a CADRe?

ANSWER: Cost estimators use the CADRe's project technical description to develop a project LCCE or ICE. The reconciliation effort of the two estimates measures success and validation, with credibility critical. If the CADRe details or assumptions are wrong, then all estimates will be flawed and reconciliation will be difficult. Cost organizations assist in developing a CADRe but it is owned and signed by the PM.

QUESTION: When is a CADRe Required?

ANSWER: Although no dollar value indicates when a CADRe is required, if an ICE is required, a CADRe is required. Per Draft 7120.5C, NASA requires that an initial ICE be performed prior to entering into Phase B. In general, the threshold for a NASA ICE is over $250 million for projects moving from Phase A to Phase B. Projects less than $250 million require an abbreviated NASA CADRe.

5.2. Cost Methodology Tasks

The next four tasks of the cost estimating process relate to selecting and administering the cost methodology, which will guide the development of the cost estimate. These four tasks are detailed below.

Task 4: Develop Ground Rules and Assumptions (GR&A)

The objective of developing GR&As is to communicate the context/environment within which the estimate is being developed.

There are three activities associated with developing the GR&As:

1. Establish a set of programmatic, technical, and schedule GR&As to define the scope of the estimate (i.e., what costs are being included and what cost are excluded).
2. Achieve consensus on the GR&A with stakeholders, vendors, end users, etc., to ensure their applicability.
3. Fully document the GR&A.

The cost estimator works with the NASA PM and members of the technical team to establish and document a complete set of GR&A that are necessary to provide definition to the project and the estimate and to bound its scope. GR&A let everyone understand what costs are being included and what costs are excluded in the current estimate. This allows for easy comparisons to future estimates and to independent ones. GR&A should be developed in coordination with and agreed upon by the NASA PM. Then, the cost estimator should spend time socializing the GR&A with other stakeholders so that consensus can be built and problems leading inaccurate or misleading estimates can be avoided.

Each estimate should have two sets of GR&A, global and element specific. Global GR&A apply to the entire estimate and include ground rules such as base year dollars, schedules, and total quantities. Detail element GR&A are developed as each WBS element is being estimated and are found in the detail section for each WBS element. Detail element GR&A provide details for each element such as unit quantities and schedules. Since it is impossible to know every technical or programmatic parameter with certainty before and into the design phase of a program/project, a complete set of realistic and well-documented GR&A adds to the soundness of a cost estimate. Descriptions of relevant missions and system characteristics, manning, maintenance, support, and logistics policies are generally included in the GR&A. GR&A are more prominent in less defined Pre Phase A and Phase A projects, because there are more unknowns and are less prominent in well defined Phase B and on projects because there are less unknowns about the program. Global and detail element GR&A can also be found in the CADRe and should be in sync with the estimate.

Following is a list of areas that should be covered by an estimator preparing the GR&A.

Examples

- Guidance on how to interpret the estimate properly.
- Clarification to the limit and scope in relation to acquisition milestones.
- What base year dollars the cost results are expressed in, e.g., FY04$.
- Inflation indices used.
- Percentages (or approach) used for computing program level wraps: i.e., fee reserves, program support, OCD, HQ taxes, Level II Program Office, etc.
- Technology assumptions and new technology to be developed.
- Production unit quantities, including assumptions regarding spares, long lead items and make or buy decisions.
- Quantity of development units, prototype or protoflight units.
- LCC considerations: mission lifetimes, hardware replacement assumptions, hardware and software heritage, launch rates, number of flights per year.
- Implementation approach aspects such as Integration and test approach/test articles, mission assurance/safety approach, planetary protection approach, launch approval approach, commercialization and outsourcing approach, and partner commitments.
- Schedule information: development and production start and stop dates, Phase B Authorization to Proceed (ATP), Phase C/D ATP, first flight, Initial Operating Capability (IOC) timeframe for LCC computations, etc.
- Use of existing facilities, modifications to existing facilities, and new facility requirements.
- Cost sharing or joint funding arrangements with other government agencies, if any (e.g., partnerships), make buy decisions, outsourcing or commercialization approach.
- Management concepts, especially if cost credit is taken for charge in management culture, New Ways of Doing Business (NWODB), in-house versus contract, etc.
- Operations concept (e.g., launch vehicle used, location of Mission Control Center [MCC], use of Tracking and Data Relay Satellite System [TDRSS], Deep Space Network [DSN], or other communication systems, etc.).
- Operations and Support (O&S) period, maintenance concept(s) and if required, training strategy.
- Commonality or design inheritance assumptions.
- Specific items or costs excluded from the cost estimate.

Task 5: Select Cost Estimating Methodology

The goal of this task is to select the best cost estimating methodology (or combination of methodologies) for the data available to develop the most accurate cost estimate possible.

Within the execution of this task are the following four activities:

1. Determine the type of system being estimated.
2. Determine the life cycle phase of the project.
3. Determine the availability of data.

Exhibit 5-2 illustrates a quick reference chart used for selecting cost estimating methodologies.

	Pre-Phase A	Phase A	Phase B	Phase C/D	Phase E
Parametric	●	●	◑	◑	○
Analogy	●	◑	◑	◑	○
Engineering Build Up	◑	◑	●	●	●

● Primary ◑ Applicable ○ Not Applicable

Exhibit 5-2:
Cost Estimating Methodology Selection Chart

Parametric Cost Estimating

Estimates created using a parametric approach are based on historical data and mathematical expressions relating cost as the dependent variable to selected, independent, cost-driving variables through regression analysis. Generally, an estimator selects parametric cost estimating when only a few key pieces of data are known, such as weight and volume. The implicit assumption of parametric cost estimating is that the same forces that affected cost in the past will affect cost in the future. For example, NASA cost estimates are frequently of space systems or software. The data that relates to estimates of these are weight characteristics and design complexity respectively. The major advantage of using a parametric methodology is that the estimate can usually be conducted quickly and is easily replicated. Exhibit 5-3 shows the steps associated with parametric cost estimating.

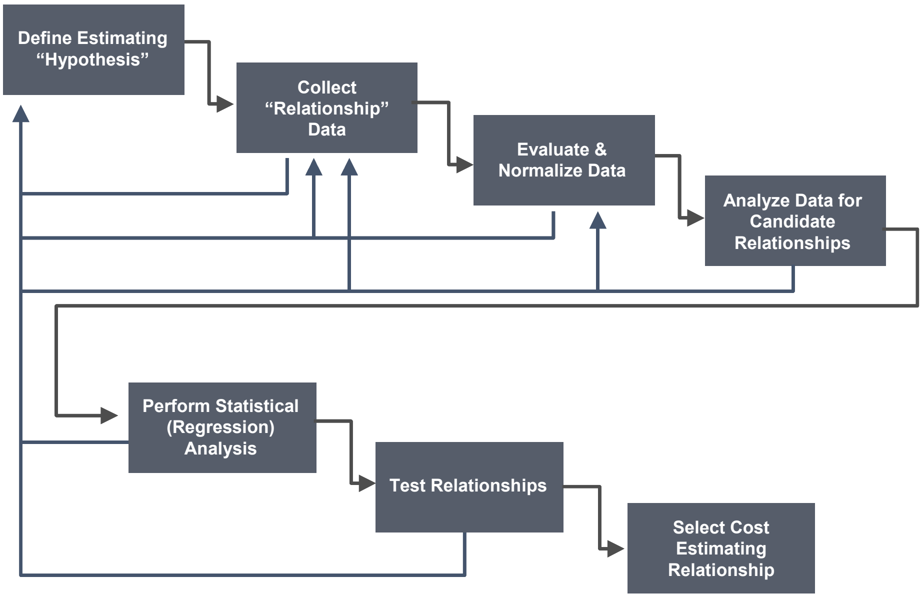


Exhibit 5-3:
Parametric Cost Estimating Process Steps

In parametric estimating, an estimator either creates his/her own CERs or uses NASA-developed, COTS, or generally accepted equations/models. If the estimator chooses to develop his or her own CERs, there are several techniques to guide the estimator. To perform the regression analysis for a CER, the first step is to determine the relationship between the dependent and independent variables. Then, the data is fit using techniques such as:

- Linear regression: involves transforming the dependent and independent variables into linear forms
- Nonlinear regression: for data that is not intrinsically linear

The dependent variable is called that because it responds to changes in the independent variable. For a CER, the dependent variable will always be cost and the independent variable will be the cost driver. The cost driver should always be chosen because there is correlation between it and cost and because there are sound principles for the relationship being investigated. For example, the assumption may be made that the complexity of a piece of computer software drives the cost of a software development project. The dependent variable is the Y variable and the independent the X variable. By plotting historical data on cost to complexity a chart that looks like Exhibit 5-4 may result.

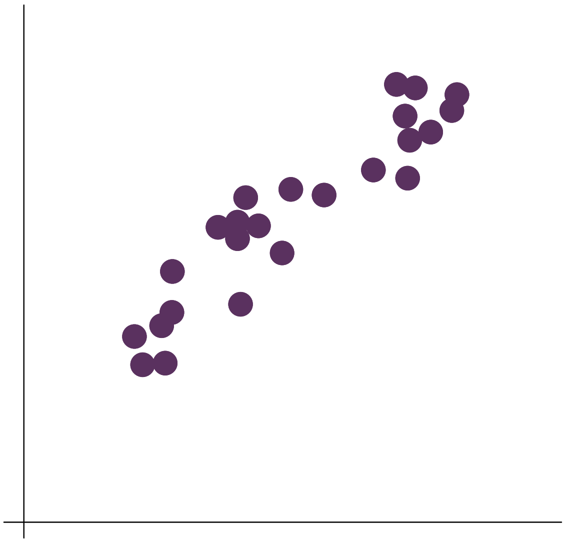


Exhibit 5-4:
Cost Complexity Chart

The point of regression analysis is to "fit" a line to the data which will result in an equation that describes that line, expressed by y = a +bx. In this case, we assume a positive correlation, one that indicates that as complexity increases, so does cost. It is very rare that a CER will be developed around a negative correlation, i.e., as the independent variable increases in quantity, cost decreases. Whether the independent variable is complexity or weight or something else, there is typically a positive correlation to cost.

One estimates the parameters of a model. The usual technique is called least squares. A linear regression model is one in which the dependent and independent variables can be transformed into a linear form. A non-linear regression model is one for which there is no such transformation. More formally, a non-linear regression model is one for which the first-order conditions for least-squares estimation of the parameters are non-linear functions of the parameters.

With the addition of possible explanatory variables (see Exhibit 5-5), a more precise and robust regression equation can be obtained. Since more than one independent variable is likely to have an effect on the dependent variable, one can calculate multivariate regression:

Regression Coefficient	Meaning
β_1	Impact of a one-unit increase in X_1 on the dependent variable Y, holding constant all the other included independent variables (X_2 and X_3)
β_2	Impact of a one-unit increase in X_2 on Y, holding X_1 and X_3 constant
β_3	Impact of a one-unit increase in X_3 on Y, holding X_1 and X_2 constant

Exhibit 5-5:
Regression Definitions

The usual method of regression coefficient estimation is using a computer program capable of calculating estimated coefficients with a technique called Ordinary Least Squares (OLS). Exhibit 5-6 provides a reference guide to help evaluate regression results.

Symbol	Check Point	Reference	Decision
X, Y	Data Observations	Check for errors, especially outliers in the data.	Correct any errors. If the quality of the data is poor, may want to avoid regression analysis or use just OLS.
$\beta\hat{}$	Estimated Coefficient	Compare signs and magnitudes to expected values.	If they are unexpected, respecify the model if appropriate or assess other statistics for possible correct procedures.
e_i	Residual	Check for transcription errors.	Take appropriate corrective action.
R^2	Coefficient of Determination	Measures the degree of overall fit of the model to the data.	A guide to overall fit.
Ř^2	R^2 adjusted for degrees of freedom	Same as R^2. Also attempts to show the contribution of an additional explanatory variable.	One indication that an explanatory variable is irrelevant is if the Ř^2 falls when it is added.
TSS	Total Sum of Squares	TSS = ?(Y_i-avg Y)^2	Used to compute R^2 and Ř^2.
RSS	Residual Sum of Squares	RSS = ? ($Y_{i\,-}$?$_i$)^2	Used to compute Ř^2 and Ř^2.

Exhibit 5-6:
Evaluating Regression Analysis Results

QUESTION: What is the Regression Analysis Methodology?

ANSWER: The Regression Analysis Methodology requires the following steps:

- Review the literature and develop the theoretical model.
- Specify the model.
- Select the independent variables(s) and the functional form.
- Hypothesize the expected signs of the coefficients.
- Collect the data.
- Estimate and test the hypotheses regarding the model's parameters.
- Document the results.

Regression analysis is used not to confirm causality, as many believe, but rather to test the strength and direction of the quantitative relationships involved. In other words, no matter the statistic significance of a regression result, causality cannot be proven. Instead, regression analysis is used to estimate and test hypotheses regarding the model's parameters.

When using the NAFCOM database, the estimator selects the inputs and NAFCOM will calculate the linear regression. Using a COTS package such as SEER (see Appendix P) or PRICE (see Appendix Q) gives the estimator the option to generate the entire estimate or to generate a point estimate to be used as output to another model.

CERs established early must be periodically examined to ensure that they are current throughout the life of an estimate and that the input range of data being estimated is applicable to the system. All CERs should be detailed and documented. If a CER is improperly applied, a serious estimating error could result. Excel© or other commercially available modeling tools are most often used for these calculations. Exhibit 5-7 lists some strengths and weaknesses of using parametric methodology to develop a cost estimate.

Strengths	Weaknesses
Once developed, CERs are an excellent tool to answer many "what if" questions rapidly.	Often difficult for others to understand the relationships.
Statistically sound predictors providing information about the estimator's confidence of their predictive ability.	Must fully describe and document selection of raw data, adjustments to data, development of equations, statistical findings and conclusions for validation and acceptance.
Eliminates reliance on opinion through the use of actual observations.	Collecting appropriate data and generating statistically correct CERs is typically difficult, time consuming, and expensive.
Defensibility rests on logical correlation, thorough and disciplined research, defensible data, and scientific method.	Loses predictive ability/credibility outside its relevant data range.

Exhibit 5-7:
Strengths and Weaknesses of Parametric/CER Cost Methodology

Analogy Cost Estimating Methodology

Analogy estimates are performed on the basis of comparison and extrapolation to like items or efforts. Cost data from one past program that is technically representative of the program to be estimated serves as the basis of estimate. Cost data is then subjectively adjusted upward or downward, depending upon whether the subject system is felt to be more or less complex than the analogous program. Clearly subjective adjustments compromise completely the validity and defensibility of the estimate and should be avoided. Best-fit, linear extrapolations from the analog are acceptable "adjustments." This estimating approach is typically used when an adequate amount of program and technical definition is available to allow proper selection, and adjustment, of comparable program costs. With this technique, a currently fielded system (comparable system) similar in design and/or operation of the proposed system is identified. An analogous approach is also used when attempting to estimate a generic system with very little definition.

The analogy system approach places heavy emphasis on the opinions of "experts" to modify the comparable system data to approximate the new system and is therefore increasingly untenable as greater adjustments are made. Exhibit 5-8 provides a list of the strengths and weaknesses of using an analogous system method to develop a cost estimate.

Strengths	Weaknesses
Based on actual historical data.	Relies on single data point.
Quick.	Can be difficult to identify appropriate analog.
Readily understood.	Requires "normalization" to ensure accuracy.
Accurate for minor deviations from the analog.	Relies on extrapolation and/or expert judgment for "adjustment factors."

Exhibit 5-8:
Strengths and Weaknesses of Analogy Method of Cost Estimating

Complexity or adjustment factors can be applied to an analogy estimate to make allowances including year of technology, inflation, basing modes, and technology maturation. A complexity factor usually is used to modify a CER for complexity (e.g., an adjustment from an air system to a space system). A traditional complexity factor is a linear multiplier that is applied to the subsystem cost produced by a cost model. In its simplest terms, it is a measure of the complexity of the subsystem being costed compared to the composite of the CER database being used or compared to the single point analog data point being used.

TIPS

Complexity Factors

Tables have been prepared by various NASA cost offices as guidelines to design engineers in making these judgments regarding selection of a complexity factor. Although these are not absolute standards, they may be useful as general guidance if the engineer is having difficulty quantifying his/her assessment of the relative complexities.

Q&A

QUESTION: How is the value of a complexity factor determined?

ANSWER:

The most uncomplicated approach to determining a value for the complexity factor of a subsystem is to work closely with the design engineer responsible for that subsystem. The following steps would generally be followed to determine the complexity factor. The design engineer (with the assistance of the cost estimator) would:

1. Become familiar with the historical data points that are candidates for selection as the costing analog,
2. Select that data point that is most analogous to the new subsystem being designed,
3. Assess the complexity of the new subsystem compared to that of the selected analog. This assessment would be in terms of design maturity of the new subsystem compared to the design maturity of the analog when it was developed, technology readiness of the new design compared to the technology readiness of the analog when it was developed, and specific design differences that make the new subsystem more or less complex than the analog (examples would be comparisons of pointing accuracy requirements for a guidance system, data rate and storage requirements for a computer, differences in materials for structural items, etc.),
4. Make a quantitative judgment for a value of the complexity factor based on the above considerations, and
5. Document the rationale for the selection of the complexity factor.

Source: JSC NASA Cost Estimating Guidelines

Engineering Build Up Methodology

Sometimes referred to as “grass roots” or “bottom-up” estimating, the engineering build up methodology rolls up individual estimates for each element into the overall estimate. This costing methodology involves the computation of the cost of a WBS element by estimating at the lowest level of detail (often referred to as the “work package” level) wherein the resources to accomplish the work effort are readily distinguishable and discernable. Often the labor requirements are estimated separately from material requirements. Overhead factors for cost elements such as Other Direct Costs (ODCs), General and Administrative (G&A) expenses, materials burden, and fee are generally applied to the labor and materials costs to complete the estimate. A technical person who is very experienced in the activity typically works with the cost analyst, who prepares these engineering build up estimates. The cost estimator’s role is to review the grassroots estimate for reasonableness, completeness, and consistency with the program/project GR&A. It is also the cost estimator’s responsibility to test, understand, and validate the knowledge base used to derive estimates.

Exhibit 5-9 illustrates a method for deriving an engineering build up estimate. While this is a simple illustration of the engineering build up methodology, it is important to remember to conduct other detail activities such as documenting the Basis of Estimates (BOEs) and schedules, and applying wage and overhead rates.

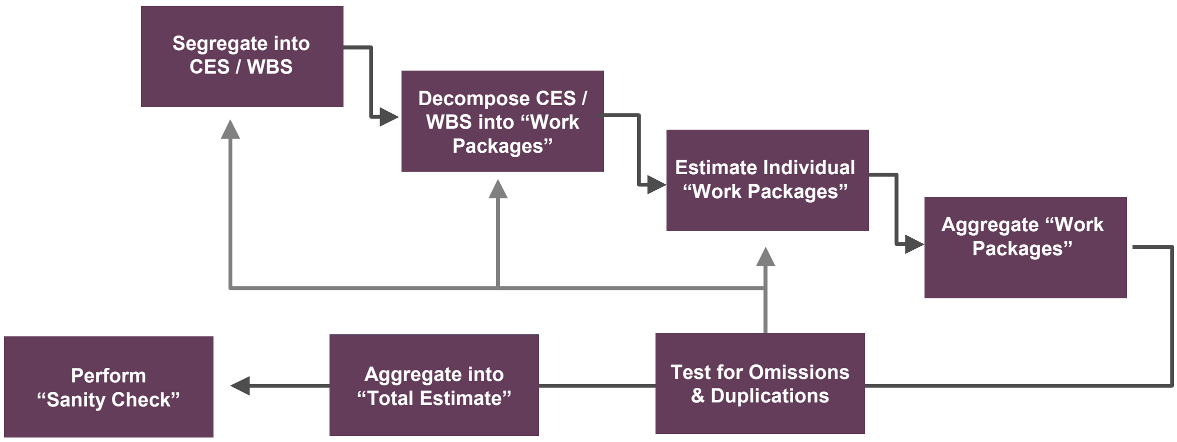


Exhibit 5-9:
Method for Developing an Engineering Build Up Estimate

There are also situations where the engineering community provides their “professional judgment,” but only in the absence of empirical data. Experience and analysis of the environment and available data provides latitude in predicting costs for the estimator with this method. This method of engineering judgment and expert opinion is known as the Delphi method. Interview skills of the cost estimator are important when relying on the Delphi method to capture and properly document the knowledge being shared from an engineer’s expert opinion. Delphi method usually involves getting a group of experts to converge on a value by iterating estimates using varying amounts of feedback. Individuals are generally not identified to the outside, and in some experiments, not identified to each other.

Exhibit 5-10 provides a list of the strengths and weaknesses of using the engineering build up method to develop a cost estimate.

Strengths	Weaknesses
Intuitive.	Costly; significant effort (time and money) required to create a build-up estimate.
Defensible.	Not readily responsive to "what if" requirements.
Credibility provided by visibility into the BOE for each cost element.	New estimates must be "built-up" for each alternative scenario.
Severable; the entire estimate is not compromised by the miscalculation of an individual cost element.	Cannot provide "statistical" confidence level.
Provides excellent insight into major cost contributors.	Does not provide good insight into cost drivers.
Reuse; easily transferable for use and insight into individual project budgets and individual performer schedules.	Relationships/links among cost elements must be "programmed" by the analyst.

Exhibit 5-10:
Strengths and Weaknesses of Engineering Build Up Method of Cost Estimating

Task 6: Select / Construct Cost Model

The objective of this task is to select the most appropriate tool/model or to create a model to estimate the cost. Factors that influence the selection process include data and resource availability, schedule, and cost.

There are three activities associated with selecting or constructing a model.

1. Review available choices and make a selection. If no suitable alternatives exist, explore the option of creating a model.
2. Be prepared to defend the choice.
3. Ensure that the model is full cost compliant.

Modeling is the systematic approach to analyzing a project that is supportive and quantifiable. Many cost estimating models exist, and, similar to the estimating methodologies, no single cost model can be used for all purposes. Some models are a basic construct to be used as a tool while other models are estimating environments that can be all-inclusive and automate many functions for the cost estimator. A model can also use a variety of estimating methodologies and direct inputs to complete a full estimate.

For each methodology described in the previous section, there are a multitude of both commercially available and government developed or owned models from which the cost estimator can make his/her selection. Generally speaking, one of these models and/or tools should help the cost estimator complete his/her task in a more efficient/effective manner. Many of the tools provide a construct to use for the model, standard WBSs, as well as data and CERs that can be used in the estimate. In addition, many cost estimators use Excel to create their own model when there are estimating needs that cannot be met by commercially available models. Information about many modeling products can be found in Appendices L through U.

Many commercially available models are parametric models that generate estimates based on specific parameters that drive an estimate's cost. These cost drivers include items such as weight, volume, quantity, and schedule. These models can be used when only a few of these input parameters are known to generate a high level estimate. If many of the cost drivers have been identified and there are many known technical input parameters, these models can also be used to generate very detailed and complex cost estimates. Commercially available parametric models use normalized industry data sets in generic and sometimes proprietary algorithms. In many cases these models should be calibrated based on the product that is being estimated to ensure the estimate takes into account factors such as the project environment (e.g., space, air) for a more accurate estimate. If a NASA estimator chooses to create his or her own parametric model with NASA data, the model is in effect, self-calibrated.

In some cases, an estimator may develop an extensive set of CERs for a specific item or to support a specific deliverable or purpose. In such cases, it may be more efficient for the estimator to develop and tailor their own model if the estimator is skilled at CER development, model building, and can have the model validated.

Most commonly used, Excel is a powerful, flexible spreadsheet tool used by the Government and the private sector. Due to its popularity, a lot of employees in the industry are savvy users and can deliver impressive models using the formulas, graphs, and Visual Basic functions that are embedded in the software. The Microsoft software package, including Access, Excel, PowerPoint, and Word are compatible with each other, which creates a seamless environment of automated tools. The advantage of creating your model in Excel is the ability of having a "glass box" model where all formulas and intricacies of your creation can be traced easily. The powerful formula and Visual Basic functions that are part of Excel provide endless avenues of creative model formulation. The ability to transfer the model from one place to another is fluid.

The disadvantage of creating a model in Excel is that the cost estimator needs to build the model from scratch. The analyst must take the time to draw the layout of how the model is going to look and how all the equations are going to fit together. Excel does not have embedded risk tools in the software but add-in tools are available to conduct risk analysis. Some of these add-in risk tools are listed in Appendix M.

If an estimator chooses to build his or her own model, following a disciplined process will ensure a credible product. Once the estimator has identified the need for a model and determined the model type, the model design can begin. The importance of spending time up front to design and understand the model cannot be underestimated. The model developer needs to define the scope of the model, how it will ultimately be used, and the approach for integrating the data and CERs collected and developed. While planning the development, it is important to document the model GR&A that will be used. The modeling environment is the next decision that should be made. The environment chosen may affect the complexity of the model and the resources required for the software development, testing, and validation.

After the model has been developed and populated with at least preliminary cost data, it must be validated before the estimator uses it. Once the model has been validated and any corrections or updates incorporated, it is fit for use to generate estimates. To complete the model development process, user documentation and training should be prepared.

Task 7: Gather and Normalize Data

The objective of this task is to arm the cost estimator with as much information as possible so that he/she can develop the most accurate and justifable cost estimate.

There are four activities associated with gathering and normalizing data.

1. Identify data needed and potential data sources.
2. Review, interview, and/or survey data sources to obtain data.
3. Conduct project schedule analysis.
4. Normalize data.

Data collection is one of the most difficult, time-consuming, and costly activities in cost estimating. Data needs are not always clear at the assignment's beginning and data requirements often evolve during an estimate's development. An estimator needs to recognize that data adjustments may be necessary to support a particular NASA Project Office's need.

It is also critical to collect risk data at this time to support the cost-risk assessment. Many of the experts that will be interviewed and the data that will be reviewed in this effort will not only support the cost estimate, but can assist in identifying risks early, and can also save time by reducing data collection later in the process during the cost risk assessment.

Typically, this is the step in the process where data collection occurs. However, as previously noted, data collection can occur in earlier steps, such as collecting data for regression analysis to support a methodology or even earlier in the process when the estimator is understanding the project. The following are potential mechanisms available to the cost estimator for identifying quantitative cost data:

- Surveys and/or questionnaires,
- Model specific data collection/input forms,
- Interviews,
- Focus groups,
- Target research (public domain or otherwise), including reviews, papers, and statistical analysis, and
- Specific cost, technical, and programmatic data from primary and secondary sources.

QUESTION: When is a Non-Disclosure Agreement (NDA) required for non-government employees?

ANSWER: Non-disclosure agreements (NDAs) are required for non-government employee access to Confidential Business Information (CBI), which includes proprietary and competition-sensitive contractor data. Applicable NDAs must be in-place between the originating and requesting organizations before access to such information can be approved.

NASA places the highest priority on protection of contractor technical and cost data. Federal employees are subject to the relevant provisions of the Federal Trade Secrets Act. For further information on this subject, contact Ron Larson at Code BC (202.358-0243 or e-mail <Ronald.Larson-1@nasa.gov>) for further information on this subject.

Based upon the resources, the schedule and the expectations, the estimator should use as many of these data collection methods as can be supported. Exhibit 5-11 provides a list of data types and sources. The cost estimator will work with the PM and members of the technical team to obtain the technical and programmatic data required to complete the cost estimate. Typically, these requirements are contained in a document, or set of documents such as a technical baseline or CADRe. A well-documented set of project requirements ensures that the cost estimators are estimating the same product that is being designed by the technical team. If some of the cost model inputs are not explicitly contained in the requirements document, the cost estimator will have to coordinate with the cognizant technical point of contacts to obtain the needed data by interview techniques and/or by survey mechanisms. Schedule analysis is another important part of data collection. More information on this technique can be found in Section 6.17.

Once data has been collected it needs to be normalized. Normalization involves analyzing the raw data collected and adjusting it to make it consistent. The inconsistencies that may be found in a data set include changes in dollar values over time (inflation), learning or cost improvements for organizational efficiency, and if more than one unit is being produced, the effects of production rates on the data set being analyzed.

When analyzing a data set, normalization considerations should include adjustments for cost (currency, base year), size and weight, complexity or mission, recurring/non-recurring and the mission platform (crewed, robotic).

Data Category	Data Type	Data Sources
	Three Principal Types of Data	
Cost Data	Historical Costs Labor Costs CERs from previous projects	Basic Accounting Records Cost Reports Historical Databases Contracts (Secondary) Cost Proposals (Secondary)
Technical / Operational Data	Physical Characteristics Performance Characteristics Performance Metrics Technology Descriptors Major Design Changes Operational Environment	Functional Specialist Technical Databases Engineering Specifications Engineering Drawings Performance / Functional Specifications End User and Operators
Project Data	Development and Production Schedules Quantities Produced Production Rates Equivalent Units Breaks in Production Significant Design Changes Anomalies (e.g., strikes, national disasters, etc.)	Project Database Functional Organizations Project Management Plan Major Subcontractors

Exhibit 5-11:
Data Types and Sources

Normalizing data for cost includes adjusting for inflation. This inflation adjustment is only to make the raw data set consistent and fit for use in CERs, models, or estimates. This data may be adjusted for inflation again in Task 8 when it has been incorporated into the cost estimate and the estimate as a whole is adjusted for inflation. The full estimate may be adjusted for inflation to show the results in BY, CY or TY dollars. Exhibit 5-12defines some common terms used for inflation and escalation.

Term	Definition
Base Year (BY) Dollar	A point of reference year whose prices form the basis for adjusting costs or prices from other years.
Constant Year (CY) Dollar (ConstY)	Money or prices expressed in terms of values actually observed in the economy at any given time. Constant dollars represent the purchasing power of dollars tied to a particular base year's prices; the base year must be identified, e.g. constant FY04 dollars.
Current Year (CY) Dollar (CurrY)	Money or prices expressed in terms of values actually observed in the economy at any given time. Current dollars represent the purchasing power of dollars at the time they are expended. (This is what NASA Calls Real-Year dollars, though that term is counter to its usage in DoD and other Federal departments, where real dollars means constant dollars.
Budget Dollar	Total Obligation Authority (TOA) inflated according to the amount of escalation used in the current budget year.
Then Year (TY) Dollar	TOA that includes a slice of inflation to cover escalation of expenditures over a multiyear period.
Real Year (RY)	Money expressed as spent dollars.
Inflation Rate	The % change in the price of an identical item from one period to another.
Outlay Profile	In percentage terms, the rate at which dollars in each appropriation are expected to be expended based on historical experience.
Raw Inflation Index	A number that represents the change in prices relative to a base period of 1.0000. Typically periods are 1 year.
Weighted Inflation Rate	Combines raw inflation indices and outlay profile factors to show the amount of inflation occurring over the entire period needed to expend the TOA.
Composite Inflation Index	A weighted average of the inflation indices for the applicable sub-appropriations.

Exhibit 5-12:
Inflation and Escalation Terms

The Cost Analysis Division in the Office of the CFO at NASA HQ provides an annual update of the NASA New Start inflation index (most recent version in Appendix V) to be used to prepare cost estimates for new R&D projects. These inflation indices can be used for:

- Inflating cost model results expressed in terms of ConstY costs to real year dollars for budgetary or POP purposes (use for inflating estimates in Task 8),
- Converting from constant dollars expressed in one year to constant dollars expressed in a different year, and
- Normalizing historical cost data expressed in real year (as-spent) dollars to ConstY dollars (use for inflating or deflating raw data in Task 7).

Through escalation, inflation adjusts costs to reflect the decrease in the purchasing power of money over time. The inflation factor is the "multiplier" used to account for the change in price of a product or service over time. Escalation factor (or weighted inflation) is the "multiplier" used to account for inflation plus the normal occurrence of allocating money in one year and it being spent over a number of years. An inflation calculation example is provided on the next page.

While inflation is the most common data normalization technique to improve consistency in a data set, there are other normalization techniques that can be just as important. Adjustments for learning or cost improvement curves may apply to the data set that you have collected. Production rate (units produced over a time period) may also have an affect on the raw data set, which calls for adjustment. In the case of production rates there may be patterns or influences in the production of the item such as facilities or manpower that affect the data. At NASA there are not many projects that involve production, however data collected from other sources that may be used in NASA estimates may have production considerations that should be taken into account. Other adjustments that may need to be made to normalize data include:

- Checking for scope consistency between product for the historical data and the product being estimated,
- Unusual events or anomalies in a projects life, such as extra testing, failures or labor anomalies,
- Technology improvements and advancements, where the data may need to be adjusted by using engineering judgment,
- Raw data adjustments from reporting system anomalies or changes, such as a change in rates, factors or hours for standard reporting,
- Reporting system differences which may require mapping accounting classifications to WBS elements, and
- Reporting system differences for categories of data with different definitions for the same item from one system to another.

Inputs (FY2002$)		FY02	FY03	FY04	Total
Example 1	BY	$ 100.000	$ 100.000	$ 100.000	$ 300.000
Example 2	CY	$ 100.000	$ 100.000	$ 100.000	$ 300.000
Example 3	TY	$ 100.000	$ 100.000	$ 100.000	$ 300.000

	FY02	FY03	FY04	
BY Inflation Factor (a)	100.000	100.000	100.000	
Weighted Inflation Factor (b)	100.000	103.100	106.300	
Multiplier (a)/(b)	1.000	0.970	0.941	

Outputs (FY2002$)					
Example 1	BY	$ 100.000	$ 100.000	$ 100.000	$ 300.000
Total		***$ 100.000***	***$ 100.000***	***$ 100.000***	***$ 300.000***
Example 2	CY	$ 100.000	$ 100.000	$ 100.000	$ 300.000
Inflation Factor		1.000	0.970	0.941	
Total		***$ 100.000***	***$ 96.993***	***$ 94.073***	***$ 291.067***
Example 3	TY	$ 100.000	$ 100.000	$ 100.000	$ 300.000
Inflation Factor		1.000	0.970	0.941	
Total		***$ 100.000***	***$ 96.993***	***$ 94.073***	***$ 291.067***

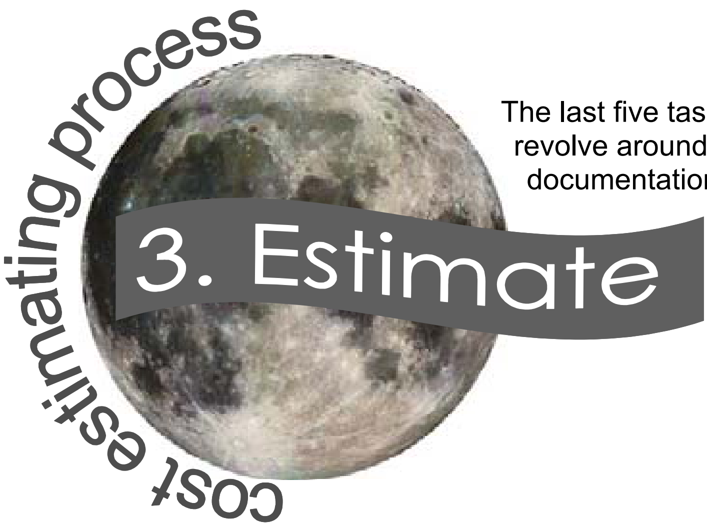
Inflation Table

Code:	108	
Term:	R&D	
Database:	System	
Source:	HQ NASA	
RevDate:	16-Apr-99	
Year	RAW	WTD
2000	94.100	94.100
2001	97.000	97.000
2002	100.000	100.000
2003	103.100	103.100
2004	106.300	106.300
2005	109.500	109.500
2006	112.900	112.900

Once data has been normalized it should be reviewed and validated. When reviewing data the estimator should ensure that a consistent data collection methodology, consistent data collection formats, and procedures to identify data anomalies are in place. Considerations such as data sufficiency to support the estimating methodology selected and documentation to ensure traceability of adjustments made to the data are also critical. These documented factors assist the estimator with the validation of the data and lead to data reliability and ultimate estimate credibility.

If an estimator takes each of these steps into consideration when identifying and collecting data, analyzing schedules, and normalizing data, the repeatability and credibility of the data supporting the estimate will be improved.

5.3. Estimate Tasks



The last five tasks of the cost estimating process revolve around the actual generation and documentation of the estimate. These tasks are detailed below.

Task 8: Develop Point Estimate

The goal of this task is to create an accurate LCC point estimate to be used in conjunction with the cost risk assessment to develop the final estimate.

There are eight activities associated with developing a point estimate.

1. Populate model with the normalized data collected.
2. Verify the GR&As.
3. Ensure the estimate is full cost compliant.
4. Run the model to calculate cost.
5. Time phase the estimate.
6. Adjust the estimate for inflation
7. Conduct any cross check estimate or estimate reconcilation.
8. Develop or update cost track to previous or independent estimate.

Once the model has been selected or constructed and the data has been gathered, the next step is to populate the model. Once the model has been populated with the data, according to the GR&A, the model is run and a point estimate established. Next, the data are properly time phased according to the planned deployment or integration schedule. This can be done using many techniques, including beta curves (see Appendix W), historical spreads, engineering judgment, or budget constraints. Just as the data needed to be normalized for inflation, the estimate must also be adjusted for inflation over its life cycle.

Before and after running the model it is important to check and recheck formulas and data entry to ensure accuracy and to document each input and formula for the detail estimate documentation. Another important step to remember is to conduct a cross check estimate, using an alternative methodology on your point estimate. This is important to ensure a "sanity check" on the original estimate and to show an alternative estimate view of the data. In addition, keeping the estimate up-to-date helps to defend the estimate, reduce updated estimate turn-around time, and gives the decision-maker a clearer picture for "what if" drills or major decisions.

Task 9: Develop Reserves from Cost Ranges / Cost Risk Assessment

The objective of this task is to produce a credible project cost "S"-curve - that is, the CDF for the range of costs of the project.

There are six activities associated with developing reserves from cost ranges and conducting the cost risk assessment.

1. Determine the project's cost drivers with input from the PM and staff.
2. Develop probability distributions for the cost model uncertainty.
3. Develop probability distributions for the technical and schedule cost drivers.
4. Run Risk Model.
5. Identify the probability that the actual cost is less than or equal to the point estimate.
6. Recommend sufficient reserves to achieve the 70% confidence level.

Cost risk assessment is the process of identifying and analyzing critical project risks within a defined set of cost, schedule, and technical objectives and constraints. It is balancing the probability of failing to achieve a particular outcome against the consequences of failing to achieve that outcome. This task also allows the cost estimator to document risks in a manner that accommodates proactive management of project costs. Details about how to conduct cost risk assessments are provided in Section 6.16, the 12 Tenets of Cost-Risk.

TIPS

Cost risk must be carefully and quantitatively assessed in developing and presenting any cost estimate for several reasons. First, when trade studies are conducted, a single cost estimate, such as an expected cost, may mislead the trade team by not revealing the potential for overruns. Second, at Confirmation Reviews and Authority to Proceed decision points, the cost estimate must include an appropriately chosen level of reserves. The objective of a cost risk analysis is to produce a credible project cost S-curve—that is, the cumulative distribution function for the cost of the project without reserves.

The cost risk assessment process forces the consideration of cost risks by the cost estimator and the PM and provides tangible data for use as the basis of decisions. The process enhances underestimating complexity of system development, attaches valuation to risk reduction activities/risk mitigation plans and integrates cost analysis and the formal technical assessment conducted by the Project known as Probabilistic Risk Analysis (PRA).

To quantify the cost impacts due to risk, one must first identify the sources of risk. There are three sources of risk for which cost-risk analysts should be concerned.

- The first is the risk inherent in the cost estimating methodology. For example, if a regression-based CER is used, it has an associated standard error of the estimate (SEE), confidence intervals, and prediction intervals, any of which can be used to include cost estimating methodology risk in the estimate. Cost risks are those risks due to economic factors such as rate uncertainties, cost estimating errors, and statistical uncertainty inherent in the estimate. Cost risk is dependent upon other fundamental risk dimensions (technical and schedule risks) so these must all be assessed to arrive at a true picture of project risk.

- The second source of risk is the risk inherent in the technical aspects of the systems being developed. Into this category of risk fall risk sources such as the technology's state of the art (TRLs are good indicators of this risk source), design/engineering, integration, manufacturing, schedule, complexity, etc. Quantifying the cost impacts due to these kinds of risk is not as statistically derivative as was CER risk. For this source of risk, a commonly used technique involves constructing a two-dimensional matrix where the rows are risk source drivers such as state of the art, design/engineering, integration, etc., and the columns are intensities such as low risk, medium risk, high risk. A technique known as Relative Risk Weighting adds a dimension for describing a worst case, best case, and reference case with respect to "technical" risk. This three-dimensional matrix produces relative scores for each case and cost-risk adjustment factors for constructing triangular WBS cost-risk distributions.

- The third source of risk for cost impacts is the correlation between WBS elements. Correlation assessment determines to what degree one WBS element's change in cost is related to another's and in which direction. For example, if the cost of the satellite's payload goes up and the cost of the propulsion system goes up then there is a positive correlation between both subsystems' costs. Many WBS elements within space systems have positive correlations with each other and the cumulative effect of this positive correlation tends to increase the range of the possible costs.

The cost risk assessment produces a credible project cost "S"-curve—that is, the cumulative distribution function for the range of costs of the project. NPR 7120.5C specifies the use of probabilistic cost risk analysis to quantify uncertainties in cost estimates. Quantifying these risks allows the estimator to address uncertainties in technical design, especially in Pre Phase A, Phase A and Phase B. It is also important for the estimator to address uncertainties in cost estimating methods (e.g. statistical variance in CERs) and provide decision makers range of cost outcomes as a function of confidence levels, and use these results for reserve determinations and recommendations. As the project proceeds through the lifecycle phases, the variance in the estimate narrows.

Cost risk must be carefully and quantitatively assessed in developing and presenting any cost estimate. As shown in Exhibit 5-13 the cost S-curve provides more information than a single number and can be used to choose a defensible level of reserves. The methods for developing a project's cost S-curve depend on the cost estimating methodology employed and the amount of risk information that the cost analyst can secure within the bounds of time and resources.

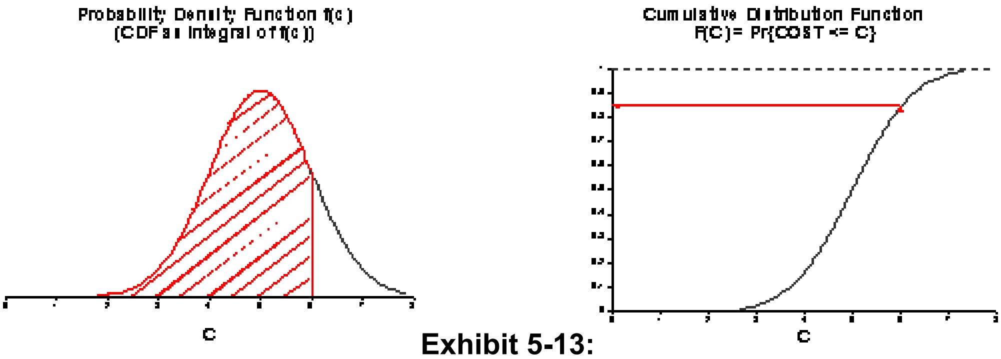


Exhibit 5-13:
A Probability Density Function (Left) and
Its Cumulative Distribution Function or S-Curve (Right)

The derivation of risk reserves for planning purposes begins with the probabilistic cost estimate range. As possible cost impacts due to estimation, technical, programmatic, and dependency risks are incorporated into the cost estimate, the reserve at the LCC level is identified. This reserve is quantified as the difference between the arithmetic sum of the WBS reference point estimates and the cost at the 70th percentile level of confidence. The 70th percentile level is chosen due to the NASA corporate risk reserve requirement for a not-to exceed 80th percentile Enterprise-level risk reserve. If each project within an Enterprise is budgeted at the 80th percentile level the Enterprise risk reserve will be statistically equivalent to approximately 96th percentile level, which is unacceptable from a Congressional appropriation request perspective.

In addition to determining the S-curve, conducting cost risk assessments contribute to:

- <u>Determining the project's cost drivers.</u> Analyzing which input variables will have a significant effect on the final cost can help determine which design (or programmatic) parameters deserve the most attention during the project's definition and design phase.
- <u>Estimating the probability of achieving the point estimate.</u> When a simulation risk analysis technique is performed using the low, most likely, and high values provided for the input variables, it can often be demonstrated that the point estimate has a less than 50-50 chance of being achieved.
- <u>Providing a cost range.</u> A cost range is often more useful to a PM than a point estimate as it provides a series of low and high values of the input parameters to establish the low end and the high end of the cost estimate.

Once the LCC model is fully developed with the input variable distributions, the model can then be subjected to a Monte Carlo simulation. A Monte Carlo simulation calculates numerous scenarios of a model by repeatedly picking random values from the input variable distributions for each "uncertain" variable and calculating the results. Typically, a simulation will consist of 2,500 to 10,000 iterations. The results of Monte Carlo simulations are risk-adjusted estimates and corresponding statistical estimate distributions. The estimate distributions provide the decision-maker with a range of possible outcomes and bounds, with a minimum and maximum value. (The input variable distributions and cost estimate range is provided with each alternative analysis.)

Q&A

QUESTION: Why is it important to conduct a cost risk analysis?

ANSWER: Cost risk analysis quantifies the budget reserves necessary for acceptable level of confidence. When asked how much of the dollar figure being proposed is for management reserve, a good strategy is to prepare the calculation below in advance, so that you can respond to that question by saying that the percentage (namely, whatever [(80th-50th)/50th]x100% turns out to be) is the amount by which the 80th percentile cost exceeds the 50th, and therefore can be considered "management reserve." Generally Code BC will recommend budgeting at 70% to 85%, (70% standard) confidence levels, depending upon project scope, importance, and sense of completeness of the risk analysis. Risk dollars should be phased in the estimate where they will most likely be needed. Most often the risk dollars are needed when common problems manifest between PDR and CDR and then again during Integration and Test. High leverage risk mitigation is commonly most effective prior to PDR.

It is recommended that a sensitivity analysis be performed to identify the major cost drivers, i.e., those variables whose changes create the greatest changes in cost. Sensitivity analysis helps to determine how the different ranges of estimates affect the point estimates. For decision- makers a range estimate with an understanding of the certainty of how likely it is to occur within that range is generally more useful than a point estimate. Due to the nature of the NASA design and development process there will always be uncertainty about the values of some, if not all, of the technical parameters during the definition phase of a project. Likewise, many of the assumptions made at the beginning of a project's definition phase will turn out to be inaccurate. Therefore, once the point estimate is developed, it is often desirable to determine how sensitive the total cost estimate is to changes in the input data.

While sensitivity analyses can occur at any stage of an estimate, it generally makes sense to derive an unconstrained solution that meets all mission objectives initially, then begin to "back off" that solution in the interests of saving money. Care must be taken, however, not to impact the material solution to such an extent that the benefits derived from that solution are significantly altered through introduction of the changes.

Cost Risk Analysis For Parametric Estimation

Any CER estimated value has some uncertainty associated with the statistical properties of the CER; these are *not* indicators of the inherent project risks. It is likely that at the time a parametric estimate is made for a project, some analytical work has been done in the form of a conceptual study or a *Design Reference Mission*, but the detailed technical and schedule/programmatic risks have yet to be understood. As a proxy for these risks, it is common to place probability distributions on the continuous inputs (such as mass) in the estimating relationship, and to use Monte Carlo simulation to develop the project cost S-curve.

Such probability distributions are often subjective. The usual source for the needed probability distributions is the responsible engineering team, though the analyst should be aware of the potential for advocacy optimism here as well. In any case, any probability elicitation and encoding should follow established protocols and methods such as those described in Morgan and Henrion.

Cost Risk Analysis For Analogy Estimation

Even with analogy estimation, it is possible to capture cost risk and build a project cost S-curve. As with a parametric estimation, analogy estimation often is made for a project before the detailed technical and schedule/programmatic risks have yet to be understood. In analogy estimation, each estimator, usually a discipline expert with substantial project experience, scales an analogous project's actual cost, taking into account changes in requirements, technology, and other project implementation decisions. As a proxy for project risks, each scaling factor can be represented by a subjective probability distribution, thus turning a point estimate into probability distribution. Monte Carlo simulation is then used to develop the project cost S-curve. As with any subjective probability elicitation, established protocols and methods should be used.

Cost Risk Analysis For Engineering Build Up Estimation

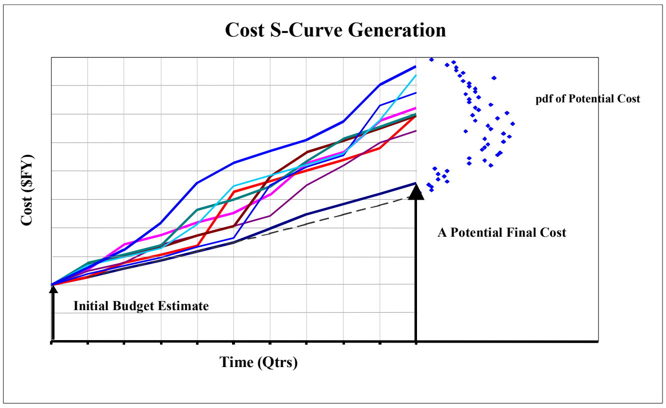
A cost risk analysis for grass-roots estimation requires an understanding of the sources of cost risk. A thorough risk analysis of the project should have already identified those elements of the WBS that have significant technical and schedule/programmatic risk. Typically these risks arise from inadequacies in the project definition/requirements information, optimistic hardware and software heritage assumptions, the requirement for large advances in the state of technology, and overestimating the performance of potential contractors and other implementers. Two methods (described below) are available for performing a cost risk analysis when performing a grass-roots estimate. The cost risk analysis method used should be identified along with the analysis data.

Method 1

For each WBS element identified as a significant risk, a three-point cost distribution (typically, the minimum, maximum, and most likely) is elicited from the individual(s) responsible. Monte Carlo simulation software (available either from in-house or commercial sources) combines these individual (triangular) distributions into a project cost S-curve. The beta distribution may be a better choice to use in the Monte Carlo simulation, but elicitation of its parameters can be more problematical. Research, however, has indicated that certain simple three-point approximations work very well in this context, allowing for improvements in the quality of the S-curve without additional effort.

Method 2

For each WBS element identified as a significant risk, "worst case" (actually, 99th percentile) costs are elicited instead. These elicited values are conditional on the proposed budget (without reserves), performance attributes, and schedules specified in the grass-roots estimates. To obtain the conditional cost S-curve, the Monte Carlo simulation tool combines them. Method 2 is based on different behavioral assumptions and uses a different mathematical approach (a constrained Weiner process) than Method 1. A spreadsheet tool is available to perform the Monte Carlo simulation and produce both a cost density function and cost S-curve. (See example below.) Schedule risk information, if it is available, may be added to the analysis to improve the quality of the S-curve.



Results of Method 2 Applied to a WBS Element

Choosing the Level of Reserves

The level of reserves or reserve percentage should be selected based on achieving a particular *level of confidence* from the resultant cost S-curve for the entire program/project. The appropriate level of confidence is chosen by the Program/Project Manager after the analysis, and the resulting reserves should be identified as the recommended level at all Confirmation Reviews.

For trade studies and formal analyses of alternatives, the cost analyst may choose to add reserves so as to hold the level of confidence constant across all alternatives and report the resulting cost, or to add reserves so as to hold the cost constant and report the resulting level of confidence.

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How is it Calculated?

A Weiner process (a type of Markov process) simulates cost growth over T periods using the simple stochastic equation shown here. Each WBS element has a characteristic volatility parameter, s, which is derived from the 99^{th} percentile elicitation and the element's duration. Since the cost growth process is stochastic, many runs are performed for each WBS element to generate a cost probability density function (PDF) like the one shown in the example below. This can be done simultaneously for all WBS elements identified as a "significant risk", and correlations across WBS elements can be represented. The cost S-curve is generated by Monte Carlo methods by combining all the cost density functions.

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TIPS

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The Cost Growth (Weiner) Equation

$$dC(t) = a\,C(t)\,dt + s\,C(t)\,dw$$

with an added constraint that $dC(t) \geq a\,C(t)\,dt$ for $t \varepsilon [0,T]$.

The choice of the units for t is application dependent.

Assuming t is measured in years, then

- $C(t)$ = predicted cost at time t in year t dollars
- $C(0)$ = initial WBS element budget estimate in base year dollars
- a = inflation rate (%/year)
- s = volatility parameter (%/year$^{1/2}$)
- T = WBS element duration (years)
- dw = a random variable distributed $N(0,dt)$, i.e. dw is normally distributed with mean zero and variance dt.

More Information

Ebbeler, Donald H., George Fox and Hamid Habib-agahi, "Dynamic Cost Risk Estimation and Budget Misspecification", AIAA-2003-xxxx, September 2003.

Morgan, M. Granger, and Max Henrion, Uncertainty: *A Guide to Dealing with Uncertainty in Quantitative Risk and Policy Analysis*, New York: Cambridge University Press, 1990.

Zaino, N.A., and J.D. D'Errico, "Optimal Discrete Approximations for Continuous Outcomes with Application in Decision and Risk Analysis", *J. Op. Res. Soc.*, 40(1989), pp. 379-388.

Task 10: Document the Cost Estimate

The objective of this task is to capture, in a continuous fashion, from project initiation through completion, the LCC results of the cost estimating process and the CCRM, and all of its by products (confidence levels, CRL, risk reserves).

There are three activities associated with documenting the cost estimate:

1. Document the LCC.
2. Determine the quality of the cost estimate, fitness for use, and document the CRL (see Section 6.1).
3. Conduct peer review.

The purpose of the cost documentation is to provide a written justification for the program cost estimate. Given the size and importance of programs, the documentation clearly should be viewed as a substantive and professional effort. A general rule-of-thumb is that the final product should provide sufficient information on how the estimate was developed so that independent cost analysts--or other review team members--could reproduce the estimate. Although standardization of the content and format of the cost estimate documentation across all NASA Centers is unrealistic, it is recommended that each Center maintain as much consistency internally with respect to the documentation content and format as possible since this promotes completeness and quality agency-wide of the cost estimate's documentation. Cost estimators document the LCC results throughout the entire cost estimating process—not just when the estimate is complete. The final documentation should capture both the estimates for each element supporting the point estimate and the cost risk assessment integration.

The means by which each part of an estimate has been derived must be fully explained, and the databases employed must be provided in the documentation or clearly identified. A Comparison Cost Track by element to identify and explain any deviations between the estimate and the prior estimate should also be included. If other alternatives are being considered, a brief summary of each alternative should also be included.

Cost documentation provides:

- A written justification for the project cost estimate.
- A brief description of the system with a brief technical and operational concept description.
- Methodology and/or models used.
- Sufficient information on how the estimate was developed to allow independent cost analysts or other review team members to reproduce the estimate if required:
    - Inflation and other supporting assumptions
    - Data used to calibrate any CERs.
    - New facilities, initial spares, and other start-up investment costs
    - Operations costs with specific operational scenarios
    - Sunk costs and project remaining life-cycle costs by phase.
    - Net Present Value
- The means by which each part of an estimate and the databases used can be fully explained.
- Schedules (e.g., Systems Engineering Master Schedule).

- Acquisition strategy.
- Cost S-curve and reserves sufficiency analysis.
- Sensitivity analyses.
- A comparison track to identify and explain any deviations between the current estimate and any prior estimate.
- CRL.

The benefit of a well-documented estimate is that the differences with other cost estimating efforts for the same program/project should be easily reconcilable from the documented information. Its value is in providing an understanding of the cost elements so that decision-makers can make informed decisions.

Reasons why proper documentation is important in a cost estimate include:

- Experience from formal cost reviews, such as NARs, has proven that poorly documented analyses do not fare well. The credibility of the total project suffers if the analyst is unable to explain the rationale used to derive each of the cost estimates. Conversely, if a reviewer understands your inputs, approach, and assumptions, your estimate remains credible in his/her eyes regardless of whether disagreements remain or adjustments are recommended.
- If the BOE is explicitly documented, it is easier to modify key assumptions as they change during the course of the project life cycle, facilitating updates to the estimate and providing a verifiable trace to a new cost baseline. Importantly, this supports the requirement imposed by NPR 7120.4 to revalidate the Program Cost Commitment (PCC) annually. A well-documented CADRe not only facilitates the establishment of the baseline PCC, but also aids the revalidation process and the development of updated PCCs.

Documentation should include a qualitative assessment of each line item, along with risk confidence levels for each element. The summary is where the detailed estimate is located. The level of detail varies with the estimate but the rule of thumb is enough detail to be replicable by another estimator. Supporting data too complex for this section should be included in the appendix. It is important for the documentation to be accessible which means not just available in the actual cost model. There should be an accompanying written document such as a BOE that provides an explanation of estimate details and data sources.

A peer review is another important part of completing an estimate. Once the estimate has been completed and documented and before the estimate is presented to decision makers it is important for the estimator to get an outside review. This "sanity check" can provide an outside perspective and a fresh view of the estimate, which can catch any issues with the estimate to be corrected before presentation. This review can also prepare the estimator for the actual process of briefing the estimate to decision makers. A peer review can be conducted continuously during the cost estimating process or at any point along the way, but should be completed in full once the estimate is complete and documented.

TIPS

Cost Documentation

- Begin documentation efforts early and continue throughout the full estimate development process. Document sources in the actual models and carry these documentation details through to the estimate write up as well as the estimate presentations.
- When a CER is used, it should be presented and its source must be cited fully, or the model and the set of data with which it was calibrated must be cited. A cost estimator reviewing the cost documentation should be able to obtain enough information either from the document or from the sources cited therein to reconstruct the CER and evaluate its associated statistics. CER documentation should include descriptive statistics, such as R-squared, correlation coefficients, T-statistics, relevant range, etc. This information is necessary to assess the applicability of a CER adequately.
- Where subjective judgments (Delphi methodology) are used to adjust estimates made by analogy with other systems or components of systems, the professions of those making the judgments must be identified (e.g., cost analysts, engineers, etc.,) and full citations for the source(s) of the costs of each element in an engineering or "grass roots" estimate must also be cited.
- Present detailed examples of the first and second levels of the cost elements normally included in LCCEs for the each phase.
- When used in the estimate, actual cost history from past or present contracts or analogous programs should be provided.
- Areas of uncertainty such as pending negotiations, concurrency, schedule risk, performance requirements that are not yet firm, appropriateness of analogies, level of knowledge about support concepts, critical assumptions, etc., should be presented.
- Sensitivity analysis should be performed to include the cost of changing significant input parameters. Risk analysis should include risk adjusted point estimates. Crosschecks should be included for all high cost/high risk portions of the estimate.
- Tracking through a comparison or cost track is required when an estimate changes. Documentation must include the specific reasons for the change.

QUESTION: What items need to be included in a Detailed Cost Estimate Summary?

ANSWER: The following items need to be included in a detailed cost estimate summary:

1. Technical and Operational Concept Description: Based on the CADRe or Technical baseline, including brief summaries of information including technical, schedules (project schedules and Systems Engineering Master Schedule), and acquisition strategy.
2. Methodology and Models: Identify the basis for using a particular method and model for primary and secondary estimates. For each model used, include all details involving parametric input or output including adjustments. Data used to calibrate CERs should be documented here.
3. Cost Estimate: To include definitions of the cost elements, a description of how the cost was derived, definition of input variables, list of values assigned to input variable, mathematical formulas used, list of cost factor drivers per cost element, and data sources, data obtained, and adjustments made to the data. This section should show the estimate by including any sunk costs (actuals) and then the remaining life cycle costs by phase. New facilities, initial spares and other start up investment costs as well as operations costs (and operational scenarios) should be included for a full life cycle cost estimate. Inflation, present value and any other supporting assumptions should be included.
4. Risk Assessment: To include the range of costs, either by utilizing statistics or expert opinion. The use of a random (+/-) is not sufficient. A cost S-Curve generated through a documented cost risk assessment and a reserves sufficiency analysis are most appropriate.
5. Cost Drivers: To include the key drivers that focus on performance, reliability, maintainability, and general operations should be included. Each driver should be looked at independently as well as in likely combinations.
6. Sensitivity Analysis: Should focus on the cost changes due to movements within the operating parameters. As with risk assessment, a random (+/-) will not suffice. If numerical analysis isn't possible, qualitative analysis should be performed. Results should be given in such a manner that it focuses attention on the cost impact for each element within the system.

Task 11: Present / Brief Results

While it may not be realistic to standardize the content and format of the cost estimating briefing charts across all NASA Centers for all estimate types, an objective of this task is to promote the quality of the cost estimating and analysis documentation by advocating consistency across and in Centers.

There are three activities associated with presenting/briefing results:

1. Create briefing materials and supporting documentation to be used for internal and external presentations as appropriate. (See Appendix H)
2. Present and defend the estimate.
3. Gather from customers and provide feedback to capture improvements for the next estimate. (See Appendix BB for a sample Customer Feedback form).

While it may not be realistic to standardize the content and format of the cost estimating briefing charts across all NASA Centers for all estimate types, consistency across and in Centers facilitates understanding during the management review process and promotes completeness and quality of the cost estimating and analysis documentation. A template for the first five pages for a standard cost estimate briefing at NASA has been provided for download at ceh.nasa.gov. A summary of this template and its use has been provided in Appendix H. Estimators are encouraged to use this template for all estimate briefings to increase consistency, decision maker familiarity, and comfort with the template and in the long run to build credibility in estimate presentations at all levels at NASA.

Cost estimates are used as baseline rationale to develop budget submissions for Presidential and Congressional approval. A budget is partly subjective; to increase the validity of requested dollars, a program that uses a valid cost estimate greatly improves the defensibility of a budget request.

The cost estimator should prepare briefing material and supporting documentation to be used for internal and external presentations as appropriate. It is again recommended that each Center maintain as much consistency internally as to the data format as possible since this facilitates understanding during the management review process and promotes completeness and quality of the cost estimating and analysis documentation by using the provided template. Thorough documentation is essential for a valid and defensible cost estimate. Cost presentation documentation provides a concise, focused illustration of key points that should direct the reader's attention to the cost drivers and cost results.

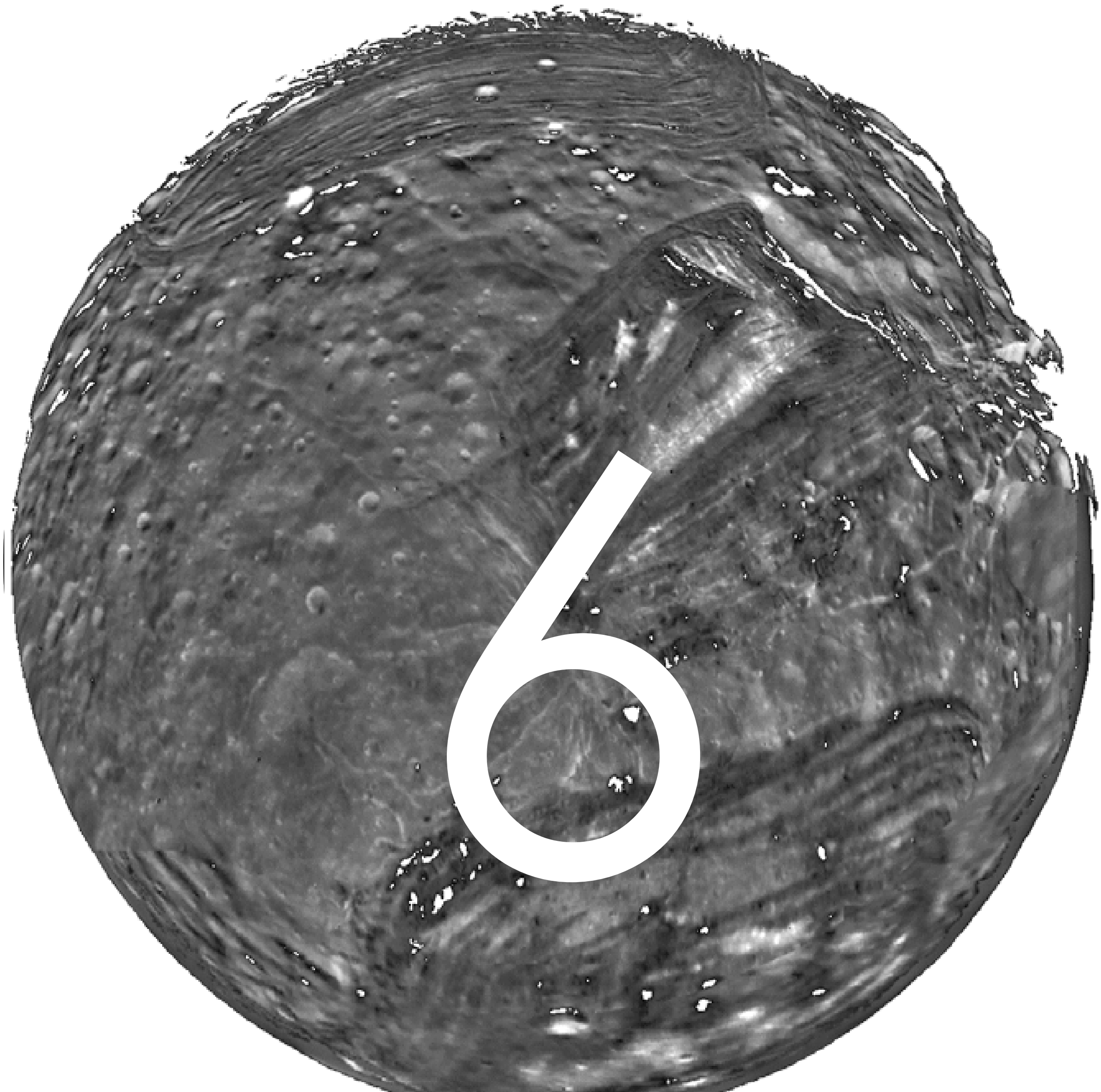
Task 12: Update Cost Estimates on a Regular Basis

The purpose of updating the cost estimate is to defend the estimate over time, to reduce updated estimate turn-around time, and to give decision-makers a clearer picture for major decisions or "what if" drills.

There are two activities associated with updating the cost estimate on a regular basis.

1. Obtain and assess customer feedback and conduct a lessons learned analysis upon estimate completion and incorporate this feedback to the next version of the estimate.
2. Update estimate when project content changes and as the project moves through its life cycle phases and conducts milestone reviews. The major connection to the CCRM in this step is using and updating the estimate for feedback into the budget and EVM.

Cost estimates must be updated whenever project content changes and reconciled to the estimate baseline. By accomplishing a cost estimate on proposed program alternatives, the Project Office can determine the cost impact of the alternatives.



6

NASA Cost Estimating Techniques

6. NASA Cost Estimating Techniques

In this section, various cost estimating techniques applied during the 12 steps of the cost estimating process and the project CCRM are detailed. Use this section as a reference guide, looking up and finding salient details about the techniques used by seasoned cost estimators to produce defensible, accurate, and fully documented estimates.

6.1 Cost Readiness Levels (CRL)s

Modeled after the NASA TRL scale, CRLs are designed to communicate the quality of the cost estimate. The CRL provides a clear and quick way to communicate the quality of the estimate to stakeholders. Instead of hoping that an estimate user reads the executive summary or understands from your presentation the conditions surrounding the estimate that might have affected the estimate quality, the CRL concisely summarizes that information in a consistent format.

Each cost estimate to be funded in the Program Operating Plan (POP) must have an associated CRL designation. Projects will be asked to provide a CRL rating with their project budget inputs. The IPAO and Code BC will make an independent assessment of CRL associated with these budget estimates. A reconciled position would then go forward to the NASA HQ Deputy CFO for Resources (Comptroller) for preparing the project budget input into the President's Budget submission.

CRLs have been modeled after the same 1 to 9 ordinal scale as TRLs. In the case of CRLs, it is the quality of the cost product itself—the estimate's fitness for use as cost information for a flight project that is measured. Exhibit 6-1 defines the CRL scale.

CRL	Description
9	End of project actual cost
8	Cost fit for very firm engineering decisions and very firm budget commitments (+/- 5%)
7	Cost fit for firm engineering decisions and firm budget commitments (+/- 15%)
6	Cost fit for PDR engineering decisions and PDR budget use (+/- 25%)
5	Cost fit for preliminary engineering decisions and preliminary budget use (+/- 35%)
4	Cost fit for very preliminary engineering decisions and very preliminary budget use (+/- 45%)

Exhibit 6-1: CRL Ratings

Common sense dictates that the CRL rating should not be higher than the lowest critical element's TRL rating for the project and the CRL should be low if the requirements for the project are not firm (i.e., the cost cannot be known with any certainty if the technology and requirements are not known).

Prior to the availability of a probabilistic cost risk analysis results, the CRL can be a judgment call based on two factors:

1. The basic technical and programmatic complexity of the "to go" work at the time of estimate. Complexity considerations include human rating, launch system requirements, planetary destination, operational versus experimental requirements, materials complexity, use of deployables, parts count, challenging thermal requirements, high data rates, electronic parts class, stabilization requirements, power generation type, propellant choice, propulsion requirements and other factors. Programmatic complexity includes team size, team experience, schedule and other factors. Exhibit 6-2 demonstrates how the CRL is determined prior to the availability of a PRA.

Basic "***Complexity****" of the to go work at the time of the estimate

	Low	Fair	High	Very High	Extremely High
Relatively Simple	6	6.5	7	7.5	8
Less Than Average Complexity	5.5	6	6.5	7	7.5
Average Complexity	5	5.5	6	6.5	7
Very Complex	4.5	5	5.5	6	6.5
Extremely Complex	4	4.5	5	5.5	6

Adequacy of "***Estimating Methods***", experience of the estimators, quality of CARD, availability of analogous data and cost tools, time allowed for estimate, independence of estimate, number of cross checks performed

CRL	Description
8	Cost fit for very firm engineering decisions and very firm budget commitments (+/ -5%)
7	Cost fit for firm engineering decisions and firm budget commitments (+/-15%)
6	Cost fit for PDR engineering decisions and PDR budget use (+/-25%)
5	Cost fit for preliminary engineering decisions and preliminary budget use (+/-35%)
4	Cost fit for very preliminary engineering decisions and very preliminary budget use (+/-45%)

*Complexity considerations include human rating, launch system requirements, planetary destination, operational vs experimental requirements, materials complexity, use of deployables, parts count, challenging thermal requirements, high data rates, electronic parts class, stabilization requirements, power generation type, propellant choice, propulsion requirements and many other factors. Programmatic complexity includes team size, team experience, schedule and many other factors.

Exhibit 6-2: CRL Rating Prior to Availability of PRA

2. The experience and adequacy of estimating team, quality of the CADRe, availability of analogous data and cost tools, time allowed for estimate, independence of estimate, number of cross checks performed.
3. Exhibit 6-3 demonstrates the establishment of the CRL rating once the PRA has been conducted. An approach recommended by NASA involves using the inter-quartile cost range to calculate the ratio of the 75th percentile cost to the 25th percentile cost on the cost risk S curve and looking up the CRL rating on the provided table.

25th Percentile Cost	Median Cost	75th Percentile Cost	Lookup Ratio of 75th Percentile Cost to 25th Percentile Cost	Read CRL	Description
100	100	100	1.00	9	End of Project Actual Cost
95	100	105	1.11	8	Cost fit for very firm engineering decisions and very firm budget commitments (+/- 5%)
85	100	115	1.35	7	Cost fit for firm engineering decisions and firm budget commitments (+/- 15%)
75	100	125	1.67	6	Cost fir for PDR engineering decisions and PDR budget use (+/-25%)
65	100	135	2.08	5	Cost fit for preliminary engineering decisions and preliminary budget use (+/- 35%)
55	100	145	2.64	4	Cost fit for very preliminary engineering decisions and very preliminary budget use (+/- 45%)

Exhibit 6-3: CRL Rating After Availability of PRA

Use of the CRL scale is a new tool within the NASA cost estimating community and will be refined through use and feedback. As the CRL is put into practice, please provide feedback on the method through the ceh_comments@nasa.gov feedback mechanism, use of the customer feedback form (see Appendix AA) or directly to Joe Hamaker at the Code BC HQ Cost Analysis Division. For the most current version of CRLs, check with Code BC or on ceh.nasa.gov to see if updates to the methodology have occurred.

6.2 Cost/Performance Trade Studies

Cost/performance trade studies are systematic, interdisciplinary examinations of the factors affecting system costs. These studies are accomplished by analyzing numerous system concepts to find acceptable ways to attain necessary performance while balancing essential requirements that must be satisfied for the system to be successful. The objective of the cost performance trade study is not to minimize the cost of the system, but to achieve a specified level of cost reduction established by the target costing system (see Exhibit 6-4). Conducting cost/performance trade studies is one of the most effective means used, especially in the early life cycle phases to define a system, to help narrow the universe of potential technologies, processes, and/or operational concepts to the most optimal solution.

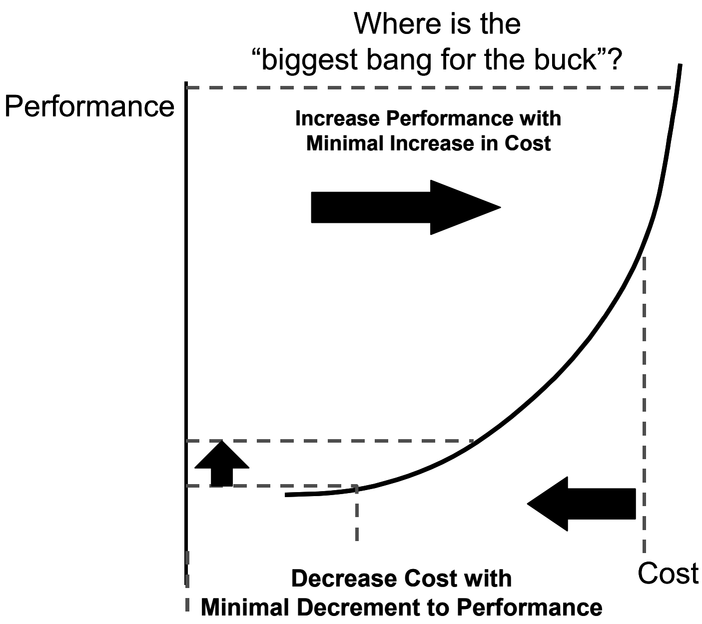


Exhibit 6-4: Cost versus Performance

Cost estimates are key inputs during cost/performance trade studies, used to determine the most realistic and cost effective mission architectures and system designs. The objective of a trade study is to obtain the merit of the worth (in a single figure) of each candidate and to select the one having the greatest relative value.
A cost/performance trade within a CAIV study can be viewed as being a special application of the cost/performance trade, one in which the cost is fixed, (i.e., independent) and the three other variables in the CAIV "equation", performance, schedule and risk levels are dependent on that fixed cost. A CAIV study then is an iterative process to find that combination of dependent variables that will satisfy the cost constraint. While there is no set formula for conducting a Cost/Performance Trade or CAIV study, key elements, KEPPs, and/or KPPs to balance include an understanding of affordability versus requirements, customer versus mission-threat expectations, quantity versus cost objectives.

In Pre-Phase A when the application of cost/performance trade studies is most prominent, the cost estimator must take the attitude of "close enough is good enough," providing ROM cost data at times on products and technologies. Working with the project staff (system designers), the cost estimator(s) must identify and prioritize key elements, KEPPs, and KPPs, balancing them to find the "knee-in-the-curve" (see Exhibit 6-5 for each alternative and then compare them on the basis of best value.

Constrained Cost	Solution Cost	Benefit	Group
13700	13700	0.212	1,1,1,1
14000	13700	0.212	1,1,1,1
14500	14400	0.25	1,2,1,1
15000	14900	0.286	2,2,1,1
15500	15200	0.386	2,3,1,1
15700	15700	0.697	1,1,3,1
16000	15900	0.311	1,1,3,1
16500	16300	0.411	1,3,2,1
17000	16800	0.835	1,3,3,1
17500	17300	0.871	2,3,3,1
18000	17300	0.871	2,3,3,1
18500	17300	0.871	2,3,3,1
19000	17300	0.871	2,3,3,1
19500	17300	0.871	2,3,3,1
20000	19800	0.882	1,3,3,2
20500	19800	0.916	3,3,3,1
21000	19800	0.916	3,3,3,1
21500	19800	0.916	3,3,3,1
22000	20300	0.918	2,3,3,2
22500	20300	0.918	2,3,3,2
23000	22800	0.983	3,3,3,2
23500	22800	0.983	3,3,3,2
24000	22800	0.983	3,3,3,2
24500	22800	0.983	3,3,3,2
25000	22800	0.983	3,3,3,2
25500	22800	0.963	3,3,3,2
26000	22800	0.963	3,3,3,2
26500	22800	0.963	3,3,3,2
27000	26800	1.019	3,3,3,3

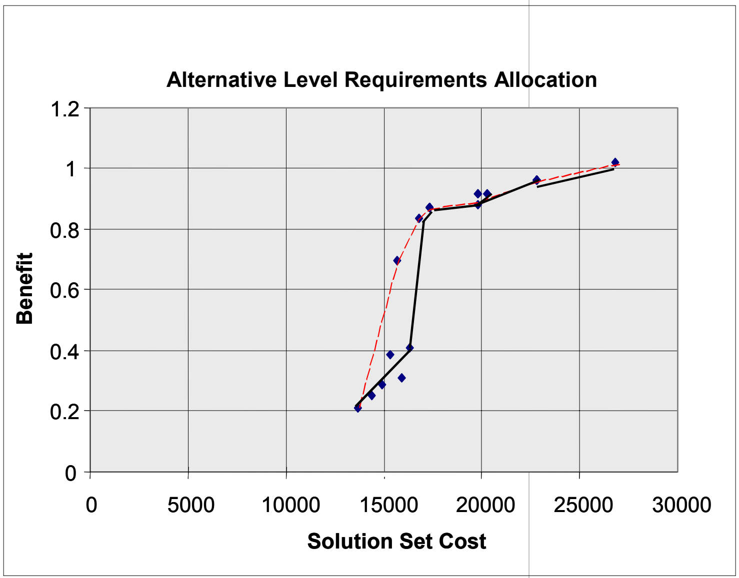


Exhibit 6-5: Optimizing the "Knee in the Curve

A cost estimator would have little success attempting to achieve an optimum CAIV result without substantial consultation. Therefore, CAIVs are most successfully conducted as a team endeavor [i.e., within the construct of a Cost Performance Integrated Product Team (CPIPT)], to include any contractors involved in the project. To do a CAIV study properly, clearly defined cost objectives are necessary. These must be consistent with requirements and projected fiscal resources. The key trade-off areas and performance specifications must be kept to a minimum and must be identified by the Project Office. Often a target cost is chosen as a baseline for the study. It may represent the budgeted cost for the system or merely the estimated cost of the baseline architecture. The system designers and the cost estimator(s) must be able to translate requirements for a performance target into a parameter that can be estimated. That parameter is often weight, but it can be aperture, or channels, or any other quantifiable figure that can be translated to cost (e.g., K$/lb, K$/channels, K$/mm, etc.). The process may be as simple as making several estimates with different parameters and arriving at a point of diminishing returns. However, it may be much more complex and depend on system architecture limitations or funding constraints. The CAIV process, when looked at from a team perspective, will provide useful data to make an optimal decision for the system.

CAIV results can help the Project Office, working with its acquisition staff, develop robust incentives proposed within any contract for achieving cost reduction objectives. This requires a system of performance metrics to facilitate progress tracking and evaluation.

A less formal process than a traditional CAIV analysis can also be considered and used, if appropriate. Referred to as Cost-Effectiveness Analysis, this discipline covers studies often referred to as Target Costing and Value Engineering.

QUESTION: Why is CAIV, target costing, and value engineering important?

ANSWER: Many Federal agencies have implemented principles that embody an old idea: buying only what you can afford and trading off some capabilities to reduce overall cost. Commonly called CAIV, target costing, and value engineering, these methods have been coupled over the past several years in support of initiatives to reduce the LCC of systems.

These Federal agencies have initiatives that require setting aggressive, but realistic, cost objectives when defining the operational requirements of a system. Effective cost management must start at the beginning of a system or product life cycle. Once a system is designed, most of the costs that will be incurred in building and operating the system have already been committed.

- CAIV is the process of using better business practices, allowing trade space for industry to meet user requirements, and considering operations and maintenance costs early in requirements definition in order to procure systems smarter and more efficiently.
- Target costing is a structured approach to determine the cost at which a system or product with specified performance and reliability must be produced to shift the decision point toward proceeding with the project.

Value engineering is used in the product design stage to find ways to achieve the specified performance at the required level of performance and reliability at the target cost.

Steps for Performing a Trade Study

The following steps provide the general framework used to conduct a trade study.

1. Define the purpose.
2. State the problem.
3. Describe the selection scheme and criteria used.
4. Identify the design approaches/characteristics.
5. Perform the analysis and review results.
6. Determine the preferred approach.
7. Formulate recommendation(s).

6.3 Cost-Benefit (C-B) and Cost Effectiveness (C-E) Analysis

C-B and C-E analysis are methods to aid decision makers in the comparison of alternative approaches, options, or projects. Benefits is an economic term that is generally understood to be measured in monetary units. Effectiveness is a multi-attributed construct used when the consequences of the choice are not or cannot be measured in dollars. Often, the terms benefits and effectiveness are used as if they are interchangeable and synonymous—they do in fact have different definitions within the cost estimating community (as described in this section). A valuable reference for C-B analysis guidelines in Federal programs is OMB Circular A-94.

C-B analysis was a political response to the demand for more government activity, especially in fostering economic growth and overcoming market failures. C-B analysis was a way of applying economic criteria to public sector projects. In the U.S., this was first embodied in the areas of making rivers navigable, flood control, and water distribution (1936), though the actual economic concepts predated that by about 100 years (1844).

The foundation of C-B analysis is the *Kaldor-Hicks compensation principle*. Distributional (equity) issues are not addressed, and so-called “secondary” or “intangible” benefits are typically ignored. Benefit measures for public investment projects designed to ultimately benefit consumers are generally based on the concept of *willingness-to-pay*. Typically a public investment allows the consumer to buy a good/service at a lower price than was possible before the investment. (A special case occurs when a good/service is made available that was previously unavailable.) Consumer willingness-to-pay is calculated as the monetary value that could (theoretically) be taken away from the consumer that exactly offsets the consumer’s gain from the investment. Benefit measures for public investment benefiting producers (firms) are generally based on calculating increased profits. When these dollar amounts, all in present value, are calculated and the result exceeds the cost of the investment, then the investment project can be justified.

C-B Analysis Examples

Examples

As an example, consider benefit measures for highway construction--*For consumers:* faster travel time, which is usually translates into a monetary equivalent using an average hourly wage rate; and *for producers*: faster travel time is valued by increased profits due to higher productivity, and/or by profits generated by new businesses along the highway. These measures when applied to public investment in new space launchers might translate as follows:

- *For consumers*: lower telecommunications prices (with the attendant increase in quantity consumed); and
- F*or producers*: increased profits in telecommunications and every other space commerce sector.

C-B analysis is appropriate when there are market prices that can be used to infer the values of the goods or services produced by the public investment. Systems analysis and C-E analysis are appropriate when such information is unnecessary (i.e., when competing benefit streams are identical), impractical to obtain, or lacks credibility. Both techniques have their role.

Systems analysis and cost-effectiveness (C-E) analysis became part of the effort to extend the economic principles to areas of government activity other than water resources, first in defense. Here, analysts attempt to find the optimal allocation of scarce resources to meet a wartime objective. An early application--hunting submarines in the North Atlantic during WWII--gave rise to *Operations Research* as a field. During the Cold War, systems and C-E analysis tackled the new problems of strategic warfare.

Since the late 1960s, systems analysis and C-E analysis have been used in support of a wide variety of government economic activity as a means of imposing some discipline on the process of selecting government projects. Systems analysis and C-E analysis is generally best applied to non-marketed, non-excludable public goods (e.g., defense and space science), where the focus is on the more restrictive question of which alternative is best, not on whether the objective or mission being considered is worth doing at all. Typically, performance requirements, levels of effectiveness, or costs are often set by the “political” process.

During the implementation of CCRM, the first opportunity for cost impacts due to risk to be introduced, albeit at a ROM level, is during analysis of alternatives utilizing cost effectiveness, cost/performance or cost/benefit trades. The trade space is defined by goal (i.e., objective or stretch goal) and threshold levels. Costs are identified for each goal and threshold and any level in between that has been defined. Value (i.e., performance) brought to the project for all of the KEPPs at each of these levels (e.g., threshold, goal, and in between) is quantified. A cost constrained optimization is performed, at continually increasing levels of total cost. This optimization produces a "Knee-in-the-Curve" graph (as described in Section 6.2 above) that identifies the point at which increases in performance requires unacceptable increases in cost.

6.4 Lease versus Buy Analysis

A lease[1] versus buy analysis can be performed once the decision is made to acquire an asset. While the process of analyzing the economics of buying an asset has been discussed in this document, the analysis behind the decision is slightly different. For a lease versus buy analysis, various tradeoffs need to be examined.

[1] A lease is a long-term agreement between a user (lessee) and the owner of an asset (lessor) where periodic payments are made by the lessee in exchange for most of the benefits of ownership. A lease is comparable to a loan in the sense that lessee is required to make a specified series of payments and that failure to meet these payments could result in loss of the asset.

When analyzing the financial considerations under the lease versus buy decision process, one needs to consider the LCC of either leasing or buying and operating and maintaining the hardware. The most meaningful financial comparison is the cost of lease financing versus the cost of debt financing. While comparing absolute LCC is important, it is equally critical to take into consideration fiscal budgetary constraints. While the LCC of leasing may be higher over the entire term the hardware is leased, the annual expenditures may fit better with NASA's budgetary limitations. However, the lease versus buy decision cannot be based purely on financial data or budgetary considerations. The decision must be made on a best value consideration. A best value selection analysis would introduce intangible benefits that could be benefits of either leasing or buying.

TIPS

Sample Factors To Consider When Making The Decision To Lease Or Buy

- Asset redeployment/disposal
- Asset tracking
- Maintenance options
- Political considerations
- Value of cancellation options
- Shortened product life cycle
- Technology refresh
- Convenience
- Ease of contracting
- Transference of residual risk

Traditionally, factors such as asset tracking and asset redeployment/disposal are considered to be advantages of leasing, however, circumstances could exist which would make these factors a disadvantage. Similarly, these types of benefits could be provided through certain procurement vehicles. It is critical to be aware of all competing purchase alternatives to leasing as well as being aware of the legislative and policy directives guiding leasing.

6.5 Sensitivity Analysis

Once the point estimate is developed, decision makers want and need to know how sensitive the total cost estimate is to changes in the data input. Therefore, NASA recommends that sensitivity analyses be performed to identify the major cost drivers for the estimate. Sensitivity analyses determine how the different ranges of estimates affect the point estimates. Cost drivers are those variables that when changed in value, create the greatest changes in cost. Due to the nature of NASA's design and development process, uncertainty will be present in some, if not all, of the technical parameters' values during the Pre-Phase A of a Project. Likewise, many initial assumptions made in the early phases of a project's definition will, in later phases, be found to be inaccurate.

To account for the uncertainty and the lack of precision in each of the assumptions, input variable distributions (minimum, most likely, maximum) can be estimated for key cost elements. Once the LCC model is fully developed for each alternative with the input variable distributions, the model can then be subjected to a Monte Carlo simulation. A Monte Carlo simulation calculates numerous scenarios of a model by repeatedly picking random values from the input variable distributions for each "uncertain" variable and calculating the results. Typically, a simulation will consist of 2,500 to 10,000 iterations. The results of Monte Carlo simulations are risk-adjusted estimates and corresponding statistical estimate distributions. The estimate distributions provide the decision-maker with a range of possible outcomes and bounds, with a minimum and maximum value. (The input variable distributions and cost estimate range is provided with each alternative analysis.)

Conducting a cost risk analysis as part of developing costs for trade study will expose the team to potential risks such as overruns that do not immediately surface when a single cost estimate provides an expected cost. With a traditional point estimate, the cost of a project might be $2.5 million, however; the risk-adjusted cost will provide an expected value (at the 50th percentile) of $2.7 million and a range of $2.5 million to $2.9 million (+/- 20%). This allows decision makers to have a “two dimensional view” of the potential outcomes, identification of cost drivers, and greater level of confidence in the results.

6.6 Present Value, Inflation, and Discounting

The present value concept captures the time value of money by adjusting through compounding and discounting cash flows to reflect the increased value of money when invested. The present value of a cash flow reflects in today’s terms, the value of future cash flows adjusted for the cost of capital. In essence, the time value of money reflects the fact that money in hand today is more *valuable* than an identical amount of money received in the future and that benefits and costs are worth more if they are realized earlier. Since money today can earn interest, all costs must be adjusted to reflect the inflation rate and then discounted to reflect their present value. The time value of money reflects the idea that a dollar in hand today is worth more than a dollar in the future, even after making adjustments for inflation.

Steps for Calculating the Present Value of an Investment

The present value of an investment is calculated from the time series of projected cash flows using discount rates specified in the OMB Circular A-94, Appendix B[2] (http://www.whitehouse.gov/omb/circulars/a094/a094.html). To estimate net present value (see Section 5.1.2), future benefits and costs must be discounted. Discount factors can be reflected in real* or nominal terms as defined by OMB Circular A-94 Appendix C. The discount rate used depends on the type of dollars to be adjusted:

Discounting translates projected cash flows into present value terms using specified discount factors. As illustrated in Exhibit 6-6, the ***discount factor*** is equal to $1/(1+ i)^n$ or $(1+ i)^{-n}$ where *i* is the interest rate and *n* is the number of years from the date of initiation for the project.

Real Discount Rates—Adjusted to eliminate the effects of expected inflation and used to discount *Constant Year* dollars or real benefits and costs. A real discount rate can be approximated by subtracting expected inflation from a nominal discount rate.

Nominal Discount Rates—Reflect expected inflation and used to discount *Then Year* (inflated) dollars or nominal benefits and costs.

* in this case, “real” indicates that the effects of general inflation have been removed

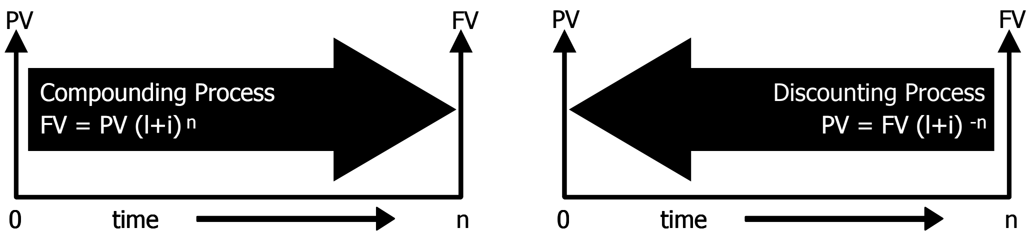


Exhibit 6-6:
Compounding and Discounting

Exhibit 6-7 provides an example of how discounting is applied.

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[2] OMB Circular A-94 provides specific guidance on the discount rates to be used in evaluating Federal programs whose benefits and costs are distributed over time.

Examples

If cost is the only deciding factor, which investment should the organization invest in?

	Year 1	Year 2	Year 3	Year 4	Year 5	Total
Project A Cost	$100	$100	$100	$100	$100	$500
Project B Cost	$500	$ ---	$ ---	$ --	$ --	$500
Project C Cost	$ ---	$ ---	$ ---	$ --	$500	$500

The organization should invest in the project with the lowest discounted cost stream. In the example below, Project C has the lowest cost in terms of present value. For example, you need $500 today for Project B. Alternatively, you could put $449 in a bank today and receive the $500 you need in year 5 for Project C. Economists contend you are better off with Project C because you can do something else with the $51 you did not put in the bank.

	Year 1	Year 2	Year 3	Year 4	Year 5	Total
Program Year	0	1	2	3	4	
Discount Factor	1.0000	0.9737	0.9481	0.9232	0.8989	
Project A PV Cost	$100	$ 97	$ 95	$ 92	$ 90	$474
Project B PV Cost	$500	$ ---	$ ---	$ ---	$ ---	$500
Project C PV Cost	$ ---	$ ---	$ ---	$ ---	$449	$449

Exhibit 6-7: Discounting Example

There are generally two methods used to account for the inflation in a cost estimate. One method is based on the Gross Domestic Product (GDP) rate, which is given in the yearly "Budget of the United States Government." For FY04, the inflator factor, which uses the increase in the GDP deflator to calculate the inflation rate is provided in the Summary Table section (http://www.whitehouse.gov/omb/budget/fy2004/pdf/budget.pdf, Table S12-Comparison on Economic Assumptions). The other method calculates inflation as follows:

Inflation = (1 + Inflation Rate) ^ Year

Exhibit 6-8 is an example of how this formula is applied:

Dollars at the value they would have in a selected Base Year. The effect of inflation are removed.

Year	Rate	FY X	FY X+1	FY X+2	FY X+3	FY X+4
Constant Year Dollar		1.0000	1.0000	1.0000	1.0000	1.0000
Then Year	1.94*%	1.0000	1.0194	1.0392	1.0592	1.0799

Dollars that include the effects of inflation or escalation, and/or reflect the price levels expected to prevail during the year at issue.

$(1 + 0.0194)^3 = 1.059336$

or

$1.0194 * 1.0194 * 1.0194 = 1.059336$

* The rate used here is for demonstration purposes only.

Exhibit 6-8: Applying the Inflation Rate

To determine the present value of money, a discount rate must be applied to costs already adjusted for inflation. There are two different types of discount rates:

1. ***Real Discount Rate*** is adjusted to eliminate the effects of expected inflation and used to discount constant year dollars or real benefits or costs.

Nominal Discount Rate
– Expected Inflation Rate

= Real Discount Rate

2. **A Nominal Discount Rate** is one adjusted to reflect inflation used to discount Then Year dollars or nominal benefits and costs. The formula used to apply the discount rate to calculate the present value is:

The Discount Process = 1/(1+Discount Rate)^Year

6.7 Return on Investment (ROI)

To determine how much value (non-financial benefits) an investment will realize, or how much money it will save, and or what its impact on the overall organization will be, financial and non-financial benefits should be compared to the estimated cost. These return-on-Investment (ROI) metrics are critical in decision-making. ROI metrics assure senior managers and OMB decision-makers that the investments they authorize will contribute to making the Federal government more cost-efficient and responsive to mission accomplishment. It is important to note, however, that cost-efficiency is only one data point in the decision-making process. No matter how cost efficient an investment appears to be, if it fails to improve the effectiveness of the government, it is unlikely to show any benefit at all. For this reason, ROI should be used as an indicator, along with other performance and risk indicators for a comprehensive view of program value.

QUESTION: What is ROI and how is it expressed?

ANSWER: ROI is the net benefit expressed as a percentage of the investment amount:

$$\text{ROI} = \frac{\text{NPV}}{\text{PV Investment}}$$

It is the incremental financial gain from an investment, divided by the cost of the investment. For example, an investment that costs $1,000 and pays back $1,500 after a defined period of time has a 50% ROI.

TIPS

The ROI of an investment can be maximized by:

1. Minimizing Costs
2. Maximizing Returns
3. Accelerating Returns

A relatively small improvement in all three may have a major impact on overall economic return of the investment.

6.8 Net Present Value (NPV)

The NPV indicates an investment's net value of in today's dollars. All costs and benefits are adjusted to "present value" by using discount factors to account for the time value of money. NPV is a way of making costs and benefits occurring in different years commensurable. It is the algebraic combination of the present value of costs and benefits. OMB Circular A-94 establishes NPV as the standard criterion for deciding whether a government project's costs can be justified on economic principles. According to OMB Circular A-94:

QUESTION: What is Net Present Value?

ANSWER: In the most general terms (again consistent with OMB Circular A-94), NPV is defined as the difference between the present value of benefits and the present value of costs. All costs and benefits are adjusted to "present value" by using discount factors to account for the time value of money.

The benefits referred to above must be quantified in cost or financial terms in order to be included in the equation below.

NPV forecasts when the investment will generate sufficient cash flows to repay the invested capital and provide the required rate of return on that capital. Because all cash flows are discounted back to the present time, the NPV compares the difference between the present value of the benefits and costs and takes into account what the project gives up to get these benefits, or the opportunity costs of both cash flows.

Calculating Net Present Value

"Net present value is computed by assigning monetary values to benefits and costs, discounting future benefits and costs using an appropriate discount rate, and subtracting the sum total of discounted costs from the sum total of discounted benefits. Discounting benefits and costs transforms gains and losses occurring in different time periods to a common unit of measurement.

Mathematically, NPV is calculated as shown:

PV(Annual Benefits)
− PV(Annual Cost)
NPV

For most government generated cost estimates, discount rates provided in OMB Circular A-94 are used to discount all cash flows as shown:

[PV (Internal Project Cost Savings, Operational) + PV (Mission Cost Savings)]
- PV(Initial Investment)
NPV

Projects with positive net present value increase social resources and are generally preferred. Projects with negative net present value should generally be avoided."

The simplified NPV accept/reject criterion is:

NPV > 0 → Accept

NPV < 0 → Reject

6.9 Payback Period and Break-Even Analysis

The payback period helps to answer the question "how long will it take to make back the money spent on the investment?" This is beneficial information to decision makers because out-year benefits are often less certain than benefits that occur early in the life cycle. The payback period represents the time required for the cumulative savings to equal to the cumulative value of investment. The payback period measures the time (i.e., years, months) needed to recover the initial investment and break even.

The payback period metric identifies projects that generate benefits occurring *early* in the life cycle. NASA decision makers must then decide if the payback period is appropriate in the context of the organization's other investment opportunities.

Calculating the Payback Period

Computing the amount of time it takes for a project to pay for itself (or return its initial investment) is another commonly used criterion for selecting among alternative courses of action in an investment analysis.

The basic question to be answered is at what point in time does:

(Internal Project Cost Savings, Operational)
+ (Mission Cost Savings)
(Initial Investment)?

In the simplest of cases, the benefits (or returns) begin predictably at the completion of the investment phase and occur in an equal amount each time period. However, for large projects that take years to complete, benefits begin accruing prior to completion of the investment phase and do not occur in equal annual amounts. In both simple and complex situations, the Payback Period in years, *x*, can be found using the following formula (where *t* = time periods in years):

$$\text{PV(Initial Investment)} = \sum_{t=1}^{t=x} \text{PV(Operational Savings + Mission Savings)}$$

6.10 Real Option Valuation

Real options valuation is a financial technique for evaluating investments under conditions of uncertainty, particularly uncertainty associated with market variables such as future product demand or the future value of an asset. Option pricing is a well-developed area of financial engineering, dealing with the valuation of puts, calls, and more complex derivatives, but when applied to non-financial assets, the term "real options" is used. In real options valuation, the general ideas from financial options pricing theory are used along with some of the mathematics.

Real option valuation has already been applied to a variety of investment decisions by industry, and is widely taught as part of a modern curriculum in business investment analysis. Only recently, though, has real options modeling and analysis have been applied to space systems[3] and NASA investments.[4]

Basically, real options valuation is a way of capturing value that goes unrecognized in traditional NPV analysis. In particular, when the future is uncertain, there is a value in having the flexibility to decide what to do after some of that uncertainty has been resolved. The managerial flexibility to wait, abandon, or expand on an investment opportunity is captured in a real option. The real option value of the investment opportunity, then, is what a value-maximizing firm would pay for the right to undertake the investment project with its inherent decision points.

Calculating the Value of a Real Option

The value v of a real (non-income producing) option that pays off W(T) at future time T is given by the general formula:

$$v(t,T) = \exp(-r\ (T - t))\ E[\ \max(0, W(T))]$$

where t is current time, E denotes the risk-neutral expected value, and r is the riskless discount rate.

The expected value of the truncated payoff function, W( ), rarely can be computed analytically. Generally, W( ), or an argument of it, is assumed to follow a stochastic to process, and methods such as Monte Carlo simulation can be employed to approximate its full probability distribution at time T. The simulated payoffs can then be averaged and discounted to obtain the option value.

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3 *Saleh, Joseph H., Lamassoure, Elizabeth, and Hastings, Daniel E., "Space Systems Flexibility Provided by On-Orbit Servicing: Part 1",* Journal of Space Cost Estimating Community Spacecraft and Rockets, *July-August 2002, 39(4), pp. 551-560; and Lamassoure, Elizabeth, Saleh, Joseph H., and Hastings, Daniel E., Space Systems Flexibility Provided by On-Orbit Servicing: Part 2",* Journal of Space Cost Estimating Community Spacecraft and Rockets*, July-August 2002, 39(4), pp. 561-570.*

4 *Shishko, Robert, Ebbeler, Donald H. and Fox, George, "NASA Technology Assessment Using Real Options Valuation",* Systems Engineering, *2003, 6(4), pp. 224-234.*

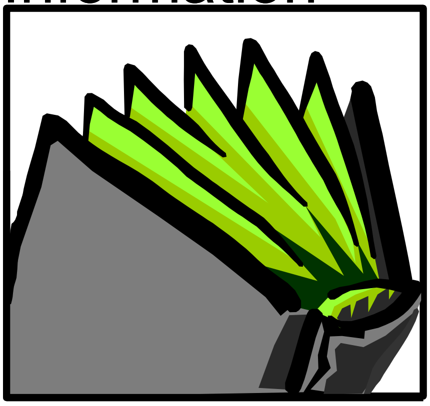
Examples

Consider, for example, an R&D investment or pilot project to develop a lower-cost technological process. The present value of the cost of the R&D or pilot project is C. Such a strategic investment opportunity can be viewed as a call option, having as [its] underlying asset the present value of the expected cash inflows from the completed and operating follow-on project, V_T, with [the] exercise price being the necessary investment outlay, I.

The ability to defer (for T – t periods) investment in the follow-on project under market demand uncertainty creates valuable flexibility for management. If, during the later stages, market demand develops favorably, the firm can make the follow-on investment and obtain the project's net present value at that time, $NPV_T = V_T - I$ [$\equiv W(T)$]. If, however, market demand is weak, management can decide not to invest and its value would be truncated to 0.

In option pricing thinking, the entire investment program is worth –C + the value of the call option on the follow-on project, namely, $-C + v(t,T) = -C + \exp(-r\,(T-t))\,E[\max(0, NPV_T)]$.

More Information



Numerous books and articles have been published on real options topics. For a very simple exposition of real options and their valuation, including what makes option value different from NPV, see:

- Timothy A. Luehrman, "Investment Opportunities as Real Options: Getting Started on the Numbers", *Harvard Business Review*, July-August 1998.
- Timothy A. Luehrman, "Strategy as a Portfolio of Real Options", Harvard Business Review, September-October 1998.
- For more advanced reading, see:
  - Avinash K. Dixit and Robert Pindyck, Investment Under Uncertainty, Princeton University Press, Princeton, NJ, 1994.
  - Lenos Trigeorgis, Real Options: Managerial Flexibility and Strategy in Resource Allocation, MIT Press, Cambridge, MA, 1996.
  - Eduardo S. Schwartz and Lenos Trigeorgis, eds., Real Options and Investment Under Uncertainty: Classical Readings and Recent Contributions, M.I.T. Press, Cambridge, MA, 2001.

6.11 Learning Curves

Learning curves, sometimes referred to as improvement curves or progress functions, are based on the concept that resources required to produce each additional unit decline as the total number of units produced increases. The term learning curve is used when referring to an individual's or organization's performance. If the analysis involves all the components of an organization, it is referred to as a progress function or an improvement curve.

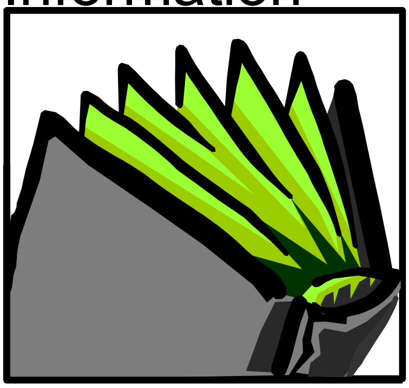
The learning curve concept is used primarily for uninterrupted manufacturing and assembly tasks, which are highly repetitive and labor intensive. The major premise of learning curves is that each time the product quantity doubles the resources (labor hours) required to produce the product will reduce by a determined percentage of the prior quantity resource requirements. This percentage is referred to as the curve slope. Simply stated, if the curve slope is 90% and it takes 100 hours to produce the first unit then it will take 90 hours to produce the second unit. As the quantity doubles (from 1 to 2) the resource requirement reduces from 100 to 90 (100 * 90%).

The two types of learning curve approaches are unit curve and cumulative average curve. The main difference between the two approaches is as indicated by their names, the cumulative average curve calculates the average unit value for the entire curve to a set point while the unit curve calculates the unit value for a specific quantity point. Over the first few units, an operation following the cumulative average curve will experience a much greater reduction in cost than an operation following a unit curve with the same slope. This difference decreases as the quantity increases.

Learning curve analysis is primarily used in situations that provide an opportunity for improvement or reduction in labor hours per unit. The following list illustrates some circumstances where it is appropriate to use learning curves:

- High proportion of manual labor,
- Uninterrupted production,
- Production of complex items,
- No major technological change, and
- Continuous pressure to improve.

More Information



For more information on learning curves please see the following websites:

- Learning Curve Calculator http://www.jsc.nasa.gov/bu2/learn.html
- Article on The Learning Curve http://www.computerworld.com/cwi/story/0,1199,NAV47-68-85-1942_STO61762,00.html
- Department of Energy Office of Science Article on Learning Curves http://www.sc.doe.gov/sc-80/sc-82/430-1/430-1-chp21.pdf
- University of Michigan Article on Learning Curves http://ioe.engin.umich.edu/ioe463/learning.pdf

Calculating Learning Curves

Cumulative Average Curve
(T.P. Wright, traditional approach)

Calculates average unit value of production lot

$Y = AX^b$

Y = Cum average unit value of the Xth unit

A = Theoretical first unit value (T1)

X = Unit number

b = Log(slope) / Log (2)

Unit Curve (J.R. Crawford/ Boeing Approach)

Calculates unit value of specific point on curve

$Y = AX^b$

Y = Unit value of the Xth unit

A = Theoretical first unit value (T1)

X = Unit number

b = log(slope) / log(2)

Midpoint Value

Point on the curve where the unit value represents the simple average of all unitsin the lot

$$MPV = \left[\frac{(X_e - X_b + 1) * (1 + b)}{(X_e + 0.5)^{1+b} - (X_b - 0.5)^{1+b}} \right]^{-1/b}$$

MPV = True lot midpoint value

X_e = End point (last unit in the lot)

X_b = Beginning point (first unit in lot)

b = log(slope) / log(2)

TIPS

Rules of Thumb

Slope by Industry:

All percentages listed above were taken from the Cost Estimator's Reference Manual.

- Aerospace 85%
- Electronics manufacturing 90-95%
- Repetitive electrical operations 75-85%
- Raw materials 93-96%
- Complex machine tools 75-85%
- Machining or punch press 90-95%
- Repetitive welding operations 90%
- Purchased parts 85-88%

Approximation/Arithmetic Mean Approach:

Shortcut to calculating the midpoint

For the first lot:

- If the lot size < 10
  - MPV = lot size / 2 + (# of prior units)
- If the lot size > 10
  - MPV = lot size / 3 + (# of prior units)
- For subsequent lots:
  - MPV = lot size / 2 + (# of prior units)

6.12 Construction of Facilities Estimation

Construction of Facilities (CofF) cost estimating is different in discipline and methodology than space cost or research and development of technology (R&T) estimating. In contrast to most space cost and R&T estimating, which is guided by NPR 7120.5, NPR 8820.2C is the guidance for most CofF design and implementation estimating. However, NPR 7120.5 guides major CofF projects (i.e., greater than approximately $15 million).

Most CofF estimators have little in common with space system cost or R&T estimators; except in offices that have oversight into all NASA functions. CofF estimators generally use the tool, RS Means, published lists of tables and regional metrics for CofF cost estimating.

"Success Cost Estimator" is a tool developed for KSC that is used for estimating the cost of construction. The CofF process is based on a five-year cycle and is summarized below.

Yearly, a budget call is initiated to determine the priority of CofF projects for the next five fiscal years. Approved projects are prioritized and assigned a year of execution. This information is included in the 5-year budget submitted by each Center on a yearly basis.

At a Center, the Facilities Division is responsible for CofF projects, which are directed by a project manager, with a facility project manager assigned to each project. Project managers have cradle to grave responsibility for each project, however no one on the facilities division staff is a cost estimator. If needed, a support contractor does ICEs. In addition, the center's independent assessment team may be asked for additional support.

TIPS

CofF Lessons Learned
by Dan Tweed, KSC

1. During the estimate, remember that construction will sometimes have to coordinate with other schedules. Build those interruptions and associated costs into the estimate and schedule by adding money and additional contingencies for schedule integration needs. In KSC's launch processing environment, we have to coordinate implementation schedules with shuttle operations schedules and payload processing schedules or space station element processing. Sometimes we have to start and stop construction around launches.
2. Remember to estimate for support costs during construction. For example, if during construction a utility service has to be taken offline, then temporary facilities must be provided and paid for that out of the construction budget.
3. Estimate and plan to spend more money initially on soil borings to get enough of a distribution on a building's footprint and find any unsuitable materials. During a building construction, KSC received a unpleasant surprise with a muck layer that was in between soil borings we took; the resulting fix cost a lot more money.
4. When estimating maintenance, rehabilitation, or revitalization for older structures, be aware of human safety needs and special handling requirements for components like lead paint or asbestos. Identify and estimate for these additional costs.

Overview of the CofF Process

1. The Center's facilities project manager requests input from individual divisions. Either division directors or contractors prepare a list of required CofF projects, including a parametric estimate for each. In addition to the parametric estimate, the engineering staff will prepare a ROM estimate.
2. The Facilities Division collects and prioritizes the input received. The Center Director and his team prioritize and approve those projects that will be submitted for budget inclusion. The CoF portion of the budget request is sent additionally to HQ (Code JX/Facilities Engineering Division) for final review and recommendations.
3. CofF cost estimating, project planning and design begins two years out, when HQ Code JX authorizes design money based on 2-year out project approved budget. (For example, in FY04, the centers will receive FY04 construction money and FY06 design money.) Cost estimating, project planning and design are paid for by design allocations.
4. After design money is received, the Facilities Division project manager issues a SOW for the design of each project. This SOW identifies project budget, scope and an estimated construction price based on approved budget amount (current cost estimate or CCE). The CCE includes construction contract award budget, approximately 10% for contingency, and 10% for supervision, inspection, and engineering services. This CCE also includes funds for field inspection services and engineering services during the construction.
5. Architecture/Engineering or Civil, Structural, Mechanical, and Electrical firms may hold on-call design services contracts. The SOW includes the target cost available to the firm for the effort. The firm will estimate and design to this budgeted amount. The project is competitively awarded through procurement with advice from facilities.
6. Following the design contract award to a firm, the Facilities Division project manager will hold a kickoff meeting –which includes the design firm, Facilities Division office representatives and other stakeholders and start a process for establishing the detailed scope. Reviews follow at 30, 60 and 90% design and cost milestones.
7. Typically, a design firm prepares detailed ground-up estimate, initially based on square foot estimates (at the 30% review.). Then, the contractor creates detailed estimates, incorporating material take-offs and linear square foot costs against each system and vendor quotes for different building components. Information is gathered from tools like RS Means and local vendors estimates, and estimates include calculations for present year cost versus future year costs and expected inflation. Each project estimate is always separated into both CofF funded and non-CofF funded estimates. (Non-CofF funded examples include outfitting an office building and activation activities after facility construction.)
8. At the 100% design and cost milestone, the facilities division project manager will review the contracted firm's cost estimate, giving input on design and tracking changes. When reviewing the cost estimate, the project manager looks for anything out of the ordinary, such as costs higher than those budgeted, and what elements are CofF funded and what elements are non-CofF funded. Then the project packaged is stored until the construction year.

Prior to contract award, the design firm will refresh the design and cost estimate (i.e., update codes, conduct a budget sanity check, etc.) in the year prior to construction. In the construction year, the facilities division awards the contract and fixes the contraction budget at the updated cost estimate amount plus 10% (covers new requirements or unforeseen sight conditions/design deficiencies). CofF contracts are always a fixed-price contract, to eliminate overrun issues. During construction, the design firm prepares engineering and cost estimates for any change orders.

6.13 Software Estimation

Software represents a substantial portion of the cost for space systems. Estimating the cost, schedule, and effort associated with a proposed software development project is a critical and challenging task. The software development industry, as a whole, does not have a good track record when it comes to completing a project on time and within budget. Recent studies have shown that only 25% of software development projects are completed successfully within the estimated schedule and budget.[5] NASA is no exception to this problem. Two studies of over 30 ground and flight software developments from 1989 through 1999 at JPL showed that they over-ran their planned effort as defined at PDR by 50% on average.[6] This inaccuracy is primarily due to a lack of clear understanding of the software requirements in the early stages of the life cycle.[7] Other major causes are overly optimistic assumptions related to software inheritance and under estimating the impact of new technologies, methods and process[8,9] NASA's CEC, in their efforts to improve cost estimating accuracy and reliability, should apply the lessons learned from these experiences and apply NASA software estimating best practices to mitigate the risks.

Although software estimation is treated as a special case of cost estimation the cost estimating process described in this handbook still applies. The primary difference between costing software and hardware or systems is that the dominant cost component is labor, therefore correctly estimating the development effort is key. The estimation methods will depend on the resources available and the level of understanding of the needs and objectives (Task 1) and the ground rules and assumptions (Task 4). (A CADRe will usually not be developed specifically for a software project, but software development will typically be a section in a space system project's WBS/CADRe.) The estimation methods will depend on the amount of data available and the size and complexity of the project. All estimates are made based upon some form of comparison using measures or data that has been recorded from completed software projects.

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5 *1998 Standish Group CHAOS Report.*

6 *JPL Software Cost Estimation Handbook (2002) (Note: Jairus Hihn, Karen Lum, et al., "Software Cost Estimation Handbook, v. 1.0", JPL D-24385 (December 2002), is publicly releaseable resource.).*

7 *Boehm, B (1981), Software Engineering Economics, Prentice-Hall, p. 311.*

8 *Hihn, J and Habib-agahi, H.* Identification and Measurement of the Sources of Flight Software Cost Growth, *Proceedings of the 22nd Annual Conference of the International Society of Parametric Analysts (ISPA), 8-10 May, 2000, Noordwijk, Netherlands.*

9 *Hihn, J and Habib-agahi, H.* Reducing Flight Software Development Cost Risk: Analysis and Recommendations, *2000-5349, Proceedings AIAA Space 2000, 19-21 September, 2000, Long Beach, CA.*

Whether the estimator chooses tool-driven estimation, historical analogy estimation, or "Rules-of-Thumb" depends on the size and complexity of the project.

This section is based on three primary sources. The most comprehensive process for software estimation is documented in JPL's Software Cost Estimation Handbook [6]. MSFC's Flight Software Group uses tool-driven estimation, in this case the Constructive Cost Model or COCOMO[10]. Finally JSC's Flight Software Group uses a "Rule of Thumb" based on historical data for mostly small developments (only one development greater than 200K SLOC).

Regardless of the method used for estimation, one of the most important and most difficult steps is determining software size. There are three sizing methods that are typically used: physical source lines of code (PSLOC), logical source lines of code (LSLOC) and function point analysis. There are advantages and disadvantages to each method. For all three methods it is important to handle inherited code properly, for details see [6,7].

Whatever method used, it must to be applied consistently and its counting rules be clearly documented. The most common sizing method within NASA is based on PSLOC[11]. The PSLOC metric is very simple to count (carriage returns excluding comments and blanks) and easily lends itself to automated counting tools.[12] Also historical physical SLOC data is available to support analogical comparisons and calibrating models. There are variations in Logical statements counting rules, which can cause differences in the number of lines counted between tools but logical SLOC measures more consistent across languages. FPA provides a sizing methodology that is tied to a functional design but the counting is subjective and the bases of counting in not well known to most reviewers making it more difficult to communicate. A table for converting between physical and logical SLOC is provided in Exhibit 6-9.

Language	To Derive Logical SLOC
Assembly and Fortran	Assume Physical SLOC = Logical SLOC
Third-Generation Languages (C, Cobol, Pascal, Ada 83)	Reduce Physical SLOC by 25%
Fourth-Generation Languages (SQL, Perl, Oracle)	Reduce Physical SLOC by 40%
Object-oriented Languages (Ada 95, C++, Java, Python)	Reduce Physical SLOC by 30%

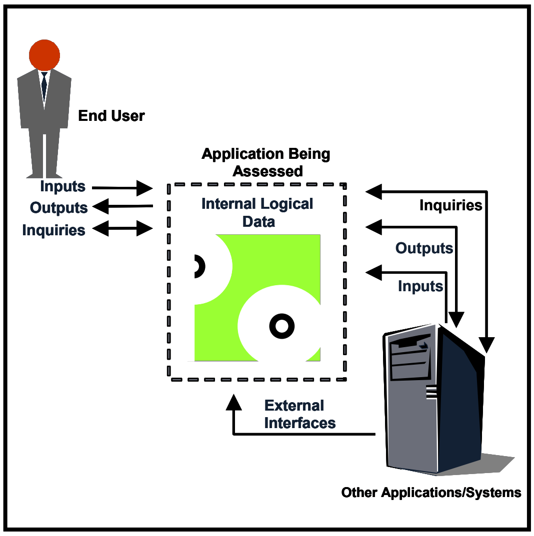
Exhibit 6-9:
Converting Between Physical and Logical SLOC

[10] *MSFC FSG Software Project Estimating Guide.*

[11] *SLOC does not include comments, blank lines, data and non-delivered programmer debug statements.*

[12] *Jones, T. Capers (1998), p. 319.*

Function Point Analysis (FPA)



Because FPA is not well known within NASA, a short over view is provided here, but for a more detailed description of FPA see [10]. Function points were established in the late 1970s as an alternative to SLOC, but only recently have they gained more attention and use. Function points measure software size based on the functionality requested by and provided to the end user. Functions are categorized as data or transactions. Data functions include logical data groups that are captured and stored by the application being estimated and external data referenced by the application. Transaction functions encompass inputs (add, change, and delete), outputs (reports), and inquiries (searches or retrievals).

One of the key benefits of using function points as the sizing method is that counting standards are established and maintained for the technique. The International Function Point Users Group (IFPUG)[13] manages, regulates, and issues updates to these standards, making function points fully documentable and traceable. Many resources can avail themselves to function point analysis at various stages in the development life cycle, including user or estimator interviews, requirements and design documents, data dictionaries and data models, use cases and user guides, and even screen captures or the actual software. Function points, like SLOC, offer certain advantages and disadvantages, which are detailed in Exhibit 6-10.

Advantages	Disadvantages
Standards are established and reviewed frequently.	Largely a manual process.
Resulting metrics are logical and straightforward.	Accurate counting requires in-depth knowledge of standards.
Counting resources are available from requirements stage and applicable for full life-cycle analysis.	Some variations exist that are not standardized (Mark II, 3D, full, feature points, object points, etc.).
Technology, platform, and language independent.	Not as much historical data available as SLOC.
Objectively defines software application from the user's perspective.	Sometimes backfiring, derived from SLOC can be inaccurate and misleading.

Exhibit 6-10:
Function Point Advantages and Disadvantages

13 *For more information on function points visit www.ifpug.org.*

Effort Estimation

Because software effort estimates are required when the requirements and design are still very immature, it is extremely important that more then one estimate be generated to establish the BOE. It is recommended that two to three different types of estimates be derived:

- A traditional engineering estimate typically based on a bottom-up decomposition,
- Model based estimate, and
- Analogical comparison to other similar tasks.

The engineering software estimate typically uses a straightforward methodology to derive effort, cost, and schedule. This includes analogy, engineering buildup, or “Rules of Thumb.” Analogy compares the project at hand to “comparable” projects. The estimate then may be adjusted to account for any obvious differences (e.g., estimated size or complexity). Engineering buildup leverages expertise of people who have experience in software development. These experts apply their best judgment to estimate the duration and effort required to complete the project. The analysis may be broken down into work packages, modules, or activities to achieve greater granularity and accuracy. CERs, or “rules of thumb,” use simple factors such as productivity metrics, percentages, or multipliers that are easily applied to size, staffing, or other estimate data to derive cost, effort, and schedule.

JPL and other Centers, e.g. JSC, track the size of development efforts and can derive a size estimate based on analogy to the historical data. Sizing by analogy, however, does not address all the relevant issues. What requires effort is the amount of code that needs to be written, modified and tested, not the amount of code that gets delivered. To estimate the development effort the number of Equivalent SLOC needs to be derived, which is based on weighting the cost of an inherited line relative to the cost of delivering a new line of code. Historically, there is a tendency to over estimate the amount of inheritance and to underestimate the cost of inheritance, so be conservative. The cost models have algorithms built in to compute Equivalent SLOC. For a simplified approach to computing Equivalent SLOC apply the adjustment factors displayed in Exhibit 6-11.

Software Heritage Category	Effort Multiplier
New design and new code	1.2
Similar design and new code (nominal case)	1.0
Similar design and some code reuse	0.8
Similar design and extensive code reuse	0.6

Exhibit 6-11:
Effort Adjustment Multipliers for Software Heritage[14]

[14] *Based on Team X’s ACS Cost Model, which is based mainly on Discovery-class missions.*

Because no analogy is ever perfect and because expert judgment must be applied to obtain a best guess as to the SLOC to be developed it also important that estimation uncertainty be factored in. What is recommended is that the estimator estimate a size distribution based on the least or minimum number of time, the likely amount of time and the most amount of time for a development effort for each software function. These can then be combined using Monte Carlo techniques or by computing the mean of the distribution. Most parametric cost models have this feature built-in. If you do not have access to Monte Carlo or statistical software, then an easy to compute heuristic is done with the use of Program Evaluation and Review Technique (PERT), which calculates the mean as Mean = (Least + 4*Likely + Most)/6.

The key to translating the number of SLOC into development effort (labor months) is the productivity factor, that is the assumption made on SLOC per labor (work) month.[15] The JPL Cost Estimation Handbook offers two productivity averages, one based on historical experience at JPL and NASA[16] and another based on industry averages. Additionally JSC's Flight Avionics Group has noted a productivity factor ranging from a low of 165.5 SLOC/LM to a high of 8,333 SLOC/LM. As can be seen the productivity ranges are very large. Hence, it is very important that software cost metrics repositories be established so that the estimator has access to data consistent with their environment.

Software Class	Mean SW Development Productivity (SLOC/WM)	Range SW Development Productivity (SLOC/WM)
Mission Critical Flight SW	125	13-467
Mission Support Flight SW	184	80-262
DSMS	197	148-347
Mission Critical Ground SW	239	116-519
Mission Support Ground SW	295	103-607
Development Support Ground SW	157	129-207

Exhibit 6-12:
Software Development Productivity for JPL and NASA Average Projects (Equivalent Logical SLOC)

15 *JPL uses the acronym WM for work month, other sources use LM. They both mean the same thing.*

16 *The data in the JPL table is computed based on the NASA Software Cost Database (1986-1990), the JPL Software Resource Center (SORCE), the JPL Interplanetary Network Directorate (IND) Software Cost Database (1990-1998) and the JPL SQI Software Cost Database (2001-present).*

Characteristic	Software Development Productivity (SLOC/WM)
Classical rates	130-195
Evolutionary approaches[17]	244-325
New embedded flight software	17-105

Exhibit 6-13:
Software Development Productivity for Industry Average Projects (Equivalent Logical SLOC)

Finally to the development effort should be added all the additionally activities related to a development lifecycle such as the Software Management effort and maintenance (sustainment). This arrives at the total work effort (labor months).

Once the development effort is calculated, the effort is costed using labor rate information. Either burdened civil service as described in Section 6.15.6 Labor Rates, contractor bid rates (if known) or industry average rates.

Parametric Model Based Estimates

Software development cost estimating tools are an important option available to the cost estimator. At some Centers, such as MSFC's Flight Software Group, parametric cost models are the estimation method of choice, whereas JPL's approach is to rely on models for cost assessment or validation. In any case, more insight is gathered when both methods are used for the purpose of comparison and validation. Parametric tools are based on data collected from hundreds of actual projects. The algorithms that drive them are derived from the numerous inputs to the models such as personnel capabilities, experience, development environment, amount of code reuse, and programming language. These tools usually provide default settings for these input parameters, which means that a reasonable estimate can be derived from a minimal amount of data. Additionally, these parametric tools provide flexibility by accepting multiple sizing metrics, so estimators can apply any number of sizing methodologies. Parametric estimation tools can receive size data either as SLOC or function points. Software cost models produce even better results when calibrated to specific development teams using actual project data. Another significant benefit of automated tools is their ability to perform sensitivity and risk analyses for a project estimate. Estimators can manipulate various inputs to gauge the overall sensitivity to parameter assumptions and then assess the overall project risk based on the certainty of those inputs.

The main drawback to software cost estimating tools is the cost and the need for users to be trained. Some tools are expensive and complex. Many commercial software estimation tools are available on the market. Currently, NASA has agency-wide licenses for both PRICE and SEER estimating suites, which both include software estimation tools. These two specific tools trend toward the higher side of the cost-complexity spectrum, but there are several other models available to estimate software costs. Please see

17 *Only for simpler, less complex systems and not a flight system.*

Appendices L for U for more information on the many models available. Although PRICE and SEER are the two agency-wide licensed tools, JPL, MSFC and JSC also use the COCOMO, which was developed by the Center for Software Engineering (CSE) at the University of Southern California, headed by Dr. Barry Boehm[18]. Training on COCOMO is available through NASA Training programs. Included in the licensing agreement with PRICE and SEER is access to training on the tool.

6.14 Estimating Operations and Support (O&S) Costs

O&S costs have not received as much attention and detailed analyses within the space costing community as development costs have. While there may be a number of reasons for this, the requirement for accurate and complete LCCEs for future NASA systems raises the importance of O&S cost estimating. O&S costs are often a substantial fraction or even the majority component of life cycle costs when long operations periods are involved. For these kind of programs/projects, the NASA cost analyst needs to understand O&S cost concepts, tools, models, and sources of cost risk on a par with development costs.

Another reason for increasing the attention given to O&S costs is that early system design decisions can exert a tremendous influence on O&S costs, locking in the level of O&S support required for the remainder of the program/project. Far off operations consequences will be determined, or fixed, and difficult to amend, but may not necessarily be known, based on these earliest of up-front system decisions. It is the job of the analyst to ensure these consequences, good or bad, are visible to a program/project as early as possible while decisions can still be altered. For this reason, a CAIV study is required for all major NASA flight programs/projects.[19] Choosing the system design based solely on development costs has been detrimental to NASA in the past, so the objectives of the NASA O&S cost analyst in supporting a CAIV study should be to ensure that:

- O&S cost drivers have been identified, and
- The O&S costs of all alternatives have been considered in the selection of the preferred alternative.

When program/project development costs can be traded against O&S costs and operational risks, the ability to make accurate O&S cost estimates that reflect alternative designs and operations concepts is essential to good systems engineering, not only early on, but throughout the life cycle. The effective O&S cost analysts participates within a creative design process that not only receives information about a design, technology, concept, schedule, development, or set of performance requirements, but also effectively feeds back and alters all these subject areas from an operations perspective. As with all cost areas, effective O&S should both receive and apply requirements within the collaborative processes that ultimately create elegant system design.

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18 *JPL is an affiliate member of the CSE.*

19 *Category 1 programs/projects as defined in NPG 7120.5C, "The Management of NASA Programs & Projects".*

As shown in Exhibit 6-14 by means of a high level and typical Design Structure Matrix (DSM), the O&S cost analysts must participate within a dual mode creative process. The first process receives information that is evaluated, such as when preparing a cost estimate. Cost estimating will be incomplete and ineffective if only this first mode is executed. The second mode, completing and making for an effective process is to be an involved O&S cost analyst, using operations perspective, models, data and all the tools at ones disposal to shape the systems that will be studied, developed, produced and eventually operated.

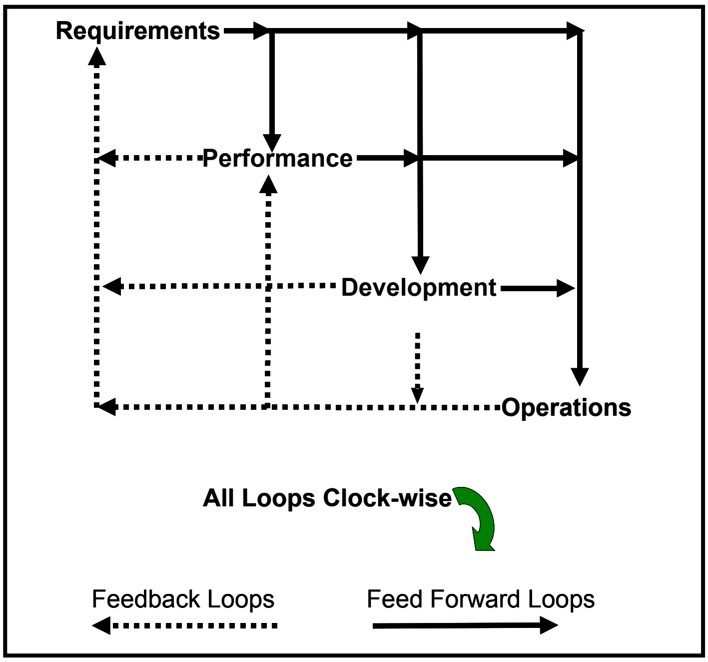


Exhibit 6-14:
The Dual Modes of O&S Cost Estimating

The following sections provide guidance to the NASA cost analyst on estimating O&S costs for new systems and an introduction to several currently available models for estimating O&S costs. These models have been developed to support three types of NASA systems/missions: robotic missions (planetary and Earth-orbiting), launch systems, and crewed space stations/bases.

Estimating O&S Costs for New Systems

In estimating O&S costs, the NASA cost analyst should follow the standard 12 tasks defined in the NASA cost estimating process as tailored and described below. Typically, certain tasks within the process are performed iteratively, especially as guidelines are revised and improved data become available.

Project Definition Tasks (1, 2, and 3)

The analyst should understand not only the systems in the program/project, but the program/project's operations concepts. At a minimum, the analyst should be familiar with the program/project's approach to:

- Real-time operations
- Flight planning
- Training
- Maintenance and support (both on-orbit and ground systems)
- Sustaining engineering
- Communications
- Data handling and analysis
- User/science integration.

These activities are generally common to planetary, Earth-orbiting, observatory, and space station operations; for space transportation vehicles and spaceport operations, the analyst needs to understand additional operations concepts such as vehicle processing.

These activities often (but not always) form the basis for a program/project's operations WBS. In the O&S cost models listed in Appendix L and described in Appendix M, these costs are typically elements of the cost breakdown structure chosen by the model developers. As such, the costs of these activities are explicitly calculated by the model, but the analyst may need to transform them to accommodate a program/project operations WBS that does not conform to the model.

The CADRe should provide strong visibility to O&S concepts and cost drivers embodied in the system design. This includes visibility of O&S parameters for all operations epochs of the mission, and operational risks for a cost risk analysis.

Cost Methodology Tasks (4, 5, 6, and 7)

The cost analyst should understand the GR&A with regard to O&S costs. This includes defining:

- The period of operations/start of operations,
- The types of dollars needed to be consistent with the development cost estimates,
- The inflation rates and discounting assumptions,
- The lengths/types of mission epochs, as applicable;
    - The planetary: spiral out/in, cruise, orbit insertion/encounter, Entry, Descent, and Landing (EDL), surface operations, extended operations, disposal,
    - For Earth-Orbiting and Observatories: deployment, routine operations, servicing/logistics operations, disposal,
    - For crewed Space Stations: launch and assembly, mature operations, phase-out operations, disposal,

- Whether operations are multi-mission (e.g., Are facilities costs to be shares, such as the STS and ISS Mission Control Center? Are operations teams to be shared across several missions?),
- The cost-sharing arrangements with partners,
- The Government or NGO operations, and
- The degree of Government oversight.

The cost analyst needs to select/develop a model depending on the level of detail available and the issues to be addressed at the time the estimate is requested. The analyst needs to ensure that the full scope of O&S costs are included, and should focus on those areas of O&S costs where costs may be substantially different for different alternatives. When selecting a model, the analyst should be concerned with model credibility and validity. The O&S cost model's computational methodology must be sound, and the results must be reproducible by another qualified analyst using the model.

A number of GOTS models listed in Appendix L and described in Appendix M are available to NASA costs analysts to deal with O&S costs for a wide variety of NASA missions. These models are capable of providing O&S cost estimates at different levels of resolution and fidelity. Generally, early in the project life cycle when information is scarce, only a ROM cost estimate may be possible or needed. For the CAIV study, the O&S cost model selected should at a minimum provide sufficient information to support architectural trades. Sometimes, more depth in the O&S cost model is needed to address critical system design and supportability issues. Exhibit 6-15 shows the capability of various GOTS O&S models to support trade studies. Other O&S assessment tools listed in Appendix L and described in Appendix M may be very useful in providing data for lower resolution models.

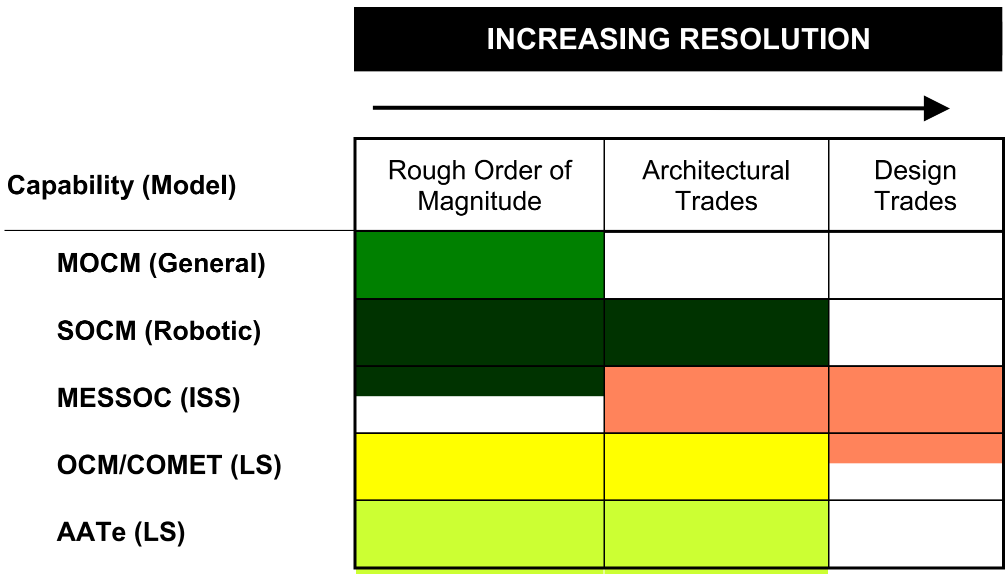


Exhibit 6-15:
GOTS O&S Cost Model Capability

The cost analyst should obtain data from the CADRe. Sometimes, it may be necessary to further interact with the development team for system characteristics, and the O&S team for operations/logistics concepts and ground system characteristics.

The Estimate Tasks (9, 10, 11, and 12)

The cost analyst should follow standard methods of performing sensitivity analyses and cost risk analyses. Some of the areas that can cause cost risk and that must be addressed while developing an O&S estimate are: mission scenario, operating tempo (such as flight rate), system reliability, and operating environments. If, for example, an O&S cost estimate is sensitive to the reliability and maintainability (R&M) of the system or one of its subsystems, the cost analyst must apply alternative R&M assumptions, just as a risk analyst would in a PRA.

This previous subject area of R&M especially requires that the O&S analyst work closely within the system definition process with performance, development, and production focused leads. A more reliable system may be traded for one that fails more often but is easier to maintain by virtue of its layout or design. Alternately, a more maintainable system may affect performance, such as by the addition of a feature, perhaps but not necessarily, adding weight to the system. Adding to the inter-relationships, a leaning toward a more reliable system, and improved O&S, may reduce weight, but require many more test/fail/fix cycles to evolve, thereby affecting development cost, and schedule. The need for defendable, measurable, credible estimation becomes especially clear in O&S when it eventually involves affecting a program/projects more visible and near term factors in exchange for benefits that may not be proven out till many years down the road.

The cost documentation should provide a concise presentation of key results, and permit a detailed review of the GR&A (for consistency with current program/project documents), cost estimating methods and models, data sources and quality, and the supporting rationale for the O&S cost estimates. Key results should cover not only costs, but operating tempo and other measures of operational effectiveness as well. O&S costs should be time-phased, showing both real-year and constant dollars by GFY. Key results also include programmatic and design cost drivers, sensitivity analyses, and cost risk results (the cost S-curve).

It is also useful to identify actual O&S costs for similar systems, noting major differences between the historical system and the one to be estimated. Another useful display shows how estimates for the new system have evolved over the life cycle, again providing explanation for significant changes (e.g., changes in flight rates, program/project descopes, improved understanding of the system).

Just like development cost models, O&S cost models require updating to be capable of providing the best estimates. These updates may include cost factors such as fully burden FTE costs, wraps, and inflation rates. They may also require structural updating from time to time in order to model current operations concepts.

TIPS

Operations and Support Cost Estimation Issues/Challenges

There are a number of issues and challenges the NASA O&S cost estimator faces when trying to develop an estimate for a new program/project. These include:

- Historical data for O&S CER development non-existent or sparse
- Operations concept(s) not established or elaborated
- Cost estimates dependent on activity levels (e.g., flight rates) that are not yet known
- O&S teams not yet formed; hard to identify O&S discipline experts
- Maintenance data (e.g., failure rates and repair times) subject to great uncertainty
- Independent validation of models usually not possible until late in project/program.

Understanding the Supply Chain

A unique and daunting O&S cost estimation challenge involves estimating the supply chain costs of a future system. Traditionally, program/projects have considered factors such as sustaining engineering, logistics, and communications among others as areas that are less visible but which can easily comprise significant O&S costs. As more precise and comprehensive estimates are required of programs/projects, it is no longer sufficient to estimate components of a systems support functions as gross percentages of more direct functions such as hands on activity. Nor is it sufficient any longer to estimate these areas as independent components of a broader system, each devoid of interaction with other support functions. The supply chain design and the factors considered as affecting its nature and cost can be viewed from an operations perspective as equal to and as critical as the design of a flight system or of a facility in which a flight system is worked upon.

Each of the 12 cost estimating process tasks when applied to O&S cost estimating should integrate supply chain considerations throughout for completeness, especially as concept definition increases. Detail at a software/hardware/component level should be matched in time by evolving operations supply chain design, understanding and cost insight.

6.15 Full Cost Accounting

In response to NASA requirements and guidance from Federal law NASA began budgeting and recording cost using Full Cost in FY 2004. Therefore, beginning with FY 2004, every cost estimate shall reflect full cost at a level consistent with the data available. Full cost will impact much of what we do but the ability to operate in a full cost environment is not meant to be a substitute for sound management practices as defined in the Strategic Management Handbook and the Program/Project Management Handbook (NPR 7120.5)

The concept of full cost ties all Agency direct and indirect costs (including civil service personnel costs) to major activities called cost objects. These cost objects are NASA's programs and projects. In the past, civil service personnel costs and certain other costs of the institution were not tied to projects. However, now they are charged or allocated. Cost estimators and financial managers need to include these costs in project/program estimates and must also conduct adequate reviews of proposals to ensure that these costs are included. The NASA Full Cost Initiative Agency-wide Implementation Guide (http://ifmp.nasa.gov/codeb/library/fcimplementation.pdf) includes policy and practice guidance with the goal of providing consistent and complete cost information for more fully informed decision making. The NASA Full Cost web site (https://fullcost.hq.nasa.gov) provides the latest information on the Full Cost Initiative. Cost Analysts are encouraged to visit this site and download the Full Cost 101 course under the training icon. To get more specific information regarding "Full Cost in Practice" training at individual Centers, select the Center of interest on the training page to get training and/or point of contact information.

QUESTION: What is the full cost of a project?

ANSWER: The full cost of a project is the sum of all direct costs, service costs, and G&A costs associated with the project. Because service and G&A costs cannot be immediately and directly identified with a specific project, service activity costs and G&A cost pools are used to accumulate costs of similar purpose.

QUESTION: How are costs categorized when using a full cost approach?

ANSWER: Costs may be categorized in different ways. NASA's full cost approach separates costs into three general categories:

1. **Direct Costs –** Direct costs are costs that are obviously and physically related to a project at the time they are incurred such as purchased goods and services, contracted support, and direct civil service salaries/benefits/travel.
2. **Service Costs –** Service pool costs are costs that cannot be specifically and immediately identified to a project, but can subsequently be traced or linked to a project and are assigned based on usage or consumption. Each pool carries all supporting costs for that function including: civil service salaries/benefits; contractor labor; travel; purchases; pool management; facility related costs.
3. **General and Administrative (G&A) Costs –** G&A costs are costs that cannot be related or traced to a specific project, but benefit all activities. Such costs are allocated to a project based on a reasonable, consistent basis.[20]

20 *NASA Full Cost Initiative Agencywide Implementation Guide, February 1999 and President's Budget FY 2004.*

Overview of Budget Planning in Full Cost

During budget planning and execution, the three general categories of cost are further refined into the following elements of cost:

a. **Procurements -** purchases of contractor hardware, contractor labor, equipment, etc.

b. **Personnel -** cost of civil service personnel labor and benefits.

c. **Travel -** cost of project travel.

d. **Service Pools -** a broad range of infrastructure capabilities that support multiple programs/projects at a Center. These costs can be traced/linked to a given project based on usage/consumption.

e. **Center G&A**[21] **-** captures Center costs that cannot be related or traced to a specific project, but benefit all activities. The following standard types of costs/functions are included in each center's G&A account: G&A civil service salaries/benefits/travel; center training and awards; grounds maintenance; pavement/roads; fire protection; library; public affairs; non-program CofF; transportation services; human resources department; financial management, equal opportunity; educational outreach; medical services; procurement, security, and legal.

f. **Corporate G&A-** Costs related to the business operations of NASA Headquarters as a Center and Agency level functions that are G&A in nature performed at a Center (for example, IFMP). This includes costs for: the NASA Administrator and immediate staff; the Enterprise level/management; Headquarters Operations management; and Functional management, including Safety and Mission Assurance (SMA).

These categories are depicted in the project planning example in Exhibit 6-16.

Cost Elements for Project "A"			Full Cost
Procurements	(Contracts, grants, hardware, direct services)		30M
Personnel	(Direct civil service FTE x Rate)		10M
Travel	(Travel requirements for project personnel)		0.5M
Service Pools			15M
Fabrication Services	(Labor hrs x Rate)	8M	
Test Services	(Labor hrs x Rate)	7M	
Center G&A	Total Direct Labor x G&A Rate)		10M
Corporate G&A*	(Direct NOA* x Percentage)		5M
Total Full Cost Budget Plan			70.5M

Exhibit 6-16:
Project "A" Planning Example

21 *Full Cost does recognize that Centers have unique services, such as the NASA Research Park at ARC, but the inclusion of such unique cost in Center G&A maintains the comparability of Agency service operations across the Centers.*

Although Corporate G&A is assessed to projects at the Agency level, during the estimating process, it must be considered by Center project. For example, when estimating the cost of new initiatives and submitting proposals for NASA Research Announcements (NRA) or Announcements of Opportunity (AO), Corporate G&A must be included to account for the cost of the entire activity.

Service Pools

The Agency has established six standard service pools. The service pools with their recommended cost assessment basis are:

- Facilities and Related Service[22] – Square footage - the square footage occupied by a project/function as a percentage of the total available square footage at the Center.
- Information Technology Service – Desktop seats and/or direct labor hours.
- Science and Engineering Service – Direct labor hours.
- Fabrication Service – Direct labor hours.
- Test Service – Direct labor hours.
- Wind Tunnel Service[23] – Operating shifts.

Every Center has established sub-pools under each of the standard pools listed above. Estimators should become aware of the sub-pools that have been created at their Centers, their content, how their Centers are planning to assess the pool costs to users, and the cost to be assessed. Center cost assessments in budget planning are conducted in a flow-down approach beginning with the assessment of leave and fringe benefits on the direct labor charges and continuing through the pools and G&A to arrive at a Center Project estimate as depicted in Exhibit 6-17.

22 *Custodial costs are included in the Facilities Service Pool.*

23 *At this time the Wind Tunnel Service Pool is only located at LaRC and ARC.*

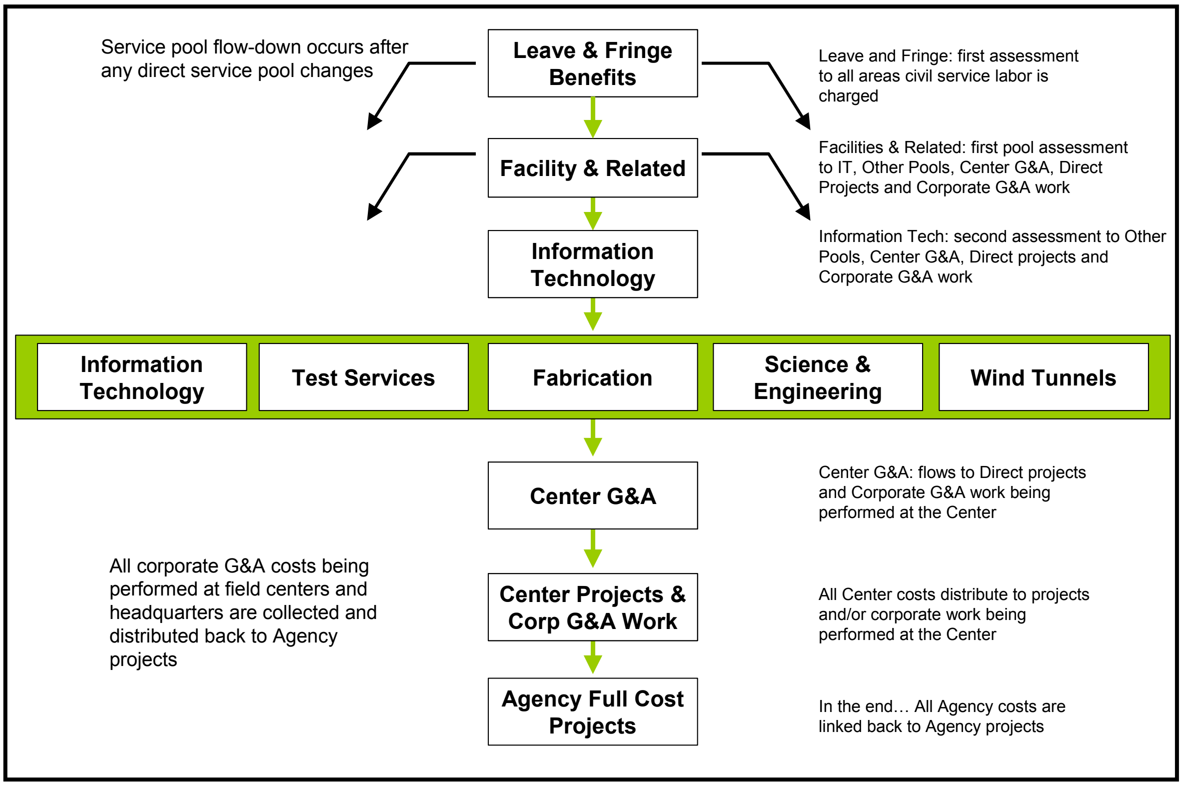


Exhibit 6-17:
Cost Assessment Flow Down

Through the cost assessment process, facilities and related services and some, if not all, of information technology may be completely flowed down to other pools and G&A leaving no costs in the pools to be assessed directly to projects. The last level of cost allocation is the assessment of General and Administrative (G&A) cost across all major activities. This includes Center G&A that is distributed based on total direct workforce equivalents (i.e., civil servants and contractors). Finally, Corporate G&A is distributed based on direct new obligation authority excluding all Center G&A. Care must be taken to avoid applying Corporate G&A to Center G&A costs. Other than facilities and IT, NASA does not allow any other cross-pool charging. After the flow-down of leave and fringe benefits, facilities, and IT, each pool/sub-pool should have a total cost associated with their operations and a planned consumption base. From this, Centers will develop rates to be charged for each service pool/sub-pool activity based on usage.

Estimating in a Full Cost Environment

Given the complexity of the Agency's Full Cost methodology, the level of full cost detail in the cost estimate depends on the nature of the cost estimate. After the cost estimate requirements have been documented and understood and after the ground rules and assumptions have been defined and agreed to, the cost estimator will know what level of detail will be available for making the estimate full cost. The driving factor is usually a factor of time and available data.

The cost estimator should attempt to estimate the functional labor that is relevant to the project being estimated whenever the level of requirements data available to a cost estimator is such that he or she can make that determination. The total NASA labor cost can then be estimated using the direct, service pool, and G&A rates for each type of labor. If functional labor cannot be estimated, estimators could use a tool such as the Excel spreadsheet developed by GRC that summarizes the full cost information from the NASA Budget Process 340 for FY04-FY08. If an analogous theme or project can be identified, this tool provides current full cost information including full time equivalents, contractor work year equivalents, and the average cost of labor. This tool was distributed with the October 2003 CASG meeting files and is available from each Center's CASG representative.

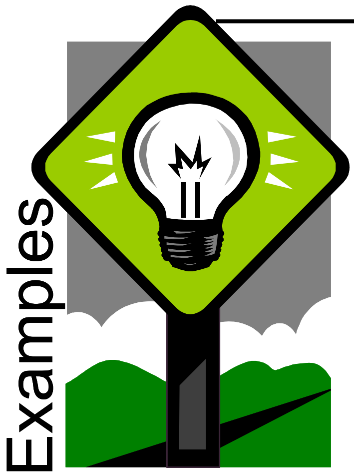
The nature of the cost estimate may be that only a ROM is called for. In such cases the NASA CASG and Code BC has established a composite NASA government cost rate to add to the ROM. Until the development of more detailed information, one approach is to use a standard percentage, i.e., the so-called 'Hamaker Factor'. It is based on current ratio of total dollars to procurement dollars from the Process 340 data. The 'Hamaker Factor' is equal to: (Total Dollars/Procurement Dollars) -1. This represents the additive costs to a prime contract estimate to arrive at the full cost of a project. This factor is calculated in the GRC Excel tool for existing projects. This factor should not be applied to projects that are performed in-house at a NASA Center since they should already include all NASA costs.

The following includes examples of full cost estimating given varying levels of information to complete the estimate.

Examples

Full Cost Estimating Example #1

A prime contract estimate of $350M was performed by GRC. The project will likely be in the Solar System Exploration Theme under Project Prometheus. There is currently no estimate of NASA FTE or support contractor WYE available to complete the full cost estimate. GRC assumes it will be managed in-house like their other Project Prometheus work. The estimate is in FY04 dollars. The estimator can then look at the Excel tool under the GRC Project Prometheus work to find the Hamaker Factor for each year. The average factor can be estimated at about 55%-60%. Using this information, a full cost estimate of ~$560M (i.e., $350M +.6*$350M) can be made. The total civil servant FTE can be estimated at 350 * 2 = 700 Total FTE using the factor of about 2 FTE per million dollars of procurements. The total contractor work years can be estimated at 350 * .8 = 280 Total WYE using the contractor support factor provided. This level of estimate lacks the detail to be broken down into the elements of cost. When using the 'Hamaker Factor' from the Excel tool, cost estimators should not use a single factor for the year of the study. Due to yearly changes in the distribution of budget amongst the elements of cost, an average of the yearly factors is more appropriate.

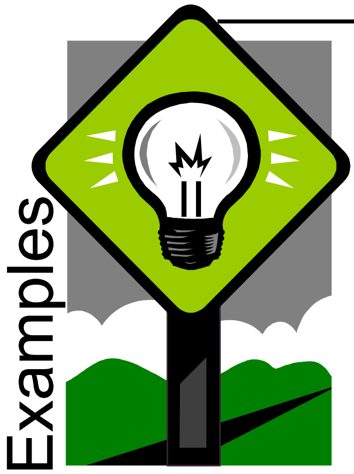


Full Cost Example #2

A prime contract estimate of $350M was performed by GRC. The project will likely be in the Solar System Exploration Theme under Project Prometheus. There is currently an estimate of 210 total NASA FTE and 80 support contractor WYE (direct project support, not service pool) required for the project. A functional labor breakdown is not available. The estimate is in FY04 dollars. Other procurements at GRC require $10M. Using the Excel tool under the GRC Project Prometheus work, the average cost for a civil servant FTE is $211K in FY04$ (i.e., $108K labor, $2K travel, $48K service pool, and $53K G&A).

The average cost of G&A is applied to all direct labor. The average Corporate G&A cannot be determined at the Center level. Looking at Project Prometheus at the Agency level, a Corporate G&A of 5.5% has been assessed and is assumed to be the same for all projects under the program. Calculating the full cost by element of cost could be accomplished as follows:

Procurements			$ 370.4M
Prime contract	$ 350M		
Other Procurements	$ 10M		
Support Contractor ($130K* 80)	$ 10.4M		
Personnel ($108K*210)			$ 22.7M
Travel ($2K*210) Service Pools ($48K*210)		$ 0.4M $ 10.1M	
Center C&A (210 FTE + 80 WYE)* $53K Corporate G&A ($370.4M + $22 .7M + $0.4M +$10.1M) * 0.055			$ 15.4M 22.2M
[redacted]			



Example #3 - A prime contract estimate of $350M was performed by GRC.
The project will likely be in the Solar System Exploration Theme under Project Prometheus. The estimate is in FY04 dollars. Other procurements at GRC are estimated at $10M. Project travel is estimated at $400K. There is currently an estimate of 210 NASA FTE and 80 support contractor WYE required for the project and functionally broke down with the direct labor with fringe benefits, service pool, and G&A rates available as follows:

			60	$130		
	150	$130	0	N/A		$45
	10	$120	0	N/A		$40
	10	$100	0	N/A		$30
	40	$100	20	$90		$50
						$53
	210		80			

GRC test contractors are assessed test service pool costs. The average Corporate G&A is assumed to be 5.5%. The full cost estimate is derived as follows:

Procurements			$	369.6M
Prime contract	$	350M		
Other procurements	$	10M		
Support Contractor ($130K * 60)	$	7.8M		
Test Contractor ($90K * 20)	$	1.8M		
Personnel ($130*150+$120*10+$100*10+$100*40)			$	25.7M
Travel			$	0.4M
Service Pools ($45*150+10*$40+10*$30+(40+20)*$50)			$	10.5M
Center G&A (210FTE + 80WYE) * $53K			$	15.4M
Corporate G&A ($369.6M+ $25.7M + $0.4M +$10.5M) * 0.055			$	22.3M
Total Full Cost of Project			$	443.9M

As shown in the above three examples, varying levels of data will be available to assist in estimating the full cost on new projects. If using the Excel full cost spreadsheet, it is recommended not to use data past three years from the current year due to poor quality of out-year planning information. The best approach to full cost estimating will always be to collect as much detailed labor information as possible to reduce estimating error associated with projecting the full cost of new projects based on current or old project data. In-house projects will be estimated similar to Example #3 except that there is no prime contract. All examples above are at the total project level. Estimators are advised to provide results at the level of detail necessary for management decision-making.

The requirement of Full Cost has an effect on the tools commonly used by the NASA cost estimating community. Whether the level of insight into the Full Cost requirements is very high, permitting the cost estimator to capture cost by pool, or very low, forcing the cost estimator to use only a wrap rate, most tools will be unaffected. For COTS tools such as PRICE and SEER, the cost estimator will use the tool the same way as before full cost, but then burden the estimate with a full cost value. The intention for GOTS tools, however, is to enable them for full cost. The intention is to have NAFCOM, AATe, MICM/SICM, and other NASA tools generate answers already in full cost based on the data input. Because of the different structures of these tools, the method of capturing the full cost burden will depend on the tool. If a GOTS tool is not modified, then the cost estimate will be performed as with the COTS and the cost estimator will complete the full cost estimate outside the model.

Data Collection

Financial system reports for Business Warehouse (BW) are being developed for projects to track their full cost by element of cost and FTE/WYE. These reports will also provide information for cost estimators down to the lowest WBS level in the system. Budget Formulation data in FY05 will provide the opportunity to compare plans versus actuals in a single report. Cost estimators can enhance the value of the data by coordinating with the projects and financial personnel to ensure the WBS in the financial system is consistent with the product-oriented project WBS. Due to the inherent limitations of the financial system, cost data collection remains a major concern within the cost estimating community.

Variance Analysis

In a full cost environment, project managers will need to actively manage more than just their R&D budgets. All elements of cost may be contributors to cost variances. Under full cost, there are two types of variances that may be observed. The first is the cost variance that is the difference between the planned cost and actual costs incurred. These may be caused by labor, service pool, and/or G&A rate variances. The second type of variance is the consumption variance. This is the difference between planned consumption of a resource and actual consumption. Project Managers and resource analysts will be responsible for understanding the variances in their cost elements.

Labor Rates

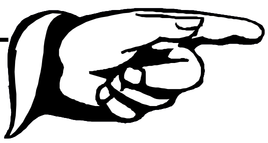
Burdened Labor Rates are used along with hours to estimate the total cost of labor that will be expended on a project. The evaluation of rates, hours, and accompanying assorted skill mixes is especially important with labor-intensive projects vice hardware intensive programs because of the significant contribution to total program/project costs.

The largest impact in the labor area will be the inclusion of civil service labor charges in program/project estimates. As NASA operates in a full cost environment, particular attention must be paid to the inclusion of civil service labor in all cost estimates, which is just as important as including contractor labor costs. Cost estimators need to obtain from their CFO the full cost direct labor and fringe benefit planning rates to use in their estimates by function/service pool.

When labor rates are not available, labor rate analysis and estimating can take on many different forms. Historical rates can be used as a starting point to escalate to future rates. Additionally, Office of Personnel Management salary tables can be used to obtain current civil service rates as the basis of estimates http://www.opm.gov/oca/payrates/index.asp. Added to the basic civil service rates will be a Leave and Fringe Benefit (L&FB) rate. L&FB includes cost elements such as:

- Contributions to Retirement Plans:
  - Civil Service Retirement System (CSRS)
  - Federal Employees Retirement System (FERS),
- Health Insurance Tax (HIT),
- Health & Life Insurance Premiums,
- Workman's Compensation,
- Thrift Savings Plan (TSP) Matching Contributions, and
- Leave and Paid Holidays.

Extracted from the NASA Full Cost Implementation Guide, located at http://ifmp.nasa.gov/codeb/library/fcimplementation.pdf, the example box below demonstrates the development of an L&FB rate for one fiscal year. It was assumed for this example that 40% of the workforce are covered by CSRS and 60% by FERS and that the Government's contributions to those plans is 9% and 19% (which includes Social Security taxes), respectively.



TIPS

Note: When using a combined L&FB rate, analysts must make assumptions on the available hours for an FTE since the leave cost for that FTE is already accounted for in the L&FB rate. Therefore the direct labor cost that the L&FB rate is applied to is the cost of the available hours only. For example, GRC estimators use an estimate of 1800 available hours per FTE after all leave and holiday hours are taken out. Given this assumption, the burdened direct labor cost for a civil servant FTE with a salary of $50,000 per year and a Center L&FB rate of 45% can be calculated as follows:

Burdened Direct Cost/FTE = $50,000 * (1800/2080) * (1 + .45) = $62,740

Examples

Calculating / Allocating Leave and Fringe Benefits

Leave and Fringe Benefit Rate	
	$000
Retirement (including HIT)	
CSRS 9% of salaries (40% of workforce)	4,680
FERS 19% of salaries (60% of workforce)	14,820
Health & Life Insurance	5,500
Thrift Savings Plan	2,500
Workman's Compensation	500
Leave & Paid Holidays	19,500
Total Leave and Benefits	**47,500**
Total Estimated Salaries Less Leave	**110,500**
Rate	**43%**

Allocation of L&FB to Cost Categories			
	Salaries	L&FB Rate	Allocate L&FB
Direct Projects	77,000	43%	33,100
Service Activities	19,250	43%	8,275
G&A	14,250	43%	6,125
Total	**110,500**		**47,500**

6.16 The 12 Tenets of NASA Cost-Risk

This section attempts to provide the reader with more details on the processes that can be used to implement credible cost-risk assessment for NASA systems. Since cost-risk assessment considerations cover many related topics, we start with 12 generally held beliefs or tenets of NASA cost-risk. These tenets of NASA cost-risk are intended to convey what the NASA cost estimating community fundamentally believes about cost-risk assessment and underpins its implementation. The examples and methods illustrating how a cost estimator might implement a particular tenet are presented for basic understanding and do not necessarily represent the only way to implement a tenet.

Tenet 1:
NASA cost risk assessment, a subset of cost estimating, supports cost management for optimum project management

Within the Project CCRM[24], a cost management architecture supporting the NASA project management process, Steps 4 and 5 are perhaps the two most vital steps in the whole CCRM (see **Exhibit 6-18** below). These two steps lay the all-important foundation for the subsequent cost-risk *feedback* provided in later the CCRM steps that can involve earned value, updated LCCE "S"-curves, risk management reporting, PRA, and schedule risk analysis. Establishing the expectations for cost impacts due to risk early in the cost management process provides a reference baseline against which actual cost-risk performance can be measured. This is valuable in providing "triggers" to project managers that application of risk reserves are required. It is also valuable to cost-risk estimators by providing validation that cost-risk distribution estimates were accurate (or not). This helps validate/update cost-risk distribution development algorithms.

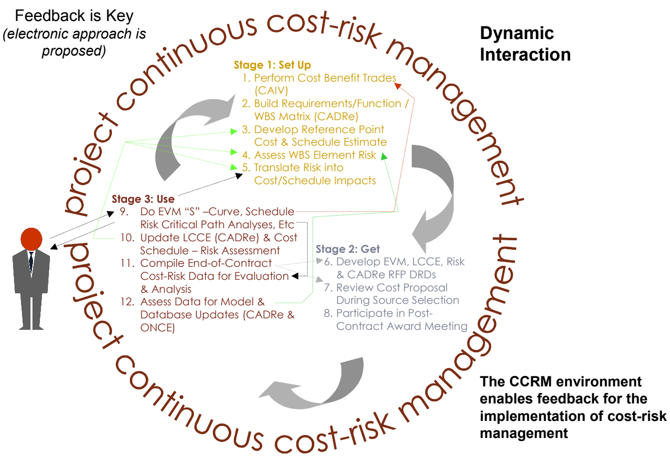


Exhibit 6-18:
CCRM Interaction Between and Among its Steps

[24] *Graham, David R.; "The 3 CCRM Charts"; Jan 2004.*

These two CCRM steps also provide a forum for quantifying subjective risk assessments. The dialogue between cost estimators and engineers working together discussing WBS element risks is a uniquely synergistic experience that is very productive in understanding both the effects, as well as a deeper understanding of the risks.

2 Tenet 2: NASA cost risk assessment is based on a common set of risk and uncertainty definitions[25]

Uncertainty is the indefiniteness about the outcome of a situation - it includes favorable and unfavorable events. We analyze uncertainty for the purpose of measuring risk. In systems engineering, this analysis might focus on measuring the risk of *{failing to achieve performance objectives}*, *{overrunning the budgeted cost}*, or *{delivering the system too late to meet user needs}*; these are examples of three unfavorable events.

- Cost Uncertainty Analysis is a process of quantifying the cost impacts of *uncertainties* associated with a system's technical definition and cost estimation methodologies.
- Risk is the chance of loss or injury. In a situation that includes favorable and unfavorable events, *risk is the probability an unfavorable event occurs.*
- Cost Risk is a measure of the chance that, due to unfavorable events, the planned or budgeted cost of a project will be exceeded.
- Cost Risk Analysis is a process of quantifying the cost impacts of *risks* associated with a system's technical definition, cost estimation methodologies and correlation assessment. We do the analysis to produce a defensible assessment of the level of cost to budget such that this cost has an acceptable probability of not being exceeded.

3 Tenet 3: NASA cost risk assessment is a joint activity between subject matter experts and cost analysts

Since cost estimators are not experts in every conceivable space system, they must work with the engineers who are the experts. The cost estimator's job, when working with the engineering experts, is to elicit risk information that can be translated into cost impacts. Discussions can take the form of interviews about the risks in a given WBS element and how *relatively risky* that WBS element's worst case (pessimistic), best case (optimistic) and most likely case (reference) scenarios are. This Relative Risk Weighting[26],[27]process is a suggested method in order to first, get the engineers to characterize the WBS element in terms of the risks in its KEPPs[28] per scenario and second, rate its three risk scenarios with respect to appropriate cost-risk drivers (e.g.,

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25 *Garvey, Paul; "Cost-Risk Analysis Without Statistics"; Oct 2003*

26 *Graham, David R. (AFMC/SMC), and Dechoretz, Jason A., (MCR Federal, Inc.), "Relative Risk Weighting – A Briefing", Oct 1997.*

27 *Graham, David R. (AFMC/SMC), and Dechoretz, Jason A., (MCR Federal, Inc.), "Relative Risk Weighting – A Paper", Oct 1997.*

28 *The Technology Puzzle: Quantitative Methods for Developing Advanced Aerospace Technology", by Liam Sarsfield; RAND, National Security Research Division, 2001.*

TRL, design/engineering, schedule, integration, etc.) If possible, it is preferred to have more than one engineer in the assessment due to the discussions that naturally evolve. These discussions usually produce a synthesis assessment that is of a higher quality than just using one engineer due to the different perspectives each engineer brings to them.

Once the cost estimator tallies the relative risk-rating scores, they are made available to the engineer for a sanity check. These relative risk-rating scores for each scenario provide the basis for developing cost-risk triangular distributions. If the results need improvement, the engineers are there to make the sensitivity adjustments. A very important by-product of these discussions is the identification of KEPP risks for the application of mitigation funding. The identification of discrete risks is very important when justifying the total risk reserve to decision makers who need to know specific reasons why risk dollars should be made a part of the budget request. These discrete risks flow naturally out of the KEPPs identified in the risk scenario development.

4 Tenet 4: NASA cost risk is composed of CERs and technical risk assessment plus cost element correlation assessment influenced by other programmatic risk factors

- CER risk is the risk inherent in the cost estimating methodology. For example, if a regression-based CER is used, it has an associated SEE, confidence intervals and prediction intervals, any of which can be used to include cost estimating methodology risk in the estimate.
- Technical risk is the inherent KEPP risk in WBS' assessed cost-risk driver categories (technology, design/engineering, integration, manufacturing, schedule, complexity, etc.) Quantifying the cost impacts due to technical risk is not as statistically derivative as CER risk. For this source of risk, a commonly used technique involves constructing a two-dimensional matrix where the rows are "technical" risk source drivers such as state of the art, design/engineering, integration, etc., and the columns are intensities such as low risk, medium risk, high risk, etc. WBS elements are assigned an intensity rating for each technical risk source driver[29,30]. A technique to be described in detail in Tenet 5 below, known as Relative Risk Weighting, adds a dimension for describing worst case, best case, and reference case scenarios with respect to various cost-risk drivers. This three-dimensional matrix produces relative risk scores for each scenario from which can be derived cost-risk adjustment factors for constructing triangular WBS cost-risk distributions.

- Correlation risk assessment determines to what degree one WBS element's change in cost is related to another's and in which direction. For example, if the cost of the satellite's payload goes up and the cost of the propulsion system goes up, then there is a positive correlation between both subsystems' costs. Many

29 *Abramson, R.L. & Book, Stephen A PhD., "A Quantification Structure for Assessing Risk-Impact Drivers" based on the "Risk-Driver Scales" of F.D. Maxwell; The Aerospace Corporation, Sept 1990.*

30 *Young, Philip H.; "Using 'Maxwell Risk-Driver Scales' in Estimating Cost-Risk for System Designs"; The Aerospace Corporation; Space Systems Cost Analysis Group, June 1997.*

WBS elements within space systems have positive correlations with each other and the cumulative effect of this positive correlation tends to increase the range of the possible costs.

- Programmatic risks are issues such as project "jointness" with other NASA and external agencies or organizations, the competency of the project management team, the newness of a system architecture, schedule stability, etc.

5 Tenet 5:
NASA technical cost-risk assessment combines both PROBABILISTIC AND DISCRETE TECHNICAL RISK ASSESSMENTS

There are three sub-tenets associated with NASA Tenet 5:

a. ***Both assessments are accomplished in parallel;***

b. ***Probabilistic technical cost-risk assessment*** results in technical risk-driven distributions at some level of system breakdown (e.g., WBS element). Worst case, best case and most likely case scenarios or profiles, in terms of KEPPs, of WBS elements are rated against pre-established, well-defined technical risk driver category templates (e.g., technology, design/engineering, etc.), understood by technical staff and cost estimators to produce credible inputs, to define these distributions. These distributions will subsequently be statistically summed for total system distribution identification (e.g., Monte Carlo simulation); and

c. ***Discrete technical cost-risk assessments***[25] involve identifying and cost estimating specific cost-driving technical risks. For example, a notional new electronic component for a spacecraft might have risk in KEPPs such as dynamic load resistance, operating voltage, power regulation, radiation resistance, emissivity, component mass, operating temperature range and operating efficiency. Technical staff can identify these KEPP risks during cost-risk assessment when evaluating the three WBS element risk scenarios. Instead of probabilistic distributions and Monte Carlo simulations, however, mitigation costs for these risks are estimated based on their probabilities of manifesting discrete changes in the technical parameters (e.g., increased component mass or power regulation).

Decision makers prefer, as a general rule, lower estimates to higher ones. The reason is fairly obvious. If estimates are lower, either more projects can be developed within limited available funding or proposed projects are more appealing to funding appropriators (or both). Cost-risk assessments generally add to estimated project costs so decision makers will want justification before agreeing to cost-risk assessments. The cost estimator needs a methodology that produces a cost-risk assessment that is beyond reproach. The comprehensive methodology presented here achieves that goal. A recommended approach to identifying and assessing technical risks that may drive costs begins with developing *cost-risk driver rating templates.* This approach is not the only valid way to do cost-risk assessment, however, it is presented here because it addresses all of the major elements involved in cost-risk assessment. Foremost among these major elements is the ability to create credible and defensible inputs to Monte Carlo simulation calculators like @RISK™ and Crystal Ball™ avoiding the "garbage in, garbage out" syndrome. It is also presented here for the cost estimator who finds himself in the position of defending all aspects of a cost-risk assessment.

Pre-established and well-defined risk driver categories function as criteria against which pessimistic, optimistic, and reference WBS element scenarios can be evaluated. Some examples of such criteria and intensity rating scales for technology state of the art, design/engineering, complexity and interaction/dependencies are presented in Exhibit 6-19 through Exhibit 6-22.

Risk Category Assessment Templates

	Level of Uncertainty		
Cost-Risk Driver Category	Very Low	Low	Moderately Low
	Rating		
Technology: Uncertainties to system performance due to reliance on the availability and promise of technology. Technology uncertainty includes the required level of technological sophistication and reflects the current stage of hardware development and testing maturity. Hardware maturity ranges from scientific research, conceptual design, brassboard, breadboard, prototype, to an operational unit. Technology risk analysis is performed at the subsystem or lower (e.g., assembly) level. (**S/W:** Uncertainties due to availability and status of concepts and algorithms required to satisfy system performance. Technology uncertainty includes the current stage of concept and algorithm development and testing maturity. Maturity ranges from scientific research, conceptual design, proof of principle completed, prototype built, to operational. Technology risk is performed at the software item level or lower level.)	Hardware is currently operational and deployed. (**S/W Tech**: S/W is currently operational and deployed.)	Hardware is in limited production and has passed all acceptance tests. (**SW Tech:** Software successfully implemented, requires qualification.)	Prototype is currently in qualification tests, but has passed performance requirements. (**S/W Tech:** A prototype has been built and meets program requrements.)

Level of Uncertainty			
Moderate	Moderately High	High	Very High
Rating			
A brassboard example has been fabricated and tested for performance and qualifications. (**S/W Tech:** Critical algorithms, functions, and characteristics demonstrated by a prototype.)	Critical functions/characteristics have been demonstrated by a brassboard example. (**S/W Tech:** Conceptual design formulated and tested for performance considerations; proof of principle completed.)	Conceptual design formulated and tested for performance and qualification considerations. (**S/W Tech:** Conceptual design formulated.)	Scientific research is required and ongoing. (**S/W Tech:** Scientific research on-going, new algorithm concept needed.)

Note: Other rating scales exist, e.g., Maxwell Risk Matrix[2]

Risk Category Assessment Templates

WBS Design and Engineering Risk Scale

Level of Uncertainty

- Other risk categories such as complexity, reliability, S/W, production, manufacturing, integration, etc.
  - Whatever is appropriate for WBS element

Exhibit 6-19:
Risk Assessment Template Example

Risk Category Assessment Templates

Level of Uncertainty			
Moderate	Moderately High	High	Very High
Rating			
Design effort required using standard, existing components beyond their original accepted specification levels. (**S/W D/E:** Design effort required using existing components beyond their original accepted specification levels or moderate development required using existing knowledge.)	Moderate engineering development is required using existing design knowledge. (**S/W D/E:** Significant development required using existing knowledge.)	Major engineering development is required using existing design knowledge. (**S/W D/E:** Major development required using existing knowledge.)	No alternative components available and/or requires new or breakthrough advance in design capability. (**S/W D/E:** No alternative components available or major development required using new knowledge.)

Note: The two category scales of Technology and Design & Engineering include some overlap since both involve the level of maturity of an item. The technology risk category primarily focuses on the hardware independent of how it will be used on any given spacecraft. The design and engineering category primarily focuses on hardware implementation partially independent of the inherent level of technological readiness (at least for design and engineering levels ≥ 2). For example, a qualified prototype star sensor may still require modification necessitated by form, fit, and function changes and specialized (i.e., radiation shielding, vibration damping, etc.) modifications that are unique to the satellite system.
Scaling assumes current Air Force qualifications procedures. Brilliant Eyes Technology/Producibility Assessment Process provided source information for Technology definitions.

Exhibit 6-20:
Design and Engineering Risk Template Example

Risk Category Assessment Templates

Level of	Uncertainty		
Cost-Risk Driver Category	Very Low	Low	Moderately Low
COMPLEXITY: Degrees of uncertainties due to combining parts/processes to make up the whole.	Very simple combinations and/or not very many parts/processes making up the whole.	Simple combinations; only a few parts and processes making up the whole.	Fair amount of parts/processes making up the whole with somewhat complex combinations.

Level of	Uncertainty		
Moderate	Moderately High	High	Very High
Significant number of parts/processes making up the whole and moderate complexity in making the combinations.	Significant number of parts/processes making up the whole and some new parts required and higher complexity in making the combinations.	Significant number of parts/processes and almost totally new parts/processes and high complexity in making the combinations.	Very large number of parts/processes, totally new part/processes and very high complexity with much uncertainty in making the combinations.

Exhibit 6-21:
Complexity Risk Template Example

Risk Category Assessment Templates

	Level of Uncertainty		
Cost-Risk Driver Category	Very Low	Low	Moderately Low
INTERACTION/DEPENDENCIES: Degrees of uncertainties due to dynamic interplay between and among external interfaces (e.g., gimball with P/L, EPS, thrusters, etc.)	Completely independent of external interfaces.	Dependent on one external interface.	Dependent on two external interfaces.

	Level of Uncertainty		
Moderate	Moderately High	High	Very High
Dependent on three external interfaces.	Dependent on four external interfaces.	Dependent on five external interfaces.	Dependent on more than five external interfaces.

Exhibit 6-22:
Interaction/Interdependencies Risk Template Example

It is important to note that not all WBS elements need to be rated against these four specific criteria. The general rule is that whatever cost-risk driver categories are relevant to the WBS element being rated are the ones that should be used. This may involve developing different risk driver categories such as *integration, schedule, manufacturing*, etc., with associated definitions for both the cost-risk driver and the intensity scales used to rate the degree of risk level involved for the pessimistic, optimistic and reference scenarios. These cost-risk driver templates are the foundation for the interactions between the cost estimators and engineers in determining risk levels in each risk scenario for later use in quantifying their cost impacts.

These templates are used by the engineers in rating the KEPP risks for the risk scenarios of the WBS element. Exhibit 6-23 illustrates a methodology called the Relative Risk Weighting (RRW) process that uses the risk scores generated by the risk rating process to define two ratios that are used as factors on the reference point cost estimate to derive a pessimistic and optimistic cost. Together with the reference point estimate, these two derived costs define that WBS elements triangular risk distribution.

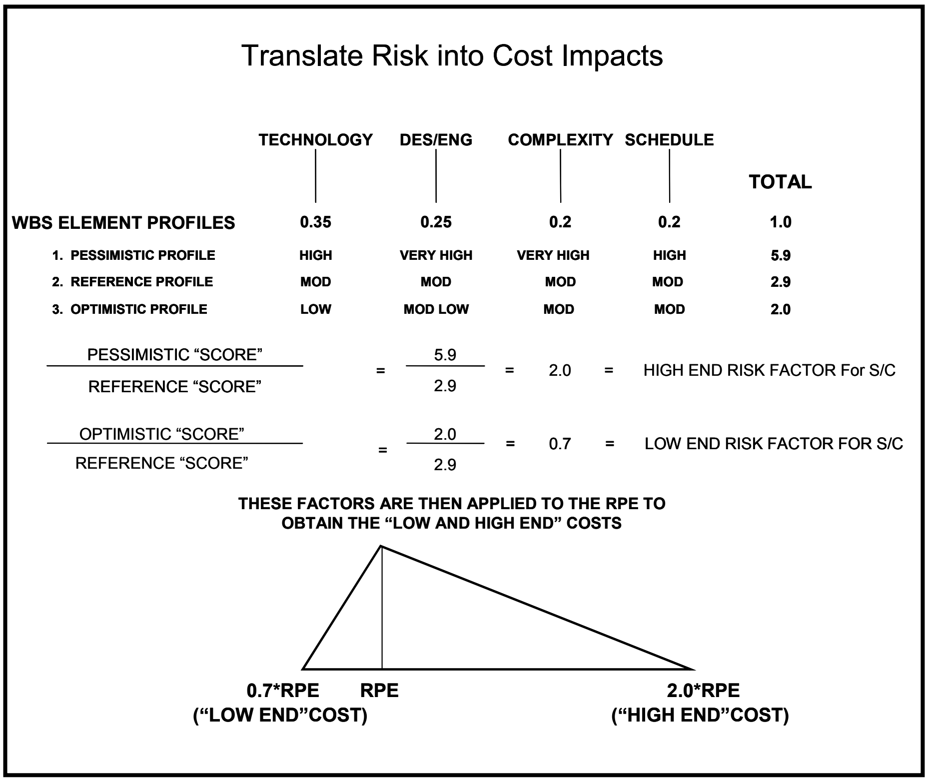

Exhibit 6-23:
Translating Risk in Cost Impacts

The risk scores for each WBS element risk scenario are developed by first deriving weights for both the risk driver categories and the rating scale intensities (e.g., very high or medium low etc.). A useful technique for deriving the weights for both risk driver categories and rating scale intensities is the application of the Analytic Hierarchy Process (AHP). Weights resulting from the AHP are ratio-scale weights, that is, they have a meaningful zero point and thus have the integrity for use in all mathematical operations. The same cannot be said of ordinal or even interval level numbers.[31] [32] The scores result from the sum of the products of each risk category weight and each rating scale intensity weight.

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31 *Forman, Ernest H., Doctor of Science; (George Washington University/Expert Choice Inc.), "Key Topics and Concepts Relating to the Analytic Hierarchy Process", paragraph 10, "Essential Concept: Numeric Scales"; Team Expert Choice Training, Feb 1998.*

32 *Pariseau, Richard Dr.; Oswalt, Ivar Dr.; "Using Data Types and Scales for Analysis and Decision Making"; DSMC Acquisition Review Quarterly, Spring 1994.*

Ratios between the pessimistic/reference scores and optimistic/reference scores are calculated and used as scalars on the reference point estimate. These ratios are credible relationships due to the equivalence of the reference profile's score to the reference point cost estimate. Both are representations of a WBS element defined by the CADRe, one is a cost and the other is a risk 'dimension' assessment. Having a common representation of the WBS element in two "dimensions", so to speak, and three risk assessment scores enables a translation from the risk 'dimension' into an optimistic and pessimistic cost 'dimension'.

A variation of the RRW process involves creating pessimistic, optimistic and reference risk profiles for a CER-driving parameter (e.g., weight). The application of the resulting RRW ratios to the nominal (reference) parameter value from the CADRe reflects the parameter's potential range of values (see Exhibit 6-24). When this range of values is entered into the CER a range of costs is produced that adds to the cost range driven by the uncertainty inherent within the CER itself. Exhibit 6-25 illustrates this new range.

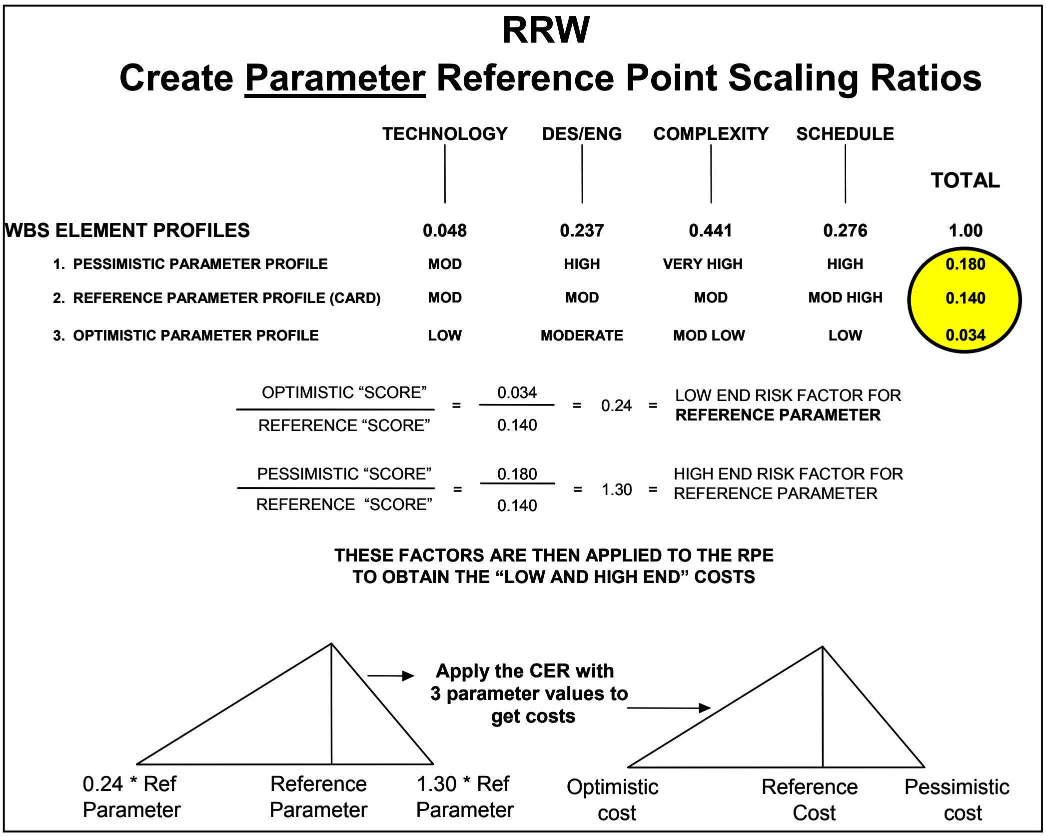

Exhibit 6-24:
Relative Risk Weighting Potential Range of Values

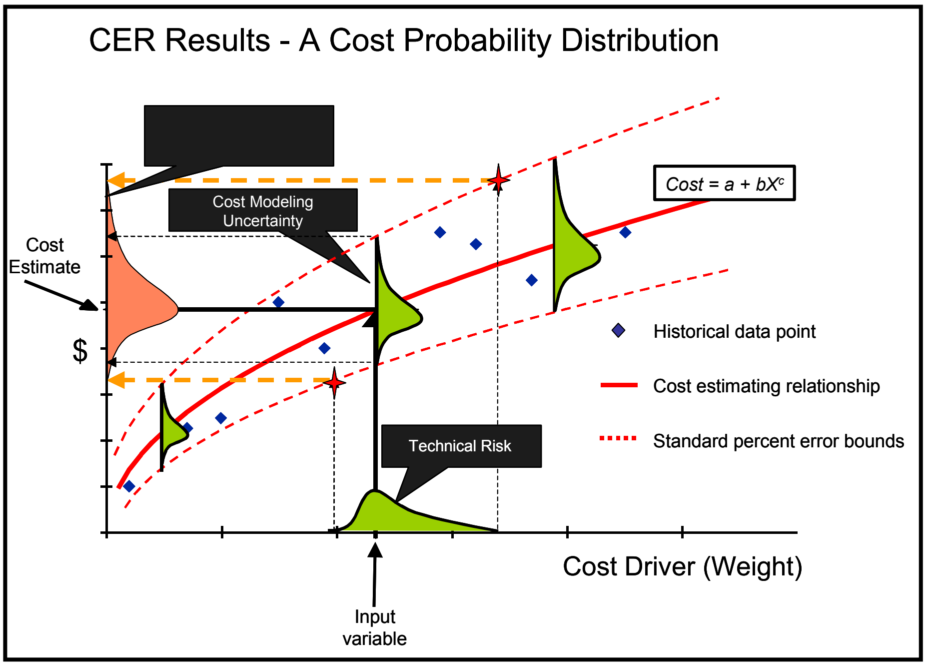

Exhibit 6-25:
New Range

Following the WBS element cost-risk distribution definition step above is the process of statistically summing all of the WBS element triangular distributions to arrive at a probabilistic range of the potential cost for the program. **Exhibit 6-26** illustrates the results of a statistical summation process normally performed by the cost estimators.

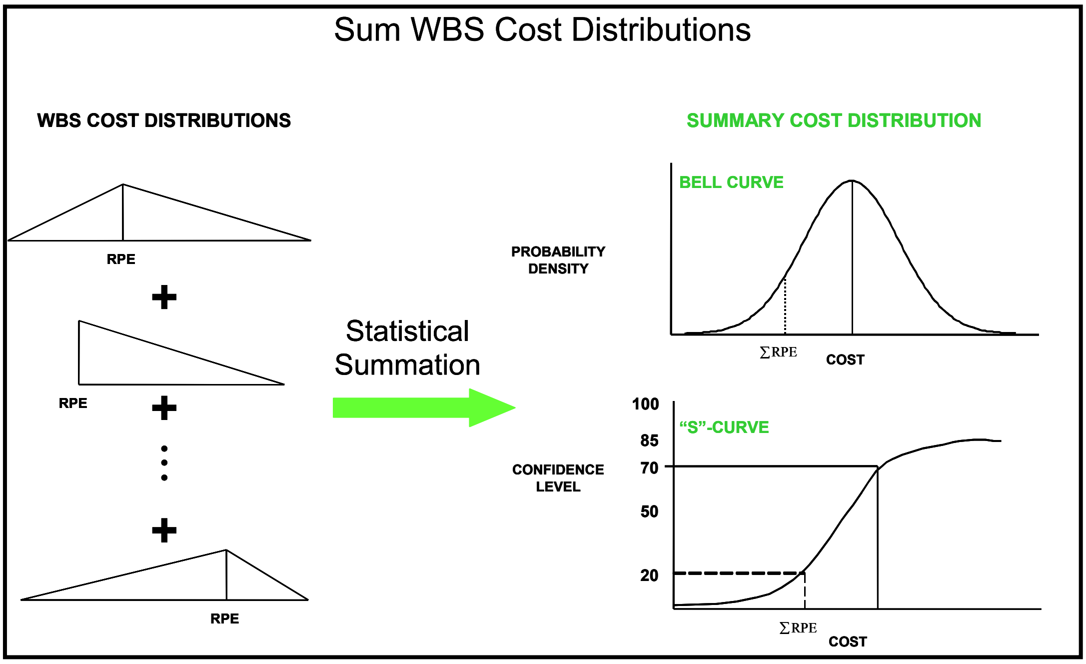

Exhibit 6-26:
Statistical Summation Process Results

Note that the sum of the reference point cost estimates, when triangles are skewed right (denoting more upside than downside risk), is at a relatively low level of confidence on the cumulative distribution function ("S"-curve). That is, the confidence level is approximately 20% that the total cost of the program will be at the arithmetic sum of the reference WBS element cost estimates. It is necessary to add margin budget[33] to even ensure that the program has a 50/50 chance of not overrunning at an even higher level of cost. In other words, there is very low confidence that the project can be successfully accomplished within such a low budget estimate. A higher budget estimate will have a higher confidence.

Discrete KEPP risks are identified and defined during the construction of the risk scenarios: pessimistic, optimistic, and reference. Each scenario has the same risks identified; it is just that in the pessimistic scenario the worst observance of them is hypothesized to occur. For example, the pessimistic scenario is a situation surrounding the development of the WBS element that assumes the realization of the worst conditions under each category of risk affecting the element in meeting the WBS performance expectations documented in the CADRe whereas the optimistic scenario is a situation surrounding the development of the WBS element that assumes the realization of the best conditions. Similarly, the reference scenario is a situation surrounding the development of the WBS element that assumes the realization of the most likely conditions. (Note: The reference point cost estimate in *cost* terms is equivalent to the reference scenario in *risk* terms. This equivalency underpins the argument for using the risk ratios as reference point estimate adjustment factors.)

Each profile or scenario for each WBS element must be described in writing, detailing the specific, discrete KEPP risks to ensure clarity of understanding the situations for rating risk during the RRW process and for clearly justifying the reason for a recommended confidence level for budgeting. For example, if the WBS element being evaluated for risk is a laser amplifier/transmitter, the discrete KEPP risks may involve wave front sensing, wave generation, coatings and gratings for the mirrors, autonomous resonator alignment, bore sighting and peak electrical power generation. Furthermore, the actual situation for these discrete risks may be characterized by the following: Sensitivity levels required for wave front sensing and the ability to control it at these levels has never been demonstrated. The continuous wave generator requires power levels that have only been demonstrated in flight at 20% of the required levels. Fabrication of the coatings and gratings for the transmitter/amplifier is an established technology. Autonomous resonator alignment requires a level of precision that has never been attempted. Bore sighting is experiencing jitter in simulations and the design processes have yet to be developed. Beam stop/attenuation power switching is an established technology. Peak electrical power amplification for durations required has only been simulated in a laboratory environment.These discrete KEPP risks are rated in pessimistic, optimistic and reference scenarios to calculate relative risk scores for cost-risk triangular distribution development. A cost is also estimated for handling and/or mitigating each discrete KEPP risk to determine its specific contribution to the total cost. All the discrete risk costs are summed and added to the reference cost estimate and the total is identified on the probabilistic cost assessment's S"-curve. The associated confidence level is then compared to the

33 *Mr. Ed "Pete" Aldridge (OUSD (AT&L)), "The Need for Margin", Program Manager Magazine, July-Aug 2001.*

70%-80% confidence level being recommended for budgeting and the resulting reserve justified on the basis of the costs for handling and/or mitigating the discrete KEPP risks.

There are other processes available to the cost estimator for developing cost-risk distributions other than the RRW process.[34] [35]

6 Tenet 6: NASA cost-risk probability distributions are justifiable and correlation levels are based on actual cost history to the maximum extent possible

There are a variety of probability distribution shapes available for the cost estimator to model cost-risk. The most common are the normal distribution (especially for cost estimating uncertainty) and the triangular for technical uncertainty. An example of a normal distribution for cost estimating methodology risk is the distribution around a regression line. Its use is justified by the statistics characterizing the regression line. If some variation of the shape for the regression line distribution is to be used, other than normal, it must be justified[36].

The distribution commonly used for characterizing technical risk is a triangular distribution. The triangular distribution is fairly simple to characterize since the cost-risk analyst only needs to produce three points: a reference point (sometimes called the "most likely"), a pessimistic point and an optimistic point as illustrated above in the RRW process. Both the cost estimating methodology cost-risk and the technical cost-risk distributions must be accounted for in the final cost-risk distribution.[37] Exhibit 6-25 above illustrates one way for which both are accounted.

Correlations between WBS elements must also be accounted for in the combining of cost estimating and technical cost-risk distributions. Commercial Monte Carlo simulation models such as @RISK™ and Crystal Ball™ contain the capability to apply correlation during the statistical summing of a project's WBS element cost-risk distributions. However, the cost-risk analyst must provide the correlation values. Correlation values could be statistically derived using a variety of methods. The first results from analyses between CER errors, for example, residual analysis. Another is the "Actuals-to-Predicted" method" that compares actual and predicted costs of historical systems and then infers the true total correlation coefficients of the CERs. A third method is to estimate the level of correlation based on the number of WBS elements to be summed.

Commercial Monte Carlo simulation software (e.g., Crystal Ball™Or @RISK™) also includes the ability to apply statistical correlation analysis between engineering drivers, for example, between complexity, weight, power, etc. Other methods to those described above can be used to determine these correlations.

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34 *Gupta, Shishu, "The IC CAIG Risk Methodology"; July 2003.*

35 *Hoy, Kirk L & Hudak, David G, "Advances in Quantifying Schedule/Technical Risk"; August, 1994; The 28th DoD Cost Analysis Symposium.*

36 *Graham, David R., "Cost Estimating Cost-Risk Credibility," Oct 1998.*

37 *Graham, David R., "Integrating Technical Cost-Risk with Cost Estimating Cost-Risk," Oct 1998.*

There are benefits and drawbacks to each approach, however. Residual analysis is difficult because the analyst needs a database of historical costs, cost drivers, CERs and CER errors. The Retro-Ice method is also difficult because the analyst needs actual cost data from several similar programs, a similar WBS structure to the one being modeled, the total error, and the use of similar cost estimating models. Estimating correlation based on the number of WBS elements is relatively easy because the analyst only needs the number of WBS items and the models' typical uncertainties but it is strongly a function of the number of correlated elements and its effect decreases with the number of correlated elements. Using the last method, adjustments can be made for the underestimating of actual correlation.

Additional "functional" correlations can also be determined through a functional (i.e., causal) relationship, for example, between cost drivers or between cost dependent CERs (e.g., SEIT/PM). However, deriving correlation between cost drivers is hard because the analyst needs a set of Cost Engineering Tools (e.g., a Concept Design Center model, Size/Weight/Power model) to do it. However, deriving correlation between cost dependent CERs is easy since the analyst only needs cost dependent CERs (such as SEIT/PM, etc.,) linked to summary costs in model.

It is important to point out that correlation is not causation (but the reverse is true). Many of the statistically high correlations derived from existing models may be in large part due to the lack of data used to determine the correlations and/or the accounting scheme used to bucket costs[38,39].

7 Tenet 7:
NASA cost-risk assessment ensures cost estimates are "likely-to-be" vice "as specified" for optimum credibility

The "as specified" project is the project represented by the "reference risk profile" scenario in Exhibit 6-24 above. It is the project without any real consideration for estimating, technical or correlation risks. The "likely-to-be" project is the "as specified" project plus cost impacts due to the risks. The following are well-defined steps for developing a "likely-to-be" cost estimate[40]:

- Step 1: Quantify the probability distributions describing the modeling uncertainty of all CERs, cost factors, and other estimating methods, specifically, the type of distribution (e.g., normal, triangular, lognormal, beta, etc.,) as well as the mean and variance of the distribution.
- Step 2: Define the "likely-to-be" program by identifying the relevant risks. Defining the technical risks is improved by implementing an independent technical assessment. Quantify the probability distributions describing the cost effects due to technical risks, specifically, the type of distribution (e.g., normal, triangular, lognormal, beta, etc.) as well as the mean and variance of the distribution as in Step 1 above.

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38 *Covert, Raymond; "Determining Correlation"; Aerospace Corporation, Oct 2003.*

39 *Hulett, David; "Correlation in Cost Risk Analysis: Modeling Risk Drivers"; Oct, 1995, 7th annual International Cost Schedule Performance Management Conference; Humphreys & Associates, Inc.*

40 *Anderson, Tim; "Development of NRO Risk Adjusted Estimates"; Aerospace Corporation.*

- Step 3: Quantify the correlation between all WBS elements that are estimated using CERs and other methods. If unknown, assess whether NO correlation, MILD correlation, or HIGH correlation, for example: NONE: $r = 0$, MILD: $r = \pm 0.2$, HIGH: $r = \pm 0.6$. The thought to keep in mind is that correlation affects the overall cost variance.
- Step 4: Set up and run the cost estimate in a Monte Carlo framework (e.g., Crystal Ball™, @RISK™) or suitable analytic method that incorporates cost estimating, technical and correlation risk. This will result in a cumulative distribution function from which the 70th percentile can be easily identified.
- Step 5: Assess "risk dollars." "Risk dollars" is defined to be the difference between the 70th percentile and the "as specified" project cost (e.g., arithmetic sum of WBS element reference point, deterministic cost estimates) and represents the estimate of "risk dollars." Risk dollars can be allocated downward to any level of WBS using a variety of simple approaches. The most recent version of NAFCOM incorporates such a risk dollar allocation algorithm.

8 Tenet 8: NASA cost-risk assessments account for all known variance sources and include provisions for uncertainty

"Known" unknowns are those risks for which a probability distribution can be defined, that is, the cost estimator knows what the risks are, and can quantify their potential cost effects as a range, but cannot pinpoint exactly what point within that range represents what will eventually become the actual result. Uncertainty is those risks for which not even a probability distribution can be defined. Examples of uncertainty can be requirements growth, budget cuts, launch vehicle failures, and small engineering change orders. Even though potential cost effects due to these risks are not specifically quantifiable ahead of time, provisions for some of their cost effects can be made as a matter of organizational policy. Justification for this additional cost can be made based on records of past cost growth due to these drivers. Practically speaking, the allowed amount should be no more than 5% because it is covering only small value unknown unknown cost-risk drivers. When uncertainty cost-risk drivers result in large cost growth, additional funding will be forthcoming, however unpleasant or unfortunate the conditions of gaining that funding may be[41].

9 Tenet 9: NASA cost-risk can be an input to every cost estimate's CRL[42]

Projects will be asked to provide a CRL rating with their project budget inputs. The IPAO and Code BC will make an independent assessment of CRL associated with these budget estimates. A reconciled position would then go forward to the NASA HQ Deputy CFO for Resources (Comptroller) for preparing the project budget input into the President's Budget submission.

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41 *MacKenzie, Don; "Risk Analysis – What Are We Striving For?," March, 2003.*

42 *Hamaker, Joe; "Cost Readiness Levels," NASA 2003.*

10 Tenet 10: NASA cost-risk integrates the quantification of cost-risk and schedule risk by enlisting the support of NASA schedule and EVM analysts

NASA cost estimators should not have to become schedule risk or EVM analysts. NASA cost estimators should, in considering the cost impacts due to cost and schedule risks, confer with schedule risk and EVM analysts within the project. Specifically, they should investigate the use of adding the dimension of duration uncertainty to activities, along with traditional early start/late start - early finish/late finish, results in developing a more realistic CPA[43], that is, Risk Path Analysis (RPA). When the results of an RPA is known, the most likely longest path through the network should be used to form the basis of projecting cost impacts to the project. These impacts can form the basis for a crosscheck to a cost-risk analysis or be integrated into an existing cost-risk analysis.

11 Tenet 11: NASA decision makers need to know[17]: How much money is in the estimate to cover risk events; To which WBS elements are they allocated; and, The confidence level of the estimate

Senior acquisition decision-makers usually want to know a couple of things about cost estimates, for example, how much 'risk' is in the estimate. What this means is how many dollars are in the estimate to guard against 'risky' events happening and, to which WBS elements are they allocated? If the cost estimator has applied the NASA tenets of cost-risk properly, these two concerns are easily addressed. As long as discrete risk events have been identified in the risk assessment (e.g., RRW process in Tenet #5 above) and costs to cover them estimated, the cost estimator can answer the decision-maker's question. As to which WBS element they are allocated, as long as an allocation methodology has been applied as mentioned in Tenet #5 above, this question can be answered. In fact, the latest version of NAFCOM contains a WBS element allocation algorithm.

The decision makers also want to know if the budget is set at the estimate (or any other value), what is the likelihood of an overrun? This question is answerable from the results of the statistical summing of the WBS element cost-risk distributions via an examination of the resulting "S"-curve or confidence level table. For example, if the budget were set at the 70th percentile, there would be a 30% chance of an overrun.

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43 *Hulett, David; "Integrated Cost/Schedule Risk Analysis"; 2003 Hulett & Associates*

12 Tenet 12: NASA project cost-risk data, collected as a function of government and contractor project estimates and actuals, contract negotiations and contract DRDs, is compiled into the ONCE database

The cost-risk information in the ONCE database is an integration of the cost estimating information collected by the CADRe and EVM reports and includes:

- Probabilistic risk assessments;
- “S”-curve updates from significant contract milestones or annual updates;
- Risk-driven cost and schedule growth documentation;
- Externally-driven cost and schedule growth documentation;
- Risk management plans, reports and results;
- Probabilistic Risk Assessment plans, reports and results;
- Medium and high risk WBS element earned value performance measurement results;
- Documentation of all engineering technical risk assessment methodologies used in assessing cost-risk;
- Technical data;
- Beginning-of-contract cost and schedule estimates and actuals; and
- End-of-contract cost and schedule estimates and actuals.

Through the collection and compiling of cost-risk data, the NASA cost estimating community will be able to validate and verify cost-risk methodologies, models and results through analysis of empirical cost-risk data. This analysis can lead to improvements over time in cost-risk projections including the calculation of cost estimating calibration factors useful in source selections.[44]

Through the creation of the 12 NASA Tenets of Cost-Risk, we have developed a comprehensive process that is acceptable community-wide, that answers these questions, and that we can readily describe to senior decision-makers.

44 *Graham, David R; “Cost-Risk Database & Acquisition Reform Calibration Factor Derivation”; Oct 1997, SSCAG Fall Meeting.*

6.17 Using Project Schedules in Cost Estimates

Project schedules play an important role in the development of any project. The cost estimator needs to understand how to estimate schedule realism as well as proposed compressions or delays in a project schedule. Part of estimating these schedule changes is being able to quantify the impacts of schedule changes o the cost and risks of the project and translate them into the cost estimate. When a project is completed early, there may be cost savings associated with using fewer resources, unless resources were fully utilized in a more compressed time period. More often, schedules impact cost when projects are late, and more resources are consumed. For example, imagine a project that is scheduled to be completed in one year. Instead, assume that the project is actually completed in one year and three months. If the original schedule was used to estimate total costs, then there are three months of cost unaccounted for in the original estimate. Even if no additional project materials were necessary, there would still be three months of time-related costs for labor, facilities, utilities, etc., which were not included in the original estimate. Schedule analysis helps answer the questions of how long will the project be delayed, and what will those delays cost the project.

Various methods are used to analyze schedules, one of the most common being the Program Evaluation and Review Technique (PERT). The Special Projects Office of the US Navy developed the basis of the approach in 1957. In 1958, a variation of this method, the Critical Path Method (CPM) or CPA was developed. The basis of any PERT/CPM chart is the network of activities needed to complete a project, showing the order in which the activities need to be completed, and the dependencies between them. The critical path notes the dependent tasks, which take the longest time to complete. This is represented graphically:

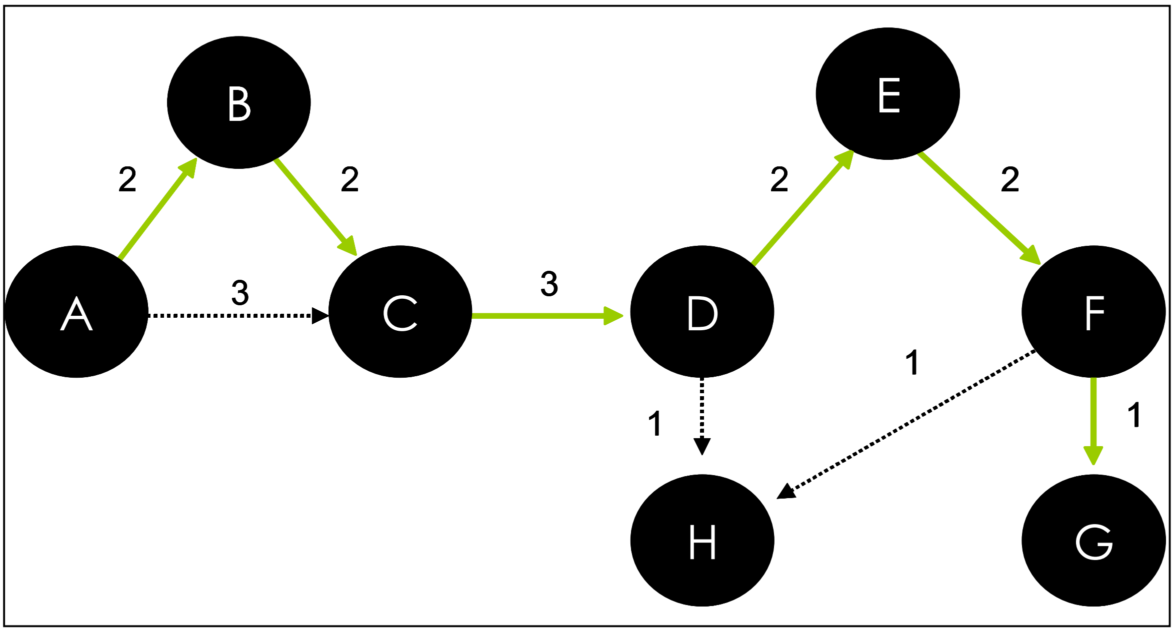


Exhibit 6-27:
The Critical Path is A, B, C, D, E, F, and G with a Duration of 12 days

The diagram consists of a number of circles, representing events within the development life cycle, such as the start or completion of an activity, and lines, which represent the logic and interdependencies of the activities. Each task is additionally labeled by its time duration. The primary benefit is the identification of the critical path. The critical path is the path for which the total activities completion time is greater than any other path through the network (delay in any activity on the critical path leads to a delay in the project). Therefore, any delay on the critical path will lead to increased cost of the project, unless other measures are undertaken to prevent it. One example of this would be wait time. If a task is delayed due to wait time, such as waiting for approval of a change or for an additional part, additional cost can be avoided if resources are diverted to, and billed to, another project during the wait. Unfortunately, this is not always feasible, and total project cost increases.

There are endless methods to calculate estimated schedule slips ranging from PERT to GANTT to variance analysis using start, end, or duration variances. The method used will be dependent upon the type of project, the data available, and the resources available to devote to schedule analysis.

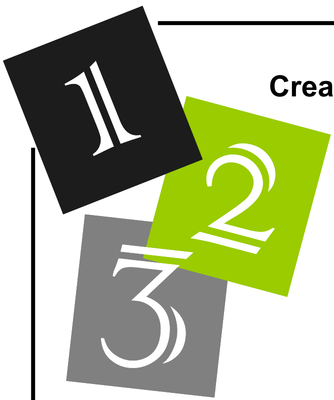
Once the schedule analysis has been completed, an amount must be assigned to any schedule delays for cost estimating or assessment purposes. Once again there are several methodologies for estimating, based on available data, resources, and project knowledge. One of these methods is calculating an average burn rate for the project. A very simplistic approach would be to divide the total cost of the project by the number of weeks (or days) the project has been open, to arrive at an average weekly burn rate. This rate can then be multiplied by the number of weeks of schedule delay identified as likely, to derive an estimate of the total cost of the schedule delay. This method is too simple for most complex projects in DoD and NASA. It is not recommend for use except ballpark estimates of delay impact. This type of estimate should always be followed by a more detailed examination of the impact of schedule delay to cost. A more detailed estimate of the burn rate may be calculated by identifying the resources impacted by a particular schedule delay (only labor, or labor, facilities and material) and calculating the burn rate based only on the cost of those resources impacted. It can also be incredibly complex if the project is in the manufacturing phase and warehousing of delicate or expensive parts is extended or complex machinery sitting idle due to schedule delays. The only way to cost this is to try to identify as many of these types of impacts and calculate the cost.

Lastly, the most important factor in schedule analysis is clarity through documentation on the methodology used to calculate both the schedule outcomes, and the approach used to estimate the increased resource requirements for those outcomes. If clearly documented assumptions and methodologies are communicated, estimates may be more easily reusable, transferable, and understood by all relevant stakeholders.

6.18 Earned Value Management (EVM) Techniques to Formulate an Estimate at Completion (EAC)

EVM is a recognized management technique that relates cost, schedule, and technical performance. Using fairly standard analysis techniques, the estimated final cost of a project is calculated from knowing the actual costs incurred, the total budget, the cost of the work completed and the cost and schedule indexes. For example, the analyst(s) relates the technical content to the time-phased, resource-loaded budget baseline. The analysts may also look at programmatic and technical risks, threats, liens, and deferred technical content with associated budget impacts. The analyst reviews all of these elements in terms of performance to date, as well as the assumptions made by the project for its future performance.

An independent review team relates the technical content to the schedule and budget by reviewing the POP and other historical budget data, earned value assessments, spend rates, cost and obligation history, programmatic and technical threats and liens, costed versus uncosted actuals, year-end carry-over amounts, anticipated budget cutbacks and fallback plans, deferred technical content, and associated budget impacts. The independent review team then converts their assessment of these programmatic elements into EAC.



Creating An EAC

The Estimate at Completion is created using the actual costs of labor and materials to date plus the latest revised estimate for all remaining work. A varied amount of information is used to prepare the EAC, including completed and remaining work scope, schedule variances.

A. Acronym List

In addition to the following list of defined acronyms, other useful cost terms can be found on the following websites:

Acronym Finder	➡	http://www.acronymfinder.com/
Cost Estimating Acronym Glossary	➡	http://www.jsc.nasa.gov/bu2/acronyms.html
NASA Acronym List (GSFC)	➡	http://library.gsfc.nasa.gov/Databases/Acronym/acronym.html
NASA Acronym List (KSC)	➡	http://www.ksc.nasa.gov/facts/acronyms.html
NASA Acronym List (MSFC)	➡	http://liftoff.msfc.nasa.gov/help/acronym.html
NASA Earth Science Acronyms	➡	http://gcmd.gsfc.nasa.gov/Aboutus/sitemap.html
WorldWide Web Acronym and Abbreviation Server	➡	http://www.ucc.ie/acronyms/

AA	Associate Administrator
AACE	Association for the Advancement of Cost Engineering
AATe	Architectural Assessment Tool - Enhanced
ABC	Activity Based Costing
ACE	Advocacy Cost Estimate
ACE-IT	Automated Cost Estimating Integrated Tools
ACEO	Assessments and Cost Estimating Office
ACWP	Actual Cost of Work Performed (“Actuals” or “Cost”)
AFIT	Air Force Institute of Technology
AFSC	Air Force Space Command
AFSMC	Air Force Space and Missile Systems Center
AGE	Aerospace Ground Equipment
AHP	Analytic Hierarchy Process
ALMC	Army Logistics Management College

AMCM	Advanced Missions Cost Model
ANP	Analytic Network Process
ANSI	American National Standards Institute
AO	Announcement of Opportunity
AoA	Analysis of Alternatives
APA	Allowance for Program Adjustment
APMC	Agency Program Management Council
ARC	Ames Research Center
ARR	ATLO Readiness Review
ASPE	American Society of Professional Estimators
AT	Acceptance Test (DSMS)
ATLO	Assembly, Test, & Launch Operations
ATP	Authorization to Proceed
AUW	Authorized Unpriced Work
BCA	Business Case Analysis
BCE	Baseline Cost Estimate
BCR	Benefit/Cost Ratio
BCTE	Baseline Cycle Time Estimate
BCWP	Budgeted Cost of Work Performed (“Earned Value”)
BCWS	Budgeted Cost of Work Scheduled (“The Plan”)
BDE	Budget Direct Effort
BVS	Best Value Selection
BMO	Business Management Office
BOE	Basis of Estimate
BY	Base Year
CA	Cost Account
CADRe	Cost Analysis Data Requirement
CAICAT	Composites Affordability Initiative Cost Analysis Tool
CAIG	Cost Analysis Improvement Group
CAIV	Cost as an Independent Variable
CAM	Centrifuge Accommodation Module
CAO	Cost Analysis Office
CASA	Cost Analysis Strategy Assessment
CBA	Cost Benefit Analysis
CBB	Contract Budget Base
CBS	Cost Breakdown Structure
CCDR	Contractor Cost Data Report
CCE	Current Cost Estimate
CCP	Cost Credibility Plan
CCRM	Continuous Cost-Risk Management
CCT	Cost Credibility Team

CDF	Cumulative Distribution Function
CDG	Career Development Guide
CDR	Critical Design Review
CEA	Cost Estimation and Analysis
CEC	Cost Estimating Community
CEH	Cost Estimating Handbook
CER	Cost Estimating Relationship
CES	Cost Element Structure
CEWG	Cost Estimating Working Group
CFO	Chief Financial Officer
CFSR	Contract Funds Status Report
CIC	Capital Investment Council
CLIN	Contract Line Item Number
CM	Configuration Management
COCOMO	Constructive Cost Model
CofF	Construction of Facilities
COMET	Conceptual Operations Manpower Estimating Tool
CONOPS	Concept of Operations
COSMIC	Computer Software Management Information Center
CoSTER	Consortium on Space Technology Estimating Research
COTS	Commercial-off-the-Shelf
CPA	Critical Path Analysis
CPI	Consumer Price Index
CPIC	Capital Planning and Investment Control
CPM	Critical Path Method
CPR	Cost Performance Report
C/SCSC	Cost/Schedule Control System Criteria
CSE	Center for Software Engineering
CSRS	Civil Service Retirement System
C/SSR	Cost/Schedule Status Report
CTER	Cycle Time Estimating Ratio
CY	Calendar Year
CY	Constant Year
CY	Current Year
DACS	Data and Analysis Center for Software
DAU	Defense Acquisition University
DCAA	Defense Contract Audit Agency
DCF	Discounted Cash Flow
DCMA	Defense Contract Management Agency
DD	Design Development
DDT&E	Design, Development, Test & Evaluation

DFRC	Dryden Flight Research Center
DoD	Department of Defense
DR	Data Request
DR	Data Requirements
DRD	Data Requirements Description
DSMC	Defense Systems Management College
DSMS	Deep Space Mission Systems
DSN	Deep Space Network
DTC	Design to Cost
EA	Economic Analysis
EAC	Estimate at Completion
EADP	Economic Analysis Development Plan
ECHO	Environmental Costs of Hazardous Operations
ECI	Employment Cost Index
ECOM	ESA Cost Modelling Software
ECOS	ESA Costing Software
ECP	Engineering Change Proposal
EIA	Electronic Industries Alliance
EMP/EMI	Electromagnetic Pulse / Electromagnetic Interference
EOSDIS	Earth Observing Station Data & Information System
EQEA	Environmental Quality Economic Analyses
ERP	Enterprise Resource Planning
ESA	European Space Agency
ETC	Estimate to Complete
EVM	Earned Value Management
EVMS	Earned Value Management System
FACGSE	Spaceport Facility and GSE Acquisition Cost Estimator
FAI	Federal Acquisition Institute
FAIR	Federal Activities Reform
FAR	Federal Acquisition Regulation
FCA	Full Cost Accounting
FEA	Front End Analysis
FEA	Functional Economic Analysis
FERS	Federal Employees Retirement System
FFE	Friendly Front End
FFP	Firm Fixed Price
FH	Flight Hardware
FPA	Function Point Analysis
FRISK	Formal Risk Assessment of System Cost Estimates
FSW	Flight Software
FTE	Full-Time Equivalent (civil servant)

FV	Future Value
FY	Fiscal Year
G&A	General and Administrative
GAO	General Accounting Office
GDP	Gross Domestic Product
GEM-FLO	Generic Environment for Modeling Future Simulation Launch Vehicle
GOTS	Government-off-the-Shelf
GPRA	Government Performance and Results Act
GR&A	Ground Rules and Assumptions
GRC	Glenn Research Center
GSE	Ground Support Equipment
GSFC	Goddard Space Flight Center
HIT	Health Insurance Tax
HQ	Headquarters
HSF	Human Space Flight
HW	Hardware
IA	Independent Assessment
IAF	International Astronautics Federation
IAR	Independent Annual Review
IBPD	Integrated Budget Performance Document
IBR	Integrated Baseline Review
ICE	Independent Cost Estimate
ICR	Independent Cost Review
IDEA	ISS Downlink Enhancement Architecture
IEEE	Institute of Electrical and Electronics Engineers
IFM	Integrated Financial Management
IFMP	Integrated Financial Management Program
IFMS	Integrated Financial Management System
IFPUG	International Function Point Users Group
IGCE	Independent Government Cost Estimate
ILCCE	Independent Life Cycle Cost Estimate
IMLEO	Initial Mass in Low-Earth Orbit
IMS/IMP	Integrated Master Schedule/Integrated Master Plans
IND	Interplanetary Network Directorate, (formerly TMOD)
IOC	Initial Operating Capability
IPAO	Independent Program Assessment Office
IPI	International Price Index
IPR	Initial Program Review
IPT	Integrated Product Team
IR&D	Independent Research and Development

IRM	Information Resource Management
IRR	Internal Rate of Return
IRS	Internal Revenue Service
ISAT	Inter-Center Systems Analysis Team
ISE	Intelligent Synthesis Environment
ISO	International Organization for Standardization
ISPA	International Society of Parametric Analysts
ISS	International Space Station
ISSAC	International Space Station Analytical Cost
I&T	Integration and Test
IT	Information Technology
ITMRA	Information Technology Management Reform Acquisition
IV&V	Independent Verification and Validation
JPL	Jet Propulsion Laboratory
JSC	Johnson Space Center
Kbase	Knowledge Base
KPP	Key Performance Parameter
KEPP	Key Engineering Performance Parameters
KSC	Kennedy Space Center
L&FB	Leave and Fringe Benefits
LaRC	Langley Research Center
LCC	Life-Cycle Cost
LCCE	Life Cycle Cost Estimate
LOC	Lines of Code
LOE	Level of Effort
LOOS	Launch and Orbital Operations Support
LSBF	Least Squares Best Fit
MAIS	Major Automated Information Systems
MC	Management Council
MCC	Mission Control Center
MCPR	Modified Cost Performance Report
MDAPS	Major Defense Acquisition Programs
MESSOC	Model for Estimating Space Station Operations Costs
MICM	Multi-Variable Instrument Cost Model
MIL-STD	Military Standard
MNS	Mission Needs Statement
MOU	Memorandum of Understanding
MPV	Mid-Point Value
MR	Management Reserve
MS	Microsoft
MSFC	Marshall Space Flight Center

MSI&T	Mission System Integration and Test
NAFCOM	NASA/Air Force Cost Model
NAR	Non-Advocate Review
NASA	National Aeronautics and Space Administration
NBS	New Business Systems
NCC	Negotiated Contract Cost
NCCA	Naval Center for Cost Analysis
NCMA	National Contract Management Association
NCRD	NASA Cost-Risk Database
NDI	Non-Developmental Item
NODIS	NASA On-line Directives Information System
NPD	NASA Policy Directive
NPG	NASA Procedures and Guidelines
NGR	NASA Procedures and Requirements
NPV	Net Present Value
N/R	Not Relevant
NRA	NASA Research Announcement
NroC	Integrated RMAT OCM/COMET Model
NWODB	New Ways of Doing Business
O&M	Operating and Maintenance
O&S	Operations and Support
OCM	Operations Cost Model
ODC	Other Direct Cost
OLS	Ordinary Least Squares
OMB	Office of Management and Budget
ONCE	One NASA Cost Estimating database
OPCU	Orbiter Power Converter Unit
OSP	Orbital Space Plane
OTB	Over Target Baseline
PAPAC	Provide Aerospace Products and Capabilities
PBS	Product Breakdown Structure
PC	Personal Computer
PCA	Program Commitment Agreement
PCAT	Project Cost Analysis Tool
PCC	Program Cost Commitment
PCD	Performing Center Director
PDC	Project Design Center
PDCR	Preliminary Design and Cost Review
PDF	Probability Density Function
PDR	Preliminary Design Review
PERT	Program Evaluation and Review Technique

PFA	Program Formulation Agreement
PLCCE	Project Life Cycle Cost Estimate
PM	Program/Project Manager
PMA	President's Management Agenda
PMB	Performance Measurement Baseline
PMC	Program Management Council
PMI	Project Management Institute
PMSR	Project Mission System Review
PO	Program Office
POC	Point of Contact
POE	Program Office Estimate
POP	Program Operating Plan
PP	Planning Package
PPI	Producer Price Index
PRA	Probabilistic Risk Assessment
PRICE	Parametric Review of Information for Cost and Evaluation
PRICE H	PRICE Hardware
PRICE HL	PRICE Hardware Life Cycle
PRICE M	PRICE Microcircuits
PRICE S	PRICE Software
PV	Present Value
PWD	Procurement Work Directive
QA	Quality Assurance
QFD	Quality Function Deployment
R&D	Research and Development
RDT&E	Research, Development, Test, and Evaluation
REVIC	Revised Intermediate COCOMO
RFP	Request for Proposal
RLV	Reusable Launch Vehicle
RMAT	Reliability, Maintainability Analysis Tool
RMO	Resource Management Office
ROI	Return on Investment
ROM	Rough Order of Magnitude
RSS	Residual Sum of Squares
RY	Real Year
SCEA	Society of Cost Estimating and Economic Analysis
SCT	Software Costing Tool
SEE	Standard Error of the Estimate
SEER	System Evaluation & Estimation of Resources
SEER-DFM	SEER Design for Manufacturability
SEER-H	SEER Hardware Estimation and Life Cycle Cost Analysis

SEER-IC	SEER Custom Integrated Circuit Development
SEER-SEM	SEER Software Estimation Model
SEER-SSM	SEER Software Sizing Model
SEI	Software Engineering Institute
SEMP	System Engineering Master Plan
SER	Schedule Estimating Relationship
SICM	Scientific Instrument Cost Model
SIR	Savings to Investment Ratio
SLOC	Source Lines of Code
SMAD	Space Mission Design and Analysis
SME	Subject Matter Expert
SMO	Systems Management Office
SOCM	Space Operations Cost Model
SORCE	Software Resource Center
SPP	Summary Planning Package
SQA	Software Quality Assurance
SQI	Software Quality Improvement
SRA	Society for Risk Analysis
SRCR	Software Review/Certification Review
SRR	Software Requirements Review
SSA	Social Security Administration
SSC	Stennis Space Center
SSCM	Small Satellite Cost Model
SVLCM	Spacecraft/Vehicle Level Cost Model
SW	Software
TAB	Total Allocated Budget
T&M	Time and Materials
T1	Theoretical First Unit Value
TBD	To Be Determined
TCO	Total Cost of Ownership
TCOR	Total Cost of Ownership Reduction
TDRSS	Tracking and Data Relay Satellite System
TIM	Technical Interchange Meeting
TIMS	Tactical Information Management System
TOA	Total Obligation Authority
TOR	Terms of Reference
TPM	Technical Performance Measure
TRL	Target Requirement List
TRL	Technical Readiness Level
TRR	Test Readiness Review
TSP	Thrift Savings Plan

TSS	Total Sum of Squares
TY	Then Year
UB	Undistributed Budget
USC	United States Code
USCM	Unmanned Spacecraft Cost Model
USSGL	United States Government Standard General Ledger
WBS	Work Breakdown Structure
WP	Work Package
WYE	Work Year Equivalent (contractor)

B. GLOSSARY

@RISK® - Risk Analysis and Simulation add-in for Microsoft Excel® or Lotus® 1-2-3. @RISK uses Monte Carlo simulation that allows taking all possible outcomes into account. Replace uncertain values in the spreadsheet with @RISK functions, which represent a range of possible values. Select bottom-line cells, like Total Profits, as outputs, and start a simulation. @RISK recalculates the spreadsheet, each time selecting random numbers from the @RISK functions entered. The result is distributions of possible outcomes and the probabilities of getting those results. The results illustrate what could happen in a given situation, but also how likely it is that it will happen.

Accounting Estimate - Uses engineering estimates of reliability, maintainability, and component cost characteristics, etc. to build estimates from the "bottom-up" for each cost category.

Acquisition Strategy - The method utilized to design, develop, and display a system through its life cycle. It articulates the broad concepts and objectives, which direct and control the overall development, production, and deployment of a materiel system. It is the framework for planning, directing, contracting for, and managing a program. It provides a master schedule for research, development, test, production, fielding, modification, postproduction management, and other activities essential for program success.

Advocacy Cost Estimate (ACE) - Prepared by cost analysts who are a part of the design team and provide the program/project management with an estimated cost based on translating the technical and design parameters characteristics into cost estimates using established cost estimating methodologies.

Analogous System Estimate - With this technique, a currently fielded system (comparable system) similar in design and/or operation of the proposed system is identified. The cost of the proposed system is developed by taking the fielded system's data and adjusting it to account for any differences. Analogous estimates are also called *Comparative* or *Extrapolated* estimates.

Analysis of Alternatives (AoA) - Broadly examines multiple elements of project or program alternatives including technical risk and maturity, and costs. AoAs are intended to illuminate the risk, uncertainty, and the relative advantages and disadvantages of the alternatives being considered; show the sensitivity of each alternative to possible changes in key assumptions; and aid decision-makers in judging whether or not any of the proposed alternatives offer sufficient operational and/or economic benefit to be worth the cost.

Analytic Hierarchy Process (AHP) - Structures problems into a hierarchical structure in order to reduce complexity. AHP is a feature of Expert Choice.

Analytic Network Process (ANP) - Uses non-linear models to demonstrate the relationship between the elements. ANP is a feature of Expert Choice.

Announcement of Opportunity (AO) - This is generally used to solicit proposals for unique, high cost research investigation opportunities that typically involve flying experimental hardware provided by the bidder on one of NASA's Earth-orbiting or free-flying space flight missions. Selections through AO's can be for periods of many years, involve budgets of many millions of dollars for the largest programs, and usually are awarded through contracts, even for non-profit organizations, although occasionally grants are also used.

Assumption - A supposition on the current situation, or a presupposition on the future course of events, either or both assumed to be true in the absence of positive proof. Assumptions are necessary in the process of planning, scheduling, estimating, and budgeting.

Base Year (BY) - A term used to define a year that is: (1) the economic base for dollar amounts in a proposal estimate, (2) the base for rate calculation or projection, or (3) the starting point for the application of inflation factors.

Benefit to Cost Ratio (BCR) - The benefit cost ratio measures the discounted amount of benefits that the project generates for each dollar of cost. Fundamentally, the computation of the benefit/cost ratio is done within the construct of the following formula: Benefits/Cost.

Best Value Selection - Best Value Selection (BVS) is most commonly used in proposal evaluation. BVS seeks to select an offer based on the best combination of price and qualitative merit of the offeror's submission, thus reducing the administrative burden on the offerors and the Government. BVS takes advantage of the lower complexity of mid-range procurements and predefines the value characteristics that will serve as discriminators among offers submitted.

Beta Curve - Developed at JSC in the 1960s; it is used for spreading parametrically derived cost estimates. It is used for R & D type contracts whereby costs build up slowly during the initial phases, and then escalates as the midpoint of the contract approaches. It is commonly known as the normal distribution curve.

Break-Even Analysis - Analysis used to uncover the point when the cumulative value of savings is equal to the cumulative value of investment.

Business Case Analysis (BCA) - Economic Analysis type that documents the review of an entire functional process or sub-process, such as the use of alternative launch vehicles, etc. It requires a risk assessment of each alternative solution, requesting a high and low estimate for each cost element and subsequent probability distribution of expected costs.

Coarse Screening - Step 5 of a Trade Study where the number of candidate solutions is reduced (if necessary) by eliminating those candidates unacceptable for delta cost, risk, safety, performance, schedule, or other reasons.

Commercial-Off-The-Shelf (COTS) - Commercial items that require no unique government modifications or maintenance over the life cycle of the product to meet the needs of the procuring agency.

Competitive Sourcing Analysis Studies (A-76 Studies) - Competitive sourcing is an economic analysis conducted to determine the most cost effective method of obtaining services that are available in the commercial market. Agency missions may be accomplished through commercial facilities and resources, Government facilities and resources or mixes thereof, depending upon the product, service, type of mission and the equipment required. The prevailing regulations for the Competitive Sourcing studies are the OMB Circular No. A-76 Revised Supplemental Handbook, Performance of Commercial Activities, revised 1999.

Compounding - Process of going from today's values, or present values (PVs), to future values (FVs).

Constant (Base) Year Dollars - This phase is always associated with a base year and reflects the dollar "purchasing power" for that year. An estimate is in constant dollars when prior-year costs are adjusted to reflect the level of prices of the base year, and future costs are estimated without inflation. A cost estimate is expressed in "constant dollars" when the effect of changes in the purchasing power of the dollar (inflation) has been removed.

Constructive Cost Model (COCOMO) - A parametric software cost estimating tool developed and described by Dr. Barry Boehm in his book Software Engineering Economics. COCOMO has three standard modes of software development: Organic, Semi-Detached, and Embedded. The Air Force Cost Analysis Agency's REVIC model is based on the original COCOMO model.

Continuous Cost-Risk Management (CCRM) - Integrating the various cost/schedule analysis discipline tools (i.e., CAIV, parametric cost estimating, EVM, cost risk analysis, etc.,) with an early focus on cost risk identification at appropriate levels of the WBS followed by communicating and tracking these cost risks as the project is managed over its life cycle and collecting the data for knowledge management and application to follow-on projects.

Contract Cost Analysis - Contract cost analysis is the traditional method for analyzing a contractor's proposal. It is the analysis of the separate cost elements and profit of (1) an offeror's cost and pricing data and (2) the judgmental factors applied in projecting from the data to the estimated costs. The analyst does this to form an opinion on the degree to which the proposed costs represent what the contract should cost.

Contract Funds Status Report (CFSR) - A report normally required on cost or incentive type contracts to inform the buyer of funds used and status of remaining funds.

Contract Line Item Number (CLIN) - Items listed in a contract and priced individually. Some may be options.

Contract Work Breakdown Structure (WBS) - A breakout or subdivision of a project typically down to level three which subdivides the project into all its major hardware, software, and service elements, integrates the customer and contractor effort, provides a framework for the planning, control, and reporting. A WBS applied within a contract.

Contractor Cost Data Report (CCDR) - A U.S. Department of Defense report developed to provide contract cost and related data in a standard format.

Contractor Estimate - Title 10 United States Code Section 2306a requires prospective prime contractors and their subcontractors to submit certified cost or pricing data in support of their proposals. They must submit cost data in the SF 1411 format, which requires the contractor to separate the proposal and supporting data into the following groups: Purchased parts, Subcontracted items, Raw material, Engineering labor, Engineering overhead, Manufacturing labor, Manufacturing overhead, Other general and administrative (G&A), and Profit.

Cost Analysis Improvement Group (CAIG) - The OSD's Cost Analysis Improvement Group (CAIG) provides an independent cost estimate. The CAIG's independent cost estimates provide useful cost information to DoD decision-makers. The CAIG estimates are intended primarily as internal working documents to ensure that senior officials receive the most candid and complete information about weapons acquisition programs.

Cost Analysis Office (CAO) - The Cost Analysis Offices at each NASA Center provide analysis, independent evaluations, and assessments of Center programs/ projects, including programs delegated to the Center as lead center. Some examples of the roles of a CAO are: Serve as the Center's focal point for independent cost estimating and analysis for programs and projects, Support Non Advocate Reviews (NARs), Independent Annual Reviews (IARs), and Independent Assessments (IAs) of Center programs and projects, and Provide cost analysis expertise to the IPAO to support independent reviews as requested.

Cost Analysis Requirements Description (CADRe) - The CADRe defines, and provides quantitative and qualitative descriptions of, the program characteristics from which cost estimates will be derived. As such, the CADRe ensures that cost projections developed by the program/project offices and the independent review organizations are based on a common definition of the system and program.

Cost as an Independent Variable (CAIV) - The process of examining cost drivers by holding cost independent. CAIV is founded upon two primary principles: first, system costs are constrained. Whereas some programs do obtain additional funding when needed, such funding is often at the expense of other programs or future modernization and second, "trade space" is the foundation for smart decisions. Trade space is the range of alternatives available to decision makers. It is four-dimensional, comprising performance, cost, schedule, and risk impacts.

Cost Benefit Analysis (CBA) - An analytic technique that compares the costs and benefits of investments, programs, or policy actions in order to determine which alternative or alternatives maximize net profits. Net benefits of an alternative are determined by subtracting the present value of costs from the present value of benefits. CBA is comprised of 8 steps: analysis of the current environment, perform gap analysis, identify alternatives, estimate costs, perform sensitivity analysis, characterize and value benefits, determine net value of each alternative, and perform risk analysis.

Cost Driver - Those input variables that will have a significant effect on the final cost.

Cost Element Structure (CES) - A unit of costs to perform a task or to acquire an item. The cost estimated may be a single value or a range of values.

Cost Estimate - The estimation of a project's life cycle costs, time-phased by fiscal year, based on the description of a project or system's technical, programmatic, and operational parameters. A cost estimate may also include related analyses such as cost-risk analyses, cost-benefit analyses, schedule analyses, and trade studies.

Cost Estimating Community (CEC) - The CEC at NASA is an increasingly cohesive group. NASA CEC falls into a different functional organization at each Center. Depending on the focus and the culture at the Center, the cost estimators are aligned with the most logical organization for the Center to access their cost estimating capability efficiently.

Cost Estimating Relationship (CER) - A mathematical relationship that defines cost as a function of one or more parameters such as performance, operating characteristics, physical characteristics, etc.

Cost Estimating Working Group (CEWG) - The purpose of the CEWG is to strengthen NASA's cost estimating standards and practices by focusing on improvement in tools, processes, and resources (e.g., training, employee development). Membership is comprised of senior cost estimating analysts from each NASA Center and JPL. The working group is also a forum to foster cooperation and interchange in areas such as sharing models and data across Centers and implementing "lessons learned".

Cost Estimation - The process of analyzing each hardware element, the buildup, integration and test of these elements, and the operation of the system over some specified life cycle (including disposal of the asset), with respect to the cost associated with the total effort.

Cost Estimation and Analysis (CEA) Competency - The total capability of an organization to provide the cost estimates required by the organization for budget planning and execution, and program planning and approval.

Cost Estimation and Analysis (CEA) Steering Group - This group is actively involved in establishing overall goals of the initiative, in decisions affecting the future of the CEA competency, in defining workforce and analysis tool requirements, and in the implementation of the initiative's elements. Group members represent the CEA-related interests of their home Centers, serve to share experiences (or lessons-learned) from cost analysis activities, and accept complementary responsibilities for various initiative actions. In addition, the group will facilitate an Agency-oriented CEA culture rather than a specific Center-oriented culture.

Cost Overruns - The amount by which actual costs exceed the baseline or approved costs. Cost overruns can also refer to the amount by which a contractor exceeds or expects to exceed the estimated costs, and/or the final limitations (the ceiling) of a contract.

Cost Performance/Schedule Trade Study - Systemic, interdisciplinary examination of the factors affecting the cost of a system to find methods for meeting system requirements at an acceptable cost. This is achieved by analyzing numerous system concepts to find ways to attain necessary performance while balancing essential requirements that must be satisfied for the system to be successful. The objective of the cost-performance trades is not to minimize the cost of the system, but to achieve a specified level of cost reduction established by the target costing system.

Cost Readiness Level (CRL) - A designation designed to communicate the quality of the cost estimate by designating an associated CRL for each cost estimate to be funded in the Program Operating Plan (POP).

Cost Risk - Risk due to economic factors, rate uncertainties, cost estimating errors, and statistical uncertainty inherent in the estimate.

Cost/Schedule Control System Criteria (C/SCSC) - A planning and control reporting system devised by the Department of Defense for its contractors to use, intended to foster greater uniformity as well as early insight into impending schedule or budget overruns.

Cost/Schedule Status Report (C/SSR) - The low-end cost and schedule report generally imposed on smaller value contracts, not warranting full C/SCSC.

Cost Spreading Model - Takes the point-estimate derived from a parametric cost model and spreads it over the project's schedule, resulting in the project's annual phasing requirements.

Crystal Ball® - Software that employs an analytical technique, called Monte Carlo Simulation to provide the capability to conduct risk and uncertainty analyses within the construct of Excel-based models.

Cumulative Average Curve - Predicts the average unit cost of a set number of production units. Also, referred to as the *Wright curve* or the *Northrop curve*.

Cumulative Distribution Function (CDF) Curve ("S" Curve) - A display of cumulative costs, labor hours or other quantities plotted against time. The name derives from the S-like shape of the curve, flatter at the beginning and end and steeper in the middle, which is typical of most activities (and whole project). The beginning represents a slow, deliberate but accelerating start, while the end represents a deceleration as the work runs out.

Data Requirement Description - The NASA Data Requirements Description (DRD) is the equivalent of the Department of Defense (DoD) Contract Data Requirements List (CDRL). The DRD defines the data in a contract that is to be delivered to the Government by the contractor. This data may be in any form specified, such as hard copy, electronic, and electronic mailable. The specific form of delivery to NASA is specified either in the SOW and/or in each individual DRD item. The DRD that the cost community is responsible for is the CADRe, which is an integrated DRD that includes the WBS Structure, Cost Input Report, and Cost Estimate Report. the CADRe DRD is proposed as a DR on Category I and high risk Category II flight projects at NASA.

Decision Tree - A graphic representation of the sequence of a specific activity or operation.

Delphi - A process where a consensus view is reached by consultation with experts. Often used as an estimating technique.

Descriptive Statistics - Descriptive statistics provide basic information on the nature of a particular variable or set of variables. In general, descriptive statistics can be classified into three groups, those that measure 1) central tendency or location of a set of numbers (i.e., mode, median, mean, etc.), 2) variability or dispersion (i.e., range, variance, standard deviation, etc.), and 3) the shape of the distribution (i.e., moments, skewness, kurtosis, etc.).

Direct Costs - Direct costs are costs that are obviously and physically related to a project at the time they are incurred and are subject to influence of the project manager. Examples of direct costs include contractor-supplied hardware and project labor, whether provided by civil service or contractor employees.

Discount Factor - The discount factor is used to make dollar amounts occurring in different time periods commensurable so that they may be combined into a single number, called present value (PV) or present discounted value (PDV). The discount factor for period n is 1/(1+r)^n) or equivalently, (1+r)^(-n), where r is the discount rate, and n is the number of periods measured from the present to when the future dollar amount or cash flow occurs. Typically, r is expressed as an annual rate, in which case the number of periods should be measured in years.

Discounted Cash Flow (DCF) - A cash flow summary that has been adjusted to reflect the time value of money.

Discounting - Technique for converting forecasted amounts to economically comparable amounts at a common point or points in time, considering the time value of money.

Earned Value Management (EVM) - A management technique that relates resource planning to schedules and to technical cost and schedule requirements. All work is planned, budgeted, and scheduled in time-phased increments constituting a cost and schedule measurement baseline.

Earned Value Management System (EVMS) - A management system and related sub-systems implemented to establish a relationship between cost, schedule, and technical aspects of a project, measure progress, accumulate actual costs, analyze deviations from plans, forecast completion of events, and incorporate changes in a timely manner.

Economic Analysis (EA) - Systematically identifies the costs and benefits of each suitable future course of action. An EA specifies the objectives and assumptions, addresses appropriate alternative courses of action, includes cost of the alternatives, and describes benefits and/or effectiveness of each alternative.

Economic Analysis Development Plan (EADP) - Constructed prior to an Economic Analysis and should include, at a minimum, the mission, background, purpose, constraints, assumptions, cost element structure, cost and benefit estimating methodology, system description, configuration, schedules, and issues.

ECONPAK - Army-developed economic analysis tool, picked by HQs, to evaluate Construction of Facilities projects for Cost Benefit analyses.

e-Government - The Office of Electronic Government in the General Services Administration was formerly named the Office of Electronic Commerce. E-Government is about using technology to enhance access to and delivery of information and services to citizens, business partners, employees, agencies, and government entities.

Environmental Quality Costs - Those costs that are specifically related to activities within the Army environmental program including pollution prevention, compliance, restoration, and conservation.

Environmental Quality Economic Analysis (EQEA) - Supports decision making associated with environmental quality costing alternatives. Environmental quality costs are those costs that are specifically related to activities including pollution prevention, compliance, restoration, and conservation. NASA NSTS 22254, Method for Conduct of Space Shuttle Program Hazard Analyses provides specific guidance related to conducting an EQEA.

Estimate at Completion (EAC) - Actual cost of work completed to date plus the predicted costs and schedule for finishing the remaining work. It can also be the expected total cost of an activity, a group of activities, or of the project when the defined scope of work is completed.

Expert Choice - Advanced decision support application that uses Analytic Hierarchy Process (AHP) and Analytic Network Process (ANP) to help quantify qualitative decisions.

Factor Cost Estimate - Cost factors are often used to address those program/project elements that must be accounted in the cost estimate but are largely undefined early in the design. Examples of cost elements that could be developed using factors and percentages include contractor fee, Advanced Development, Operations Capability Development, Program Support, and Center and agency taxes.

Federal Activities Inventory Reform (FAIR) Act - The FAIR Act directs Federal agencies to issue each year an inventory of all commercial activities performed by Federal employees, e.g., those activities that are not inherently governmental. OMB is to review each agency's Commercial Activities Inventory and consult with the agency regarding its content. Upon the completion of this review and consultation, the agency must transmit a copy of the inventory to Congress and make it available to the public. The FAIR Act establishes a limited administrative appeals process under which an interested party may challenge the omission or the inclusion of a particular activity on the inventory as a commercial activity. With completion of the inventory, including the challenge and appeals process, the FAIR Act requires agencies to review the activities on the inventory.

Front-end Analysis - Front-end analysis is comprised of two parts: a needs assessment and a task analysis. A needs assessment is the systematic effort to gather opinions and ideas from a variety of sources on performance problems or new systems and technologies. Task analysis breaks down job tasks into steps and solves performance problems. Task analysis works to determine the operational components of an objective, describe what and how they are to be performed, describe the sequence and describe the scope.

Full Cost Accounting - Full cost accounting ties all Agency costs (including civil service personnel costs) to major activities. All costs will be associated with an activity and, as a result, referred to as a cost object.

Function Point Analysis (FPA) - A standard methodology for measuring software development and maintenance using function points. Function points is a standardized metric that describes a unit of work product suitable for quantifying software that is based on the end-user's point of view.

Functional Economic Analysis (FEA) - Economic Analysis type that documents the review of an entire functional process or sub-process, such as the use of alternative launch vehicles, etc. It requires a risk assessment of each alternative solution, requesting a high and low estimate for each cost element and subsequent probability distribution of expected costs.

Future Value (FV) - Value a specified number of years in the future, after the interest earned has been added to the account.

Gap Analysis - Step Two in the CBA process. After evaluation of the current environment, the results of the current process are compared to the investment's stated objectives (i.e., a "to-be" environment). The outcome of this comparison enables determination of current environment shortfalls and identifies change opportunities. The gaps between where the organization is today and how it wants to look after the investment represent the opportunities for improvement.

General and Administrative (G&A) Cost - G&A costs are costs that cannot be related or traced to a specific project, but benefit all activities. Such costs are allocated to a project based on a reasonable, consistent basis. Examples of G&A costs include costs associated with financial management, procurement, security, and legal activities.

Government-Off-The-Shelf (GOTS) - GOTS are pre-packaged software or (less commonly) hardware purchase alternatives. The technical staff of the government agency for which it is created typically develops them. It is sometimes developed by an external entity, but with funding and specification from the agency. Because agencies can directly control all aspects of GOTS products, these are generally preferred for government purposes.

Grassroots Cost Estimating - This costing methodology approach involves the computation of the cost of a WBS element by estimating the labor requirements (in terms of man-hours or man-years, for example) and the materials costs for the specific WBS line item. It is also referred to as "bottoms-up," or engineering build-up estimating.

Ground Rules and Assumptions (GR&A) - Ground rules and assumptions are external circumstances or events that are believed likely to happen. Ground rules and assumptions are based on the operation, maintenance and support of the system. Ground rules and assumptions generally include: the O&M period, base year of dollars, type of dollars, inflation indices, costs to be included or excluded, guidance on how to interpret the estimate properly, and clarification to the limit and scope in relation to acquisition milestones.

Independent Annual Review (IAR) - An IAR provides the status and performance of the project to the NASA Program Management Council (PMC) and is conducted to validate conformance to the Program Commitment Agreement (PCA) by detailing the progress/milestone achievement against original baseline; cost, schedule, and technical content evaluation and review of the project over its entire life cycle, technical progress, risks remaining, and mitigation plans, and any project deficiencies that will result in revised projections exceeding predetermined thresholds .

Independent Cost Estimate (ICE) - Prepared as a result of an independent review of a program/project. ICEs are developed by the cost analyst members of the independent review team in order to provide program/project management with the review team's assessment of how realistic the project's life cycle costs are.

Independent Life Cycle Cost Estimate - A life cycle cost estimate developed outside normal channels which generally includes representation from cost analysis, procurement, production management, engineering and project management.

Independent Program Assessment Office (IPAO) - The IPAO is a headquarters office located at Langley Research Center (LaRC). The IPAO role in cost estimating is to provide leadership and strategic planning for the cost estimation core competency by: interfacing with the Agency CFO and the Office of the Chief Engineer (Code AE) at NASA Headquarters regarding cost analysis requirements and processes, providing instruction on cost tool use, developing specialized cost tools, ensuring consistent, high-quality estimates across the Agency, fostering a "pipeline" of competent NASA analysts, providing independent, non-advocate cost estimates and cost-benefit analyses, and chairing the Cost Estimating Working Group and the annual NASA Cost Symposium Workshop.

Indirect Costs - Costs, which, because of their incurrence for common or joint objectives, are not readily subject to treatment as direct costs.

Inflation - An increase in the volume of money and credit relative to available goods and services resulting in a continuing rise in the general price level.

Integrated Budget Development Plan (IBDP) - NASA's consolidated budget document.

Integrated Financial Management (IFM) - NASA new integrated financial management system used to track budget and project costs.

Integration Complexity Risk - Includes risks associated with the number of data dependencies, the number of actual interfaces between this module and other modules, and the technical issues involved regarding programming and application solutions.

Intelligent Synthesis Environment (ISE) - The Intelligent Synthesis Environment (ISE) program is a NASA initiative to develop a virtual reality design environment. The goal is an advancement of the simulation based design environment involving the integration of design and cost models with analytical tools using intelligent systems technology. As a result of this new environment, the time to develop new system designs and to estimate the costs will be greatly reduced.

Interest - The service charge for the use of money or capital, paid at agreed to intervals by the user, and commonly expressed as an annual percentage of principal.

Internal Rate of Return (IRR) - The Internal Rate of Return (IRR) is another ROI metric used to measure an investment. The IRR is defined as the rate at which a bond's future cash flows, discounted back to today, equal its price. It is also defined as discount rate at which the NPV equals zero. IRR can be estimated using the formula:

$$IRR = NPV = PV\ Benefits - PV\ Costs = 0.$$

Learning Curve - Learning curves, sometimes referred to as *improvement curves* or *progress functions*, are based on the concept that resources required to produce each additional unit decline as the total number of units produced increases. The term learning curve is used when an individual is involved and the terms progress function or an improvement curve is used when all the components of an organization are involved. The learning curve concept is used primarily for uninterrupted manufacturing and assembly tasks, which are highly repetitive and labor intensive.

Lease - A lease is a long-term agreement between a user (lessee) and the owner of an asset (lessor) where periodic payments are made by the lessee in exchange for most of the benefits of ownership.

Lease vs. Buy Decision - The Lease vs. Buy decision has three steps: estimate the cash flows associated with borrowing and buying the asset, estimate the cash flows associated with leasing and asset, and compare the two financing methods to determine which has the lower cost. The decision rule for the acquisition of an asset is: buy the asset if the equivalent annual cost of ownership and operation is less than the best lease rate that can be acquired from an outsider.

Lessee - Renter or the user of the asset. Lessee contracts to make a series of payments to the lessor, and in return, gets to use the asset for the lease term.

Lessor - Legal owner and normally is entitled to the tax privileges of ownership like depreciation deductions or investment tax credits, if they are available. At the end of the lease period, the equipment reverts to the lessor.

Level of Effort (LOE) - Effort of a general or supportive nature which does not produce definite end products or results, i.e., contract for man-hours.

Life Cycle Cost (LCC) - The total cost for all phases of a project or system including design, development, production, operations, and disposal. It is also referred to as a *benefit-cost analysis*.

Life Cycle Cost Estimate (LCCE) - Presents life cycle costs with alternatives, by comparing the current estimate to the independent estimate (or prior estimate).

Linear Regression - A statistical technique used to illustrate how a linear relationship between two variables (namely X and Y) can be quantified using appropriate data. It is also referred to as *Simple Regression*.

Logical Decisions for Windows - Software that allows evaluation of numerous alternatives based on a hierarchy of goals and objectives.

Manual Software Estimation - Manual software estimation typically utilizes a simple, straightforward methodology to derive effort, cost, and schedule. This includes analogy, engineering buildup, or cost estimating relationship (CER) factors.

Market Risk - Includes risks associated with the stability of vendors and their software and related tools and services within the market (in this case federal HR commercial off-the-shelf [COTS] product market).

Model - A representation of a system broken into its component factors, or parts, such as to mimic or behave as the actual system would, were such parts or factors to be varied and intermixed. A model is used to gain knowledge about a system without actually executing the system.

Monte Carlo Simulation - Calculates numerous scenarios of a model by repeatedly picking random values from the input variable distributions for each "uncertain" variable and calculating the results.

Multivariate Regression - A statistical technique used to illustrate how a relationship between multiple variables can be quantified using appropriate data.

NASA / Air Force Cost Model (NAFCOM) - An innovative computer model for estimating aerospace program costs. NAFCOM96 is a user-friendly estimating tool, which operates in the Microsoft Windows environment. The model gives users flexibility in estimating by accommodating up to five systems and ten WBS levels, and by providing the user with the option of inputting throughput hardware or integration cost or allowing the model to calculate the cost using NAFCOM96 estimating methodology or user defined equations.

NASA Research Announcement - An NRA is used to announce research in support of NASA's programs, and, after peer or scientific review using factors in the NRA, select proposals for funding. Unlike an RFP containing a statement of work or specification to which offerors are to respond, an NRA provides for the submission of competitive project ideas, conceived by the offerors, in one or more program areas of interest. NRAs may result in grants, contracts or cooperative agreements.

Net Present Value (NPV) - Project's net contribution to wealth; Present Value minus Initial Investment.

Nominal Discount Rate - The nominal discount rate is adjusted to reflect expected inflation used to discount *Then Year* (inflated) dollars or nominal benefits and costs.

Non-Advocate Review (NAR) - An independent verification of a candidate project's plans, LCC status, and readiness to proceed to the next phase of the projects life cycle. A Pre-NAR is conducted when the project is moving from Phase A to Phase B. A NAR is conducted when a project is moving from Phase B to Phase C.

Non-Developmental Item (NDI) - Non-Developmental Items (NDI) are items, other than real property, that are customarily used for Non-Government purposes.

Non-Linear Regression - Type of regression used for data that is not intrinsically linear. Techniques for non-linear regression include: nonlinearity removed by logs, logs as relative changes and utilizing commercial software for modeling non-linear data.

Non-Quantifiable Benefits - Benefits that are able to be measured and therefore quantified. Non-quantifiable benefits include enhanced information security, consistency and compatibility throughout the enterprise, improved quality, enhancement of best practices, adherence to statutory and regulatory requirements, and enhanced modernization.

Normalize - Database to render constant or to adjust for known differences. Dollars, previous-year costs are escalated to a common-year basis for comparison.

Operating and Maintenance Costs (O&M) - Those operating expenditures incurred in the normal course of business to operate, maintain, support and update the system. It is also referred to as **recurring costs**.

Ordinary Least Squares (OLS) - Regression technique that works to find the best possible equation (relationship) between variables while minimizing the squares of error terms.

Parametric Cost Estimate - An estimating methodology using statistical relationships between historical costs and other project variables such as system physical or performance characteristics, contractor output measures, or manpower loading, etc. Also referred to as *"top down"* estimating.

Parametric Estimation - Involves the development and utilization of cost estimation relationships between historical costs and program, physical, and performance characteristics. The analysis uses analysis tools, or models, that relate hardware elements, complexity, and risks of failure to expected costs – a parametric analysis.

Payback Period - The payback period is the time required for the cumulative value of savings to be equal to the cumulative value of investment. The payback period measures the number of years needed to recover the investment or break even. The accept-reject criterion for this financial indicator is the ability of the program to equal or better the organization's required payback period.

Point Estimate - An estimate with a single point result, rather than a probabilistic estimate with a cost range. Or take a sample and then calculate the sample mean, sample variance, etc.

Present Value - Reflects in today's terms the value of future cash flows adjusted for the cost of capital - the time value of money. Present value is calculated from the time series of constant dollars estimates, using the real discount rate as specified by OMB policy.

President's Management Agenda (PMA) - The PMA identifies government-wide and program initiatives. Of these initiatives, there are four that directly relate to NASA: Competitive Sourcing, Improved Financial Performance, Budget and Performance Integration, and Better R&D Investment Criteria.

PRICE H/HL/M - A suite of hardware parametric cost estimating models that accurately estimate development, production, and operations and support costs. The suite allows for generating estimates at any WBS level, which includes integration and test cost calculations. The models operate in Microsoft Windows and interface with Microsoft Excel, Project, and other office tools. Monte Carlo risk simulations capability is available with the suite.

PRICE S - A suite of software sizing, development cost, and schedule, along with associated software operations and support cost models. The models operate in Microsoft Windows and interface with Microsoft Excel, Project, and other office tools. Monte Carlo risk simulations capability is available with the suite.

Productivity Paradox - The productivity paradox is a phenomenon where the programming language that seems to have the best productivity metrics (e.g. effort per SLOC), actually results in the highest total cost because the language is less efficient than other, more modern programming languages.

Program - An activity involving the development and operation of a hardware system, or more specifically, a space system. A strategic investment by Enterprises or Codes having defined goals, objectives, and funding levels, and consisting of one or more projects or research activities

Program Commitment Agreement (PCA) - The contract between the NASA Administrator and the Associate Administrator for Space Science for the implementation of a program in terms of cost, schedule, and content.

Program Office Estimate (POE) - A detailed estimate of acquisition and ownership costs normally required for high-level decisions. The estimate is performed early in the program and serves as the base point for all subsequent tracking and auditing purposes.

Program Formulation Agreement (PFA) - The PFA establishes resource estimates, cost risks, contingency reserves, and related Level 1 requirements.

Program Work Breakdown Structure (WBS) - A family tree, usually product oriented, that organizes, defines, and graphically displays the hardware, software, services, and other work tasks necessary to accomplish the project objectives.

Project - An investment with a finite time span having defined goals, objectives, requirements, and total cost, that yields new or revised products, services, or capabilities that meet the Agency's strategic needs.

Project Schedule Risk - Project Schedule risks are risks that the module implementation will be successful and run according to planned schedule. Schedule risk is defined as uncertainty in the project completion or fielding schedule, and the subsequent impact on costs and level of benefits. A stretched-out schedule may increase costs due to extended level-of-effort funding requirements, and result in delivery of systems too late to have the desired effect (reduced benefits). This category also addresses factors such as the thoroughness of project approach and plan, the degree to which plans incorporate risk mitigation techniques, and the impact of not meeting or adjusting the project's anticipated timeline.

Probability Density Function (PDF) - Translating risk assessments into cost impacts by providing a range of possible costs.

Quantifiable Benefits - Quantifiable benefits are those that can be measured or assigned a numeric value, such as dollars, physical count of tangible items, time, revenue, or percentage change. Dollar valued benefits comprise cost reductions, cost avoidance, and productivity improvements. Quantifiable benefits are calculated by subtracting the cost of an alternative from the cost of baseline operations over the period of the estimate (normally 10 years for IT investments). The difference is the "savings" that is often referred to as ROI.

Real Discount Rate - Discount rate adjusted to eliminate the effects of expected inflation used to discount Constant Year dollars or real benefits and costs.

Real Options Approach - The real options approach is a financial technique for valuing investment alternatives. This approach is primarily a decision tool that indicates whether or not to proceed with an investment after pre-established decision points are reached. This approach is more suited to large scale, multi-year acquisition projects where NASA would need to decide whether to continue spending or abandon a specific project. This approach integrates NPV techniques with a decision-tree framework to determine the whether a project should proceed or be terminated.

Regression Analysis - A quantitative technique used to establish a line-of-best-fit through a set of data to establish a relationship between one or more independent variable and a dependent variable. That line is then used with a projected value of the independent variable(s) to estimate a value for the dependent variable.

Request for Proposal (RFP) - A formal invitation containing a scope of work, which seeks a formal response (proposal) describing both methodology and compensation to form the basis of a contract. The Request For Proposal consists of a Solicitation Letter, Instructions to Bidders, Evaluation Criteria, Statement of Work, and a System Specification. The provider issues an RFP to potential subcontractors.

Reserve - A provision in the project plan to mitigate cost and/or schedule risk. Often used with a modifier (e.g., management reserve, contingency reserve) to provide further detail on what
types of risk are meant to be mitigated.

Return on Investment (ROI) - The strict meaning of ROI is "Return on Invested Capital." Most business people, however, use "ROI" simply to mean the incremental gain from an investment, divided by the cost of the investment. ROI is the net benefit expressed as a percentage of the investment amount:

$$\text{ROI} = \text{NPV} / \text{PV Investment}$$

REVIC - Parametric software cost estimating tool distributed by the Air Force Cost Analysis Agency that implements the Intermediate Constructive Cost Model (COCOMO) developed and described by Dr. Barry Boehm in his book Software Engineering Economics.

Risk - A situation in which the outcome is subject to an uncontrollable event stemming from a known probability distribution.

Risk Analysis - Process of examining each identified risk area to: isolate the cause; investigate the associative risk effects (e.g. dependencies/correlations); and determine the probable impacts.

Risk Assessment - Process of identifying and analyzing critical process and entity risks to increase the likelihood of meeting cost, performance (technical), and schedule objectives.

Rough Order of Magnitude (ROM) Estimates - It is an estimated cost based on approximate cost models or expert analysis. It is usually based on top-level requirements or specifications, and an overall prediction of work to be done to satisfy the requirements. The ROM is usually used for financial planning purposes only.

Savings to Investment Ratio (SIR) - The NPV of the savings divided by the NPV of the investment. The savings is the difference in the recurring costs between the status quo alternative and the proposed alternative. When the SIR equals one then discounted payback occurs.

Service Cost - Service costs are costs that cannot be specifically and immediately identified to a project, but can subsequently be traced or linked to a project and are assigned based on usage or consumption. Examples of services costs include automatic data processing and fabrication.

Scope of Work - The work involved in the design, fabrication and assembly of the components of a project's deliverable into a working product.

SEER-DFM - A software tool used to evaluate product and manufacturing costs, improves productivity and quality, and speeds products to market. (Design for Manufacturability)

SEER-H - A development and production estimation and management tool that predicts, measures, and analyzes resources, materials and schedules for an array of products and complex systems. It presents a view of the operational and maintenance costs of a product throughout its life cycle. (Hardware Estimation and Life Cycle Cost Analysis)

SEER-IC - A complement to SEER-H, helps estimate custom integrated circuit development and production costs, generate specifications, and evaluate potential yields. (Custom Integrated Circuit Development)

SEER-SEM - A development and program management tool that predicts, measures, and analyzes costs, schedules, risks, and reliability for software projects. (Software Estimation Model)

SEER-SSM - A software-sizing tool that creates realistic and highly reliable estimates of a project's scope. (Software Sizing Model)

Sensitivity Analysis - A technique used to discover how sensitive the results from economic and financial models are to changes in the input values of the variables used to calculate the results. A high degree of sensitivity is a warning to interpret the results of the model with care and circumspection, especially because many of the input variables themselves, will have been estimated and therefore be subject to error. Use of econometric models must not obscure awareness of their limitations and possible pitfalls, especially when they are being used for forecasting.

Should Cost Analysis - A study of contract price, which reflects reasonably achievable contractor economy and efficiency. It is accomplished by a government team of procurement, contract administration, audit and engineering representatives performing an in-depth cost analysis at the contractor's and subcontractor's plants. Its purpose is to develop a realistic price objective for negotiation purposes.

Simulation - A representation in time of a system, especially representing the interaction of parts of a system, including the effects of randomness and interference as the system parts interact with each other. A simulation is used to gain knowledge about a system operation without actually exercising the system.

Software Size - How big the application is being developed.

Source Lines of Code (SLOC) - Counting physical SLOC is accomplished by tallying the number of carriage returns in the source document. Logical SLOC are counted by tallying logical units (e.g., an IF-THEN-ELSE statement is considered one logical unit). SLOC methodology is based upon estimating the lines of code (deliverable) and the man-months effort required to develop a software program, with the advice of Subject Matter Experts (SMEs).

Space Operations Cost Model (SOCM) - A suite of tools to estimate space mission operations costs for future NASA projects. The estimating methodology is based on a mix of parametric estimating relationships derived from collected data and constructive approaches capturing assessments of advanced technology impacts and reflecting experience from current mission planning teams. At completion, SOCM will include modules for Planetary and Earth Orbiting robotic science missions, Orbiting Space Facilities, Launch/Transportation Systems, and Human Spaceflight (Lunar/Mars) missions.

Status Quo System - The system as it currently exists.

Target Costing - Structured approach to determine the cost at which a system or product with specified performance and reliability must be produced to shift the decision point toward proceeding with the project.

Technical Risk - Technical risk is defined as uncertainty in the system performance or "benefits." Technical risk may result from an immature technology, use of a lower-reliability component, degree to which products employ the latest standards in technology and design, availability of skilled resources to support the product, and then degree of tailoring required. Technical risk can be reflected in increased costs (to fix the technical problem) and lower overall system benefits.

Then-Year Dollars (TY) - Dollars that are escalated into the time period of performance of a contract. Sometimes referred to as escalated costs, inflated costs, or real-year dollars.

Time Phased - Related to the deployment schedule and operating concept, shows costs over time.

Time Value of Money - The time value of money refers to the fact that a dollar in hand today is worth more than a dollar promised at some future time. By compounding and discounting, the time value of money adjusts cash flow to reflect the increased value of money when invested. The time value of money also reflects that benefits and costs are worth more if they are realized earlier.

Tool-Driven Software Estimation - Tool-driven software estimation can produce more thorough and reliable estimates than manual methods. These parametric tools are based on data collected from hundreds or thousands of actual projects. The algorithms that drive them are derived from the numerous inputs to the models from personnel capabilities and experience and development environment to amount of code reuse and programming language.

Total Cost of Ownership (TCO) - Sum of all financial resources necessary to organize, equip, train, sustain, and operate military forces sufficient to meet national goals in compliance with all laws, all policies applicable to DoD, all standards in effect for readiness, safety, and quality of life, and all other official measures of performance for DoD and it's components. TOC is comprised of cost to research, develop, acquire, own, operate, and dispose of weapon and support systems, other equipment and real property, the costs to recruit, train, retain, separate and otherwise support military and civilian personnel, and other cost of business operations in DoD.

Uncertainty - A situation in which the outcome is subject to an uncontrollable event stemming from an UNKNOWN probability distribution.

Unit Curve - Predicts unit values for a given point on the curve. It is a plot of the cost of each unit of a given quantity. The total cost for the given quantity in the sum of the cost of each individual unit. Also referred to as the *Crawford* or *Boeing* curve.

Value Engineering - Used in the product design stage to find ways to achieve the specified performance at the required level of performance and reliability at the target cost. Value engineering is implemented in practice through cost-performance trades of design concepts.

Variance - A measure of the degree of spread among a set of values; a measure of the tendency of individual values to vary from the mean value. It is computed by subtracting the mean value from each value, squaring each of these differences, summing these results, and dividing this sum by the number of values in order to obtain the arithmetic mean of these squares.

Vendor Quote - Obtaining actual costs on WBS items such as hardware, facilities, or services, directly from the vendor who provides it.

Work Breakdown Structure (WBS) - A technique for representing all the components, software, services and data contained in the project scope statement. It establishes a hierarchical structure or product oriented "family tree" of elements. It is used to organize, define and graphically display all the work items or work packages to be done to accomplish the project's objectives.

"What-If" Analyses - The process of evaluating alternative strategies.

Wrap Rate - NASA wrap rates can be defined as those additional service pools (charges) that should be included in project/program estimates because they are a part of doing business from which projects/programs receive benefit. Examples (not all inclusive) of these service charges or additional costs can include such items as: system engineering, project management, workstation maintenance, application programming, computer usage, facilities, and fabrication.

C. References

This appendix provides a convenient, though not comprehensive, list of references for cost estimating. Some of these references were used in compiling this handbook; others should prove useful to the NASA CEC. This appendix is organized by reference type (e.g., books, websites, manuals, etc.,) and by topic. In addition to the references listed below, a good locator source is the Library of Congress Online Catalog, which can be found at http://catalog.loc.gov/.

Books

2002 Craftsman Cost Estimating Guides

Advanced Engineering Economics (by Chan S. Park and Gunter P. Sharp-Bette)

CHAOS Chronicles 3.0 (by The Standish Group)

CMMI Distilled (by Ahern, Clouse, & Turner)

Construction Cost Analysis and Estimating (by Phillip F. Ostwald)

Cost Estimating (by Rodney D. Stewart)

Cost Estimator's Reference Manual (by Rodney D. Stewart, Richard M. Wyskida, and James D. Johannes)

Design to Cost (by Jack V. Michaels and William P. Wood)

Engineering Cost Estimating (by Phillip F. Ostwald)

Estimating and Bidding for Heavy Construction (by S.H. Bartholomew)

Estimating in Building Construction (by Frank R. Dagostino and Leslie Feigenbaum

Estimating Software Costs (by T. Capers Jones)

Financial Management Theory and Practice (by Eugene F. Brigham and Michael C. Gapenski)

Function Point Analysis: Measurement Practices for Successful Software Projects (by Garmus and Herron)

How to Estimate with Means Data & CostWorks (by Saleh Mubarak and Means)

Investment Under Uncertainty (by Avinash Dixit and Robert Pindyck)

IT Measurement: Practical Advice from the Experts (by IFPUG)

Managing the Construction Process: Estimating, Scheduling, and Project Control (by Frederick E. Gould)

Means Building Construction Cost Data (by R.S. Means Company, Inc.(http://www.rsmeans.com)

Principles of Corporate Finance (by Richard A. Brealey and Stewart C. Myers)

Handbooks and Manuals

Practical Software Measurement: Objective Information for Decision Makers (by McGarry, et. al.)

Real Options; Managerial Flexibility and Strategy in Resource Allocation (by Lenos Trigeorgis)

Real Options: Managing Strategic Investments in an Uncertain World (by Martha Amram and Nalin Kulatilaka)

Reducing Space Mission Cost (by James R. Wertz and Wiley J. Larson)

Simplified Estimating For Builders And Engineers (by Joseph E. Helton)

Software Assessments, Benchmarks, and Best Practices (by Capers Jones)

Software Cost Estimation with COCOMO II (by Barry W. Boehm)

Space Mission Design and Analysis (SMAD) (by Wiley J. Larson and James Richard Wertz)

Technological Forecasting for Decision Making (by Joseph P. Martino)

The Goal Question Metric Method (by van Solingen & Berghout)

The Mythical Man Month (by Frederick P. Brooks)

Walker's Building Estimator's Reference Book (by Scott Siddens and Frank R. Walker Co.)

Air Force Space Command (AFSC) Cost Estimating Handbook Series, Volume VI - Space Handbook

Department of the Army Cost Analysis Manual
http://www.ceac.army.mil/default.asp

Department of the Army Economic Analysis Manual
http://www.asafm.army.mil/pubs/cdfs/manual/economic.pdf

Department of Defense Operating and Support Cost Estimating Guide
http://www.ncca.navy.mil/resources/caig_os_guide.pdf

Department of Defense Parametric Estimating Initiative Handbook
http://www.ispa-cost.org/PEIWeb/newbook.htm

Department of the Navy Center for Cost Analysis Software Development Estimating Handbook

IFPUG Counting Practices Manual, Version 4.1.1

IFPUG Case Study 1, Release 2.0: ERD, Hierarchical Process, DB2 Data Base, and GUI Windows

IFPUG Case Study 2, Release 2.0: ERD, Data Flow Diagrams, IMS Data Base, Common User Access Screens

IFPUG Case Study 3, Release 2.0: Class Diagram (UML), Use Case Diagrams, GUI Windows

IFPUG Case Study 4, Release 1.0: Traffic Control Systems with Real-Time Components

IFPUG Guidelines to Software Measurement ('96-'97)

IFPUG Guidelines to Counting Logical Files

IFPUG Guidelines to Counting Enhancements

ISBSG Benchmark Summary Release 6

NAFCOM Manual

NASA Systems Engineering Handbook
http://ldcm.gsfc.nasa.gov/library/Systems_Engineering_Handbook.pdf

PRICE Manual

SEER Manual

Policies, Procedures, and Guidelines

To find NASA Agencywide directives please reference the NASA Online Directives Information System (NODIS) at http://nodis3.gsfc.nasa.gov/library/main_lib.html.

NASA Policy Directives

NPD 1000.1B: NASA Strategic Plan
http://nodis3.gsfc.nasa.gov/displayDir.cfm?Internal_ID=N_PD_1000_001C_&page_name=main

NPD 7120.4B: Program/Project Management
http://nodis3.gsfc.nasa.gov/library/displayDir.cfm?Internal_ID=N_PD_7120_004B_&page_name=main&search_term=7120

NASA Procedures and Guidelines

NPR 1000.3: The NASA Organization
http://nodis3.gsfc.nasa.gov/library/displayDir.cfm?Internal_ID=N_PG_1000_0003_&page_name=main&search_term=1000

NPR 7120.5A: Program and Project Management Processes and Requirements[1]
http://nodis3.gsfc.nasa.gov/main_lib.html

NPR 7500.1: NASA Technology Commercialization Process
http://nodis3.gsfc.nasa.gov/library/displayDir.cfm?Internal_ID=N_PG_7500_0001_&page_name=main

NASA Procedures and Guidelines Directive No. 210-PG-5100.1.1
Purchase Request (PR) Initiator Documentation Guide for Simplified Acquisitions
http://msc-docsrv.gsfc.nasa.gov/GDMS_docs/Pgwi200/210-PG-5100.1.1-.pdf

[1] *NPG 7120.5B will be released soon.*

Other Federal Agency Guidelines

Contract Pricing Reference Guides http://www.acq.osd.mil/dp/cpf/pgv1_0/

Cost Analysis Improvement Group (CAIG) Operating and Support Cost Estimating Guide http://www.dtic.mil/pae/

DoD 5000.2-R Mandatory Procedures for Major Defense Acquisition Programs (MDAPS) and Major Automated Information System (MAIS) Acquisition Programs http://www.acq.osd.mil/ar/doc/dodd5000-2-r-061001.pdf

DoD 5000.4 Cost Analysis Improvement Group (CAIG) http://www.dtic.mil/whs/directives/corres/pdf/d50004wch1_112492/d50004p.pdf

DoD 5000.4-M Cost Analysis Guidance and Procedures

http://www.hanscom.af.mil/ESC-BP/pollprev/docs/50004m.pdf

http://www.dtic.mil/whs/directives/corres/html/50004m.htm

http://web1.deskbook.osd.mil/default.asp (Search for DoD 5000.4-M)

The Federal Activities Inventory Reform Act (FAIR), P.L. 105-270 http://www.whitehouse.gov/omb/procurement/fair-index.html

JPL Formal Cost Estimation Procedure (JPL D-16376)
Hamid Habib-agahi, Cost Estimation Process Owner
David B. Smith, Manager, Product Delivery Engineering Office

Military Handbook 881 for WBS http://www.acq.osd.mil/pm/newpolicy/wbs/mil_hdbk_881/mil_hdbk_881.htm

NASA FY2003 Congressional Budget http://ifmp.nasa.gov/codeb/budget2003/

NASA Federal Acquisition Regulation (FAR) Supplement http://www.hq.nasa.gov/office/procurement/regs/nfstoc.htm

NASA Full Cost Initiative Agencywide Implementation Guide http://ifmp.nasa.gov/codeb/library/fcimplementation.pdf

Office of Management and Budget (OMB) Circular No. A-11
Preparing and Submitting Budget Estimates
http://www.whitehouse.gov/omb/circulars/a11/02toc.html

Office of Management and Budget (OMB) Circular No. A-76
Performance of Commercial Activities
http://www.whitehouse.gov/omb/circulars/a076/a076.html

Office of Management and Budget (OMB) Circular No. A-76
Performance of Commercial Activities Revised Supplemental Handbook
http://www.whitehouse.gov/omb/circulars/a076/a076s.html

Office of Management and Budget (OMB) Circular No. A-94
Guidelines and Discount Rates for Benefit-Cost Analysis of Federal Programs
http://www.whitehouse.gov/omb/circulars/a094/a094.html

Office of Personnel Management Salary Tables
http://www.opm.gov/oca/payrates/

Title 10 United States Code Section 2306a (10 USC 2306a)
Cost or Pricing Data: Truth in Negotiations
http://www4.law.cornell.edu/uscode/10/2306a.html

Papers and Reports

Aerospace Systems Design in NASA's Collaborative Engineering Environment
http://techreports.larc.nasa.gov/ltrs/PDF/1999/mtg/NASA-99-50iac-dwm.pdf

GAO Defense Acquisition: Historical Insights Into Navy Ship Leasing
http://www.gao.gov/archive/1999/ns99141t.pdf

The President's Management Agenda
http://www.whitehouse.gov/omb/budintegration/pma_index.html

Report of the Advisory Committee On the Future of the U.S. Space Program
http://history.nasa.gov/augustine/racfup1.htm

Software Size Measurement: A Framework for Counting Source Statements
(by Robert E. Park)
http://www.sei.cmu.edu/pub/documents/92.reports/pdf/tr20.92.pdf

Jacobs, Mark, "Space Operations Cost Model (SOCM) Version 1.0 User's Manual and Program Documentation", Science Applications International Corporation, January 1998.

NASA, "An Operational Assessment of Concepts and Technologies for Highly Reusable Space Transportation", November 1998.

NASA, "Space Launch Operations Cost Estimating Process Definition Handbook", Kennedy Space Center, NAS10-02020, 2002

Quintana, Mauricio, "ISSAC Model (Version 2.0) User Guide", Booz, Allen, Hamilton, December 2003

Shishko, Robert, "MESSOC (Version 3.16) Algorithms Documentation and User Help Files" *in html*, Caltech Jet Propulsion Laboratory, October 2002.

Zapata, Edgar, and A. Torres, "Space Transportation Operations Cost Modeling and the Architectural Assessment Tool – Enhanced", American Institute of Aeronautics and Astronautics, IAA-99-IAA.1.1.01, 1999.
(http://science.ksc.nasa.gov/shuttle/nexgen/Tools1.htm#aate)

McCleskey, Carey, "Shuttle Root Cause Analysis (RCA) database (Version 2.0)", NASA Kennedy Space Center, April 28, 2003

Professional Societies

American Institute of Aeronautics and Astronautics (AIAA) http://www.aiaa.org

American National Standards Institute (ANSI) http://www.ansi.org/

American Society of Professional Estimators (ASPE) http://www.aspenational.com/

Association for the Advancement of Computing in Education http://www.aace.org/

The Association for the Advancement of Cost Engineering through Total Cost Management (AACE) International http://www.aacei.org/

Association of Cost Engineers (ACostE) http://www.acoste.org.uk/

Center for International Project and Program Management (CIPPM)
http://www.iol.ie/~mattewar/CIPPM/

International Cost Engineering Council (ICEC) http://www.icoste.org/

International Function Point Users Group (IFPUG) www.ifpug.org

International Project Management Association (IPMA) http://www.ipma.ch/

International Society of Parametric Analysts (ISPA) http://www.ispa-cost.org/

National Contract Management Association (NCMA) http://www.ncmahq.org/

Project Management Institute (PMI) http://www.pmi.org/

Society of Cost Estimating and Analysis (SCEA) http://www.sceaonline.net/

Society for Risk Analysis (SRA) http://www.sra.org/

Space Systems Cost Analysis Group (SSCAG) http://sscag.saic.com/

General NASA Websites

Aerospace Technology Enterprise http://www.aero-space.nasa.gov/

Ames Research Center http://www.arc.nasa.gov/

Ames Research Center Educational Site http://education.arc.nasa.gov/

Biological and Physical Research Enterprise http://www.hq.nasa.gov/office/olmsa/

Chief Financial Officer http://ifmp.nasa.gov/codeb/

Budget Request http://ifmp.nasa.gov/codeb/budget2003/

Dryden Flight Research Center http://www.dfrc.nasa.gov/

Earth Science Enterprise http://www.earth.nasa.gov/

External Relations http://www.hq.nasa.gov/office/codei/

Glenn Research Center http://www.grc.nasa.gov/

Goddard Space Flight Center http://www.gsfc.nasa.gov/

Goddard Institute for Space Studies http://www.giss.nasa.gov/

Wallops Flight Facility http://www.wff.nasa.gov/

Human Exploration and Development of Space Enterprise
http://www.hq.nasa.gov/osf/heds/

Human Resources and Education http://www.hq.nasa.gov/office/codef/

Independent Validation and Verification Facility http://www.ivv.nasa.gov/

Inspector General http://www.hq.nasa.gov/office/oig/hq/

Java EOSDIS Acronym Finder
http://dmserver.gsfc.nasa.gov/ecsdev/gui/html/acronym_finder/

Jet Propulsion Laboratory http://www.jpl.nasa.gov/

Johnson Space Center http://www.jsc.nasa.gov/bu2/

White Sands Test Facility http://www.wstf.nasa.gov/

Kennedy Space Center http://www.ksc.nasa.gov/

Langley Research Center http://www.larc.nasa.gov/

Legislative Affairs http://legislative.nasa.gov/

Marshall Space Flight Center http://www.msfc.nasa.gov/

NASA Acronym List (GSFC)
http://library.gsfc.nasa.gov/Databases/Acronym/acronym.html

NASA Acronym List (MSFC) http://liftoff.msfc.nasa.gov/help/acronym.html

NASA Advisory Council http://www.hq.nasa.gov/office/codez/new/poladvisor.html

NASA Earth Science Acronyms http://gcmd.gsfc.nasa.gov/Aboutus/sitemap.html

NASA Financial Management Manual http://www.hq.nasa.gov/fmm/

NASA Headquarters http://www.hq.nasa.gov/

NASA Homepage http://www.nasa.gov/

NASA Human Space Flight http://spaceflight.nasa.gov/

NASA HQ Office of the Chief Engineer http://www.hq.nasa.gov/office/codea/codeae/

KSC Next Gen Site http://science.ksc.nasa.gov/shuttle/nexgen/rlvhp.htm

NASA ISO 9000 Certification http://www.hq.nasa.gov/hqiso9000/

NASA Lessons Learned Information System http://llis.nasa.gov/

NASA Online Directives Information System (NODIS)
http://nodis3.gsfc.nasa.gov/library/main_lib.html

NASA Spacelink http://spacelink.nasa.gov/

NASA Strategic Management Handbook
http://www.hq.nasa.gov/office/codez/strahand/frontpg.htm

NASA Strategic Plan http://www.hq.nasa.gov/office/nsp/

NASA HQ Systems Management Office (SMO)
http://www.hq.nasa.gov/office/codea/codeae/smo.html

NASA Watch http://www.nasawatch.com/

Procurement http://www.hq.nasa.gov/office/procurement/

Public Affairs http://www.nasa.gov/newsinfo/index.html

Safety and Mission Assurance http://www.hq.nasa.gov/office/codeq/

Science@NASA http://science.nasa.gov/default.htm

Small and Disadvantaged Business Utilization http://www.hq.nasa.gov/office/codek/

Space Science Enterprise http://www.hq.nasa.gov/office/oss/

Stennis Space Center http://www.ssc.nasa.gov/

Cost Analysis

Air Force Cost Analysis Agency (AFCAA) http://www.saffm.hq.af.mil/afcaa/

Army Cost & Economic Analysis Center (CEAC) http://www.ceac.army.mil/

Carnegie Mellon Software Engineering Institute http://www.sei.cmu.edu/sei-home.html

Contract Pricing Reference Guides http://www.acq.osd.mil/dp/cpf/pgv1_0/

Cost Analysis Division of European Space Agency (ESA) http://www.estec.esa.nl/eawww/

DoD Primer on Cost Analysis Requirements Description (CARD)
http://acc.dau.mil/simplify/ev.php?ID=21696_201&ID2=DO_TOPIC

Cost Estimating http://cost.jsc.nasa.gov/

Cost Estimating Acronym Glossary http://www.jsc.nasa.gov/bu2/acronyms.html

Cost Estimating Databases http://cost.jsc.nasa.gov/bu2/data.html

Cost Estimating Glossary http://cost.jsc.nasa.gov/bu2/glossary.html

Cost Estimating References http://cost.jsc.nasa.gov/bu2/references.html

Cost Estimating Resources http://cost.jsc.nasa.gov/bu2/resources.html

Department of Energy (DOE) Office of Science Article on Learning Curves
http://www.sc.doe.gov/sc-80/sc-82/430-1/430-1-chp21.pdf

DOE Environmental Management (EM) Applied Cost Engineering (ACE) Team
http://web.em.doe.gov/aceteam/

Formal Risk Assessment of System Cost Estimates (FRISK)

http://www.acq.osd.mil/io/se/risk_management/tools_and_products.htm

Inflation Calculator
http://cost.jsc.nasa.gov/bu2/inflate.html

JSC Cost Estimating
http://cost.jsc.nasa.gov/bu2/about.html

The Learning Curve Article by Computerworld

http://www.computerworld.com/cwi/story/0,1199,NAV47-68-85-1942_STO61762,00.html

Learning Curve Calculator
http://cost.jsc.nasa.gov/bu2/learn.html

NASA Online Cost Models http://cost.jsc.nasa.gov/bu2/models.htm

- Advance Missions http://cost.jsc.nasa.gov/bu2/PCEHHTML/pceh.htm
- Aircraft Turbine Engine http://cost.jsc.nasa.gov/bu2/ATECM.html
- Airframe http://cost.jsc.nasa.gov/bu2/airframe.html
- CPI Inflation Calculator http://cost.jsc.nasa.gov/bu2/inflateCPI.html
- Cost Estimating Cost Model http://cost.jsc.nasa.gov/bu2/CECM.html
- Cost Spreading Model http://cost.jsc.nasa.gov/bu2/beta.html
- ECI Inflation Calculator http://cost.jsc.nasa.gov/bu2/inflation/eci/inflateECI.html
- GDP Deflator Inflation Calculator http://cost.jsc.nasa.gov/bu2/inflateGDP.html

IPI Inflation Calculator http://cost.jsc.nasa.gov/bu2/inflation/ipi/inflateIPI.html

Labor & Material http://cost.jsc.nasa.gov/bu2/instruct.html

Learning Curve Calculator http://cost.jsc.nasa.gov/bu2/learn.html

Mission Operations http://cost.jsc.nasa.gov/bu2/MOCM.html

NAFCOM Cost Model http://nafcom.saic.com/

PPI Inflation Calculator http://cost.jsc.nasa.gov/bu2/inflation/ppi/inflatePPI.html

SOCM Model http://cost.jsc.nasa.gov/bu2/SOCM/SOCM.html

Spacecraft/Vehicle Level http://cost.jsc.nasa.gov/bu2/SVLCM.html

Naval Sea Systems Command (NAVSEA) Cost Engineering and Industrial Analysis
http://www.navsea.navy.mil/sea017/index.html

Parametric Cost Estimating Process Flow (Analogy)
http://cost.jsc.nasa.gov/bu2/analogy.html

Parametric Cost Estimating Process Flow (CERs)
http://cost.jsc.nasa.gov/bu2/CERproc.html

Resource Data Storage and Retrieval System (REDSTAR)
http://redstar.saic.com/

Unmanned Space Vehicle Cost Model
http://cost.jsc.nasa.gov/bu2/PCEHHTML/pceh.htm

Software Applications

ACEIT http://www.aceit.com/

AATe – Architectural Assessment Tool – enhanced
http://science.ksc.nasa.gov/shuttle/nexgen/IAF99AATe.htm

Best Estimate http://www.best-estimate.com/

BREAK™ http://www.protech-ie.com/break.htm

Building Systems Design SoftLink http://www.bsdsoftlink.com/

Constructive Cost Model (COCOMO)

- COCOMO II http://sunset.usc.edu/research/COCOMOII/
- COCOPRO http://www.iconixsw.com/Spec_Sheets/CoCoPro.html
- COMET http://www.ncca.navy.mil/services/comet/index-frame.htm
- COOLSoft http://www.wwk.com/coolsoft.html

Costar http://www.softstarsystems.com/

COSMIC http://www.openchannelfoundation.org/cosmic/

Cost Analysis Strategy Assessment (CASA) https://www.logsa.army.mil/alc/casa/

Cost Xpert http://www.costxpert.com/

COSTIMATOR http://www.costimator.com/

Crystal Ball http://www.decisioneering.com/crystal_ball/index.html

CURV1 http://www.protech-ie.com/curv-v2.pdf

Data and Analysis Center for Software (DACS)
http://www.dacs.dtic.mil/databases/url/key.hts?keycode=4:1&islowerlevel=1

DeccaPro http://www.deccansystems.com/DeccaPro.htm

Decision by Life Cycle Cost http://www.ald.co.il/products/dlcc.html

Decision Tools http://www.palisade.com/html/decision_analysis_software.html

European Space Agency Cost Modeling Software (ECOM)
http://www.estec.esa.nl/eawww/ecom/ecom.htm

European Space Agency Costing Software (ECOS)
http://www.estec.esa.nl/eawww/ecos/ecos.htm

Eviews http://www.eviews.com/

Expert Choice http://www.expertchoice.com/

Learning Curves http://www.simpleworks.com/LC/index.htm

Links to Software Development Resources http://www.construx.com/reslink.htm

Logical Decisions http://www.logicaldecisions.com/

Mainstay (Proposal Pricing) http://www.mainstay.com/

Minitab http://www.minitab.com/

NAFCOM http://nafcom.saic.com/

Palisade http://www.palisade.com/
- @Risk http://www.palisade.com/html/risk.html
- Decision Tools Suite http://www.palisade.com/html/decisiontools_suite.html
- BestFit http://www.palisade.com/html/bestfit.html
- Precision Tree http://www.palisade.com/html/ptree.html
- Evolver http://www.palisade.com/html/evolver.html

PRICE Estimating Suite http://www.pricesystems.com/

Primavera Systems, Inc. http://www.primavera.com/
- Primavera Enterprise Suite http://www.primavera.com/products/enterprise.html
- Primavera Expedition Suite http://www.primavera.com/products/expedition.html
- Primavera TeamPlay Suite http://www.primavera.com/products/teamplay.html
- Prime Contract http://www.primavera.com/products/primecontract.html
- Primavera Project Planner http://www.primavera.com/products/p3.html
- SureTrack Project Manager http://www.primavera.com/products/sure.html

REVIC http://www.jsc.nasa.gov/bu2/PCEHHTML/pceh.htm

SEER www.galorath.com

Small Satellite Cost Model (SSCM) http://www.aero.org/software/sscm/

Space Operations Cost Model (SOCM) http://www.jsc.nasa.gov/bu2/SOCM/SOCM.html

SPSS http://www.spss.com/products/

Welcom http://www.welcom.com/

Cobra http://www.welcom.com/content.cfm?node=24

Colleges and Universities

Air Force Institute of Technology (AFIT) http://www.afit.edu/

Army Logistics Management College (ALMC) http://www.almc.army.mil/

California State University, Long Beach (Regression)
http://www.csulb.edu/~msaintg/ppa696/696regs.htm#REGRESSION

Carnegie Mellon University http://www.cmu.edu/

Defense Acquisition University (DAU) http://www.dau.mil/

University of Exeter (Regression)

http://www.exeter.ac.uk/~SEGLea/psy2005/simpreg.html

http://www.exeter.ac.uk/~SEGLea/psy2005/basicmlt.html

University of Southern California (Regression)
http://www-rcf.usc.edu/~moonr/econ419/econ414_2.pdf

Other Government Websites

Department of the Treasury http://www.ustreas.gov/

e-Government http://egov.gov/

Federal Acquisition Regulation (FAR) http://www.arnet.gov/far/

General Accounting Office (GAO) http://www.gao.gov/

Office of Management and Budget (OMB) http://www.whitehouse.gov/omb/

Office of the Under Secretary of Defense for Acquisition, Technology, and Logistics
www.acq.osd.mil/

United States Government Standard General Ledger (USSGL)
http://www.fms.treas.gov/ussgl/index.html

Technical Papers

NASA Technical Report Service http://cost.jsc.nasa.gov/bu2/NTRS.html

RAND Reports http://www.rand.org/publications/search.html

The Standish Group CHAOS Reports http://www.pm2go.com/

Magazines

Controller Magazine (Business Finance) http://www.businessfinancemag.com/

Fast Company http://www.fastcompany.com/

Federal Employee's News Digest http://www.fendonline.com/

Government Executive http://www.govexec.com/

Newsletters

The Critical Path Newsletter http://fpd.gsfc.nasa.gov/news.html

NASA Procurement Countdown http://www.hq.nasa.gov/office/procurement/cntdwn.html

Other Research Tools

DoD Dictionary http://www.dtic.mil/doctrine/jel/doddict/

NASA Earth Science Glossary http://gcmd.gsfc.nasa.gov/Aboutus/sitemap.html

NASA Glossary of Financial Terms http://www.jsc.nasa.gov/bu2/glossary.html

Project Management Glossary http://www.maxwideman.com/pmglossary/index.htm

SCEA Glossary http://www.sceaonline.net/

WorldWideWeb Acronym and Abbreviation Server http://www.ucc.ie/acronyms/

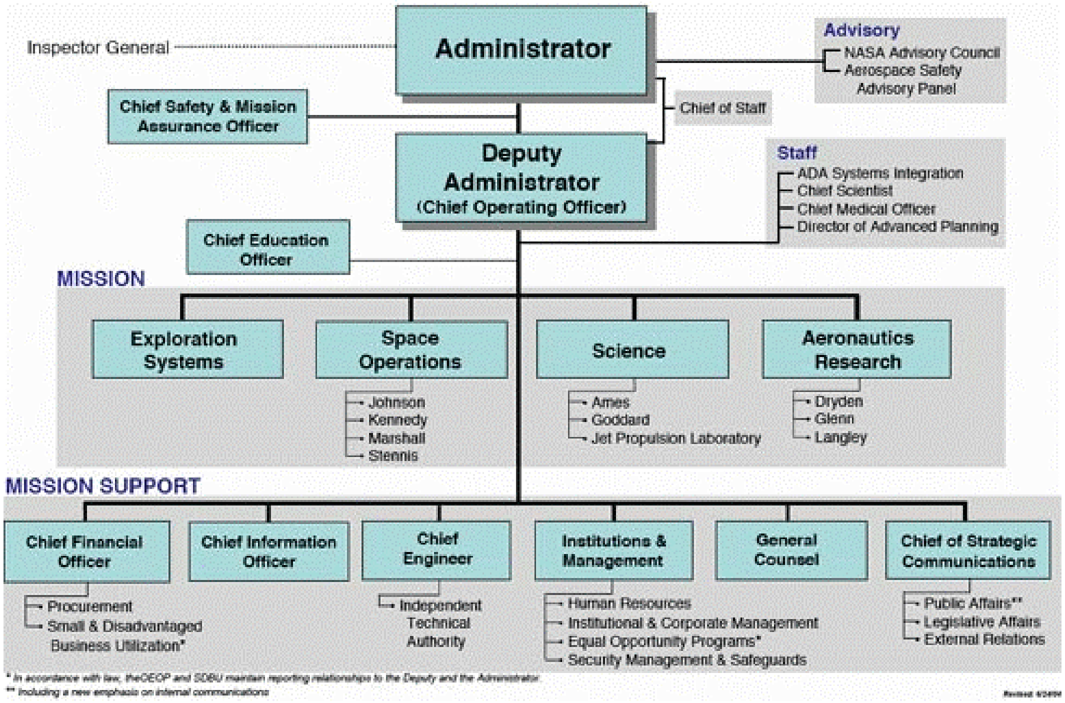
D. NASA Organizational Charts

This Organizational Chart Appendix includes charts from all NASA Centers and the entire NASA organization. For more detailed information please refer to the NASA Procedures and Guidelines (NPG) 1000.3. This NPG includes detailed information on the entire NASA organization, including mission statements, responsibilities, special relationships, and lines of succession.

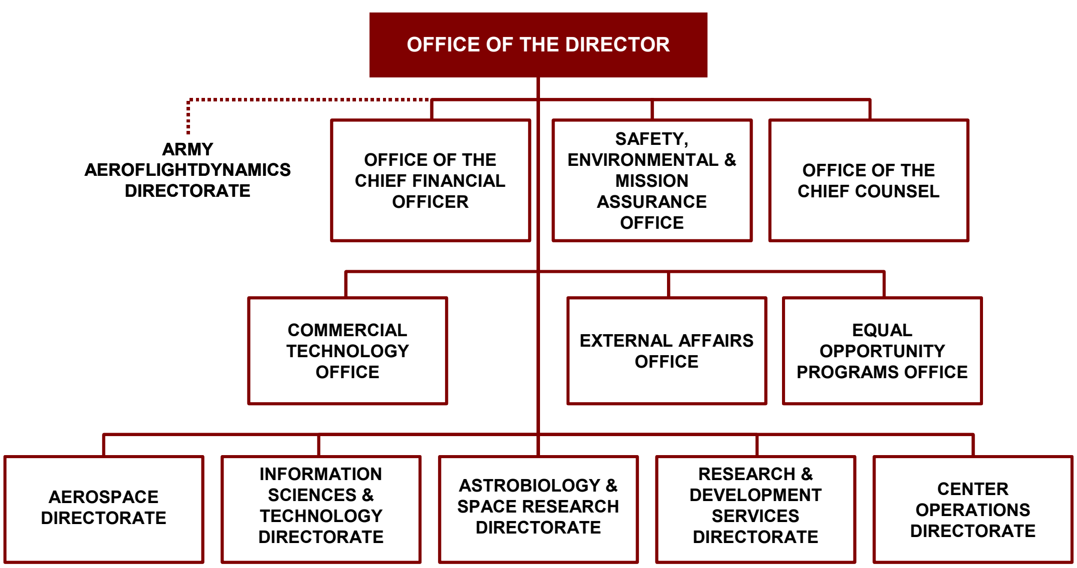
NASA Centers	Cost Group	Location
NASA Headquarters	Code BC	HQ Code B
NASA IPAO	Independent Program Assessment Office	HQ Code D
ARC	Independent Cost Estimating Group	CFO
DFRC	Center Cost Office	CFO
GRC	Center Cost Office	CFO
GSFC	Resource Analysis Office	SMO (Section 300)
JPL	Cost Estimation Group and Cost, Risk and Systems Analysis Group	Systems Division, Mission and System Architecture Section
JSC	Cost Estimating and Assessment Office	SMO
KSC	Center Cost Office	SMO / Systems Engineering Office
LaRC	Center Cost Office	SMO
MSFC	Engineering Cost Office	Advanced Concepts and Analysis Department
SSC	Center Cost Office	SMO

NASA Cost Group Locations by Center

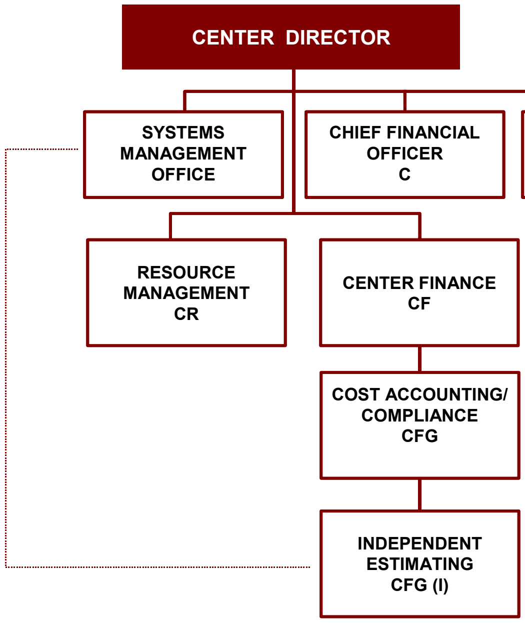
NASA Organizational Chart



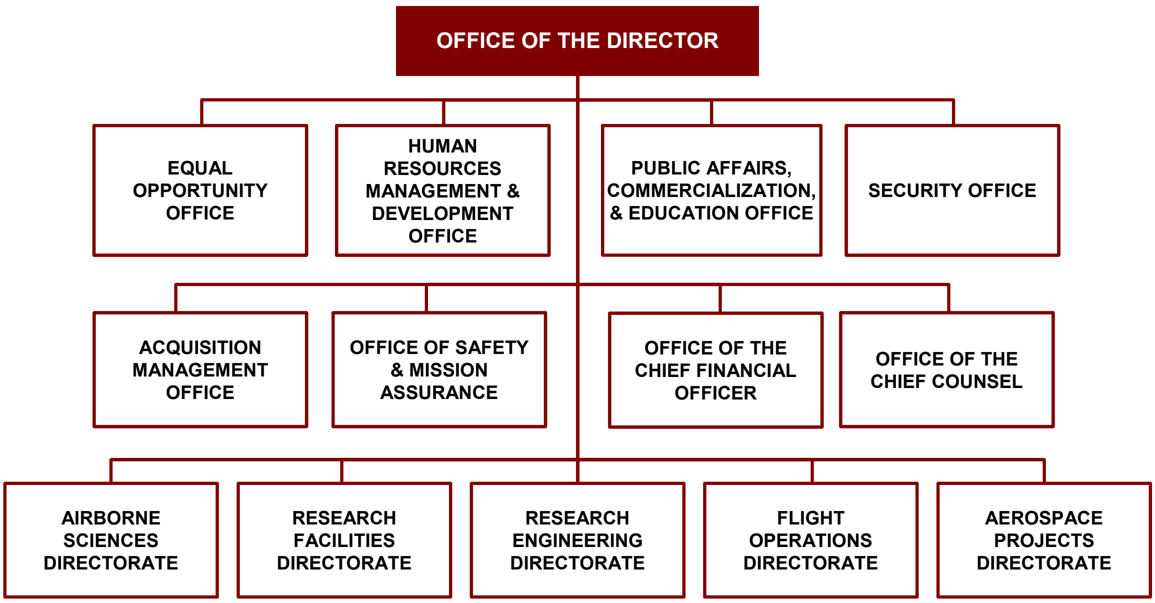
Ames Research Center Organizational Chart



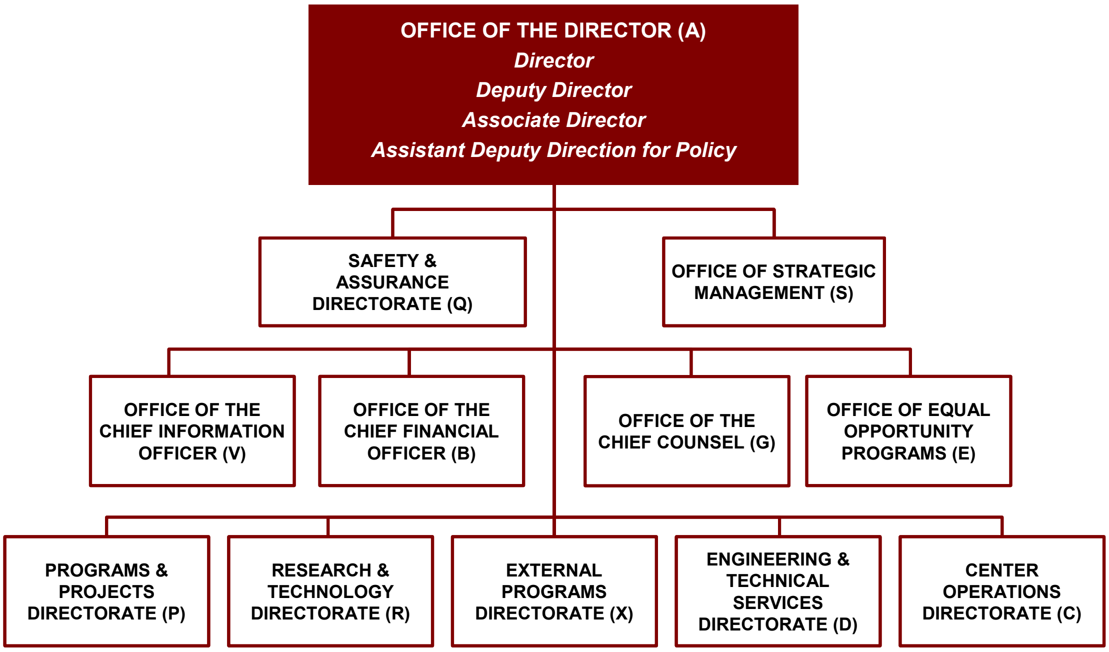
Ames Research Center
Independent Cost Estimating Organizational Chart



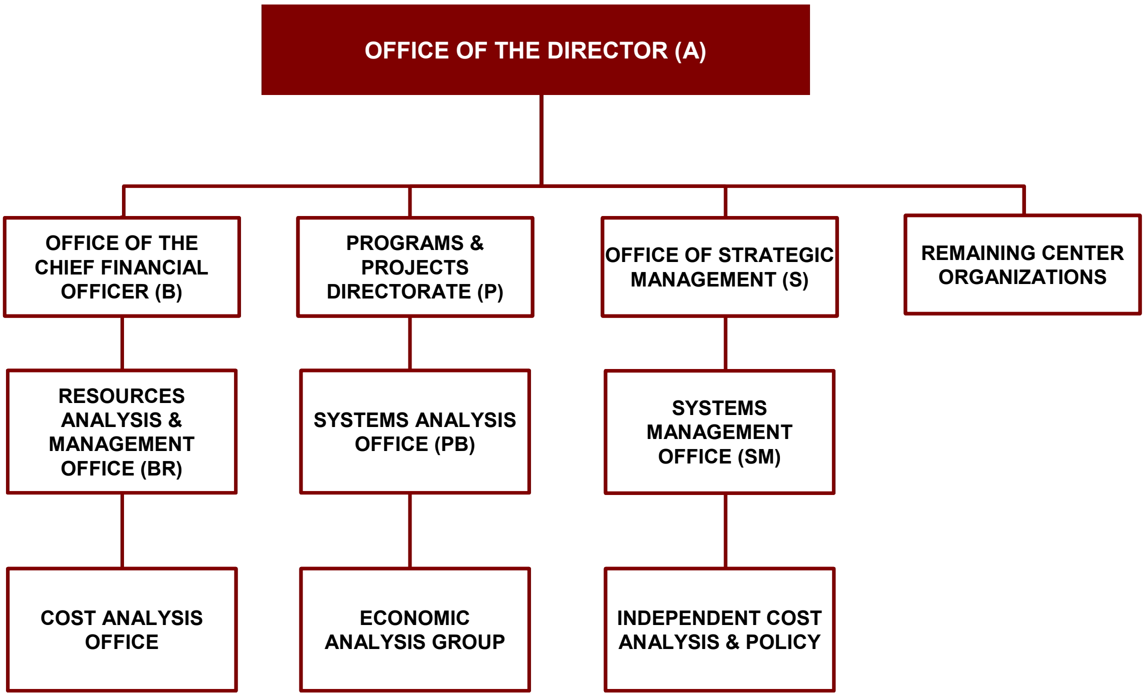
Dryden Flight Research Center
Organizational Chart



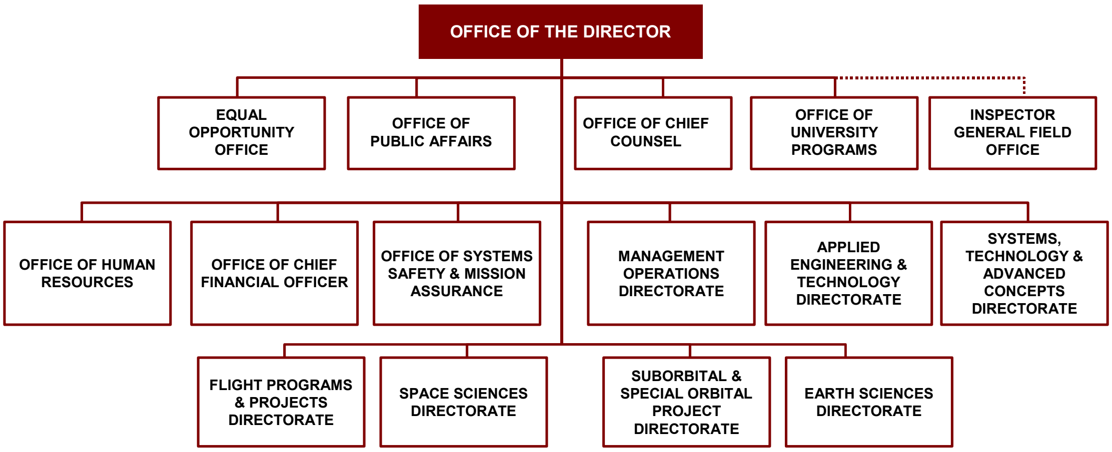
Glenn Research Center Organizational Chart



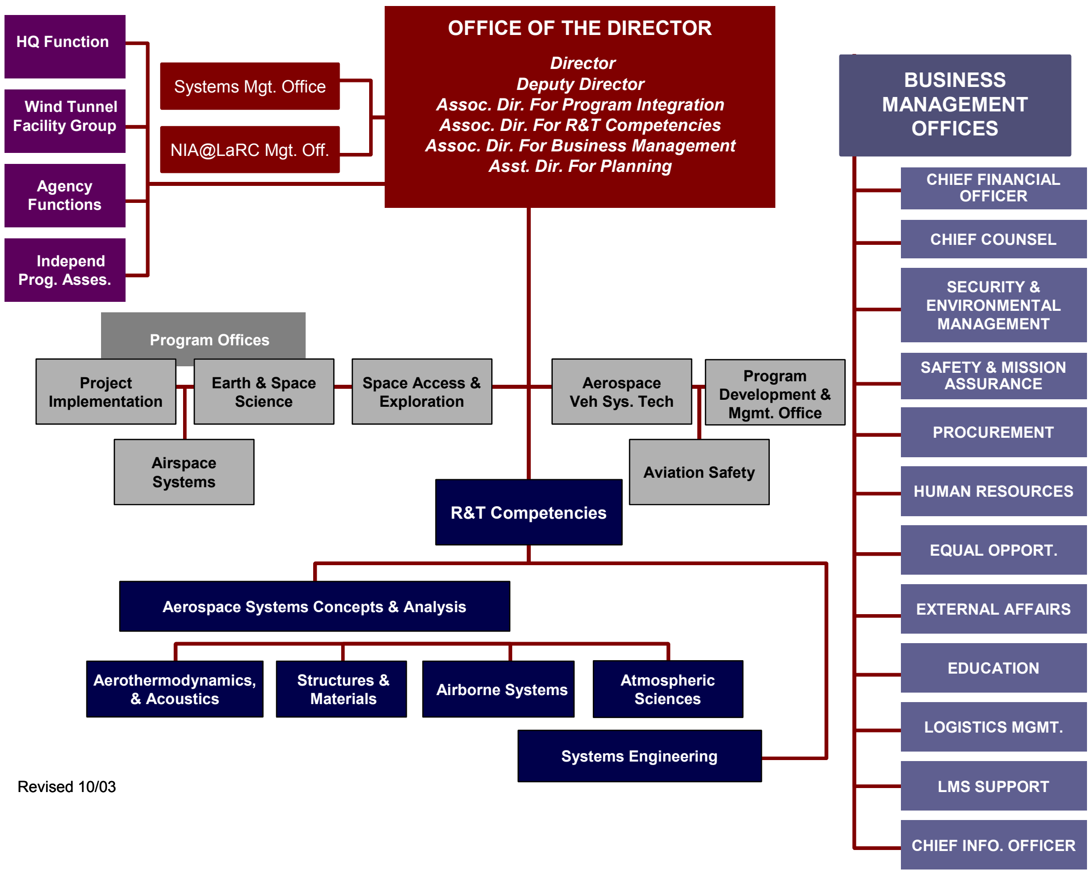
Glenn Research Center Cost and Economic Analysis Organizational Chart



Goddard Space Flight Center Organizational Chart

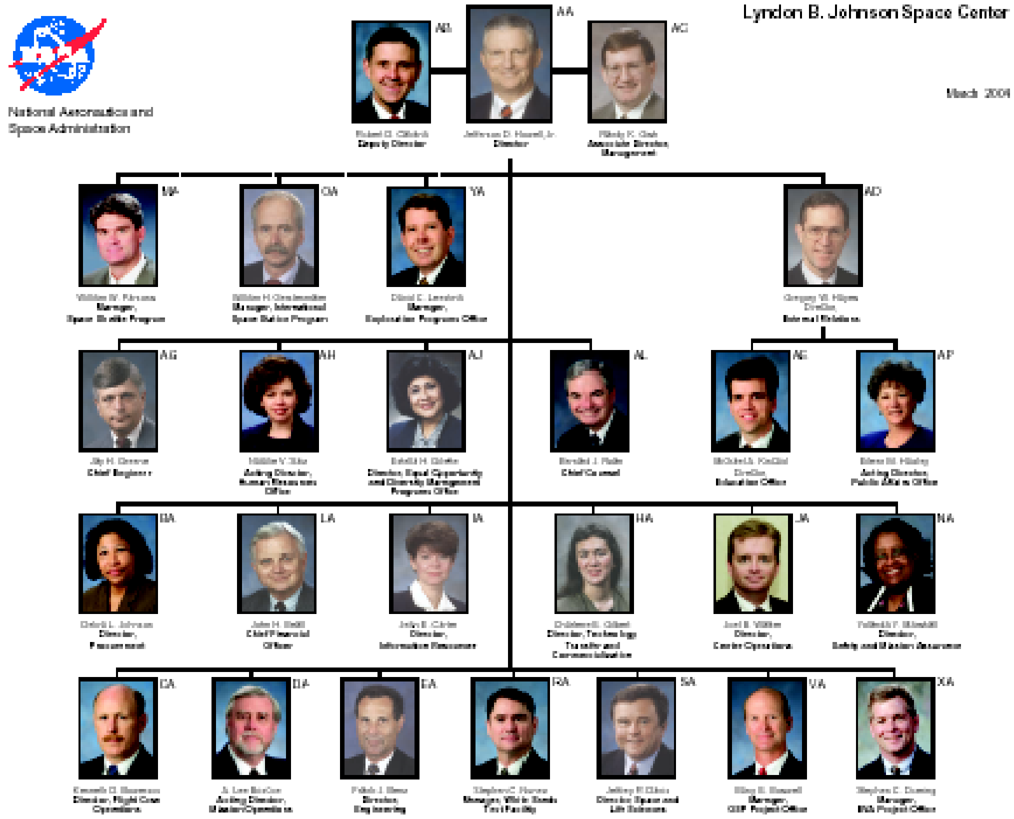


Langley Research Center Organizational Chart

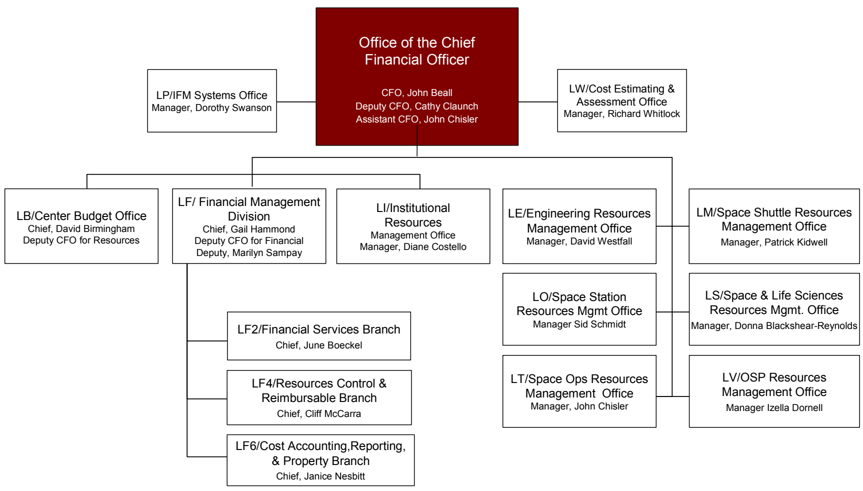


appendix d

Johnson Space Center Organizational Chart

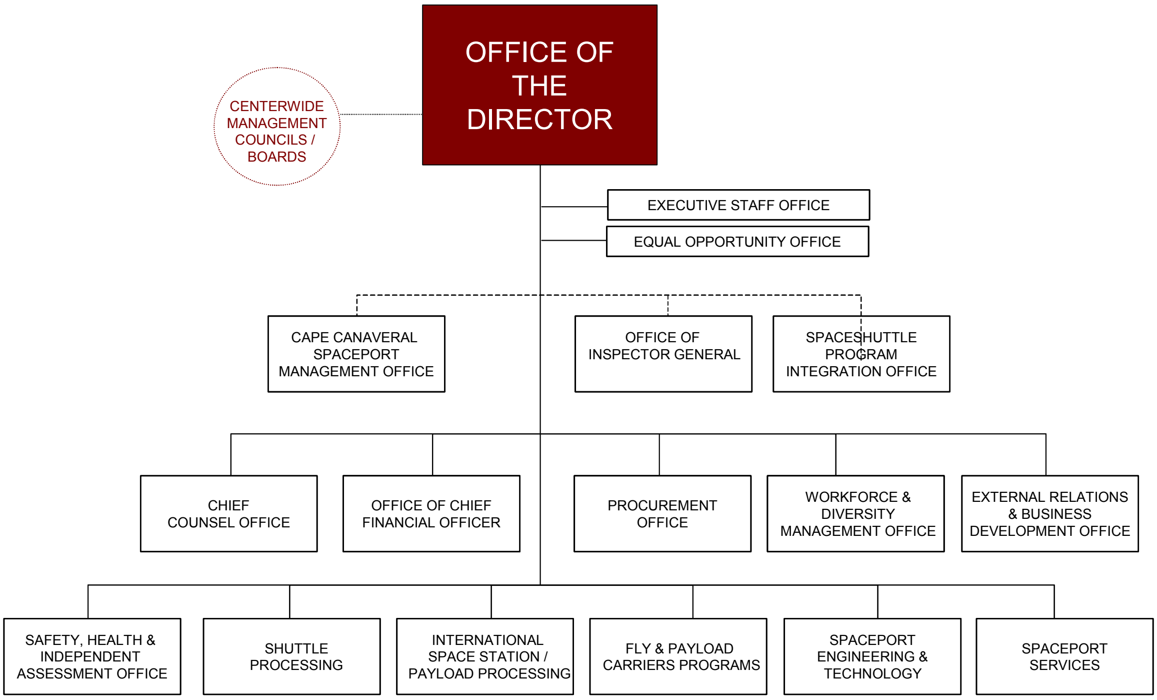


Johnson Space Center Systems Management Office (SMO) Organizational Chart

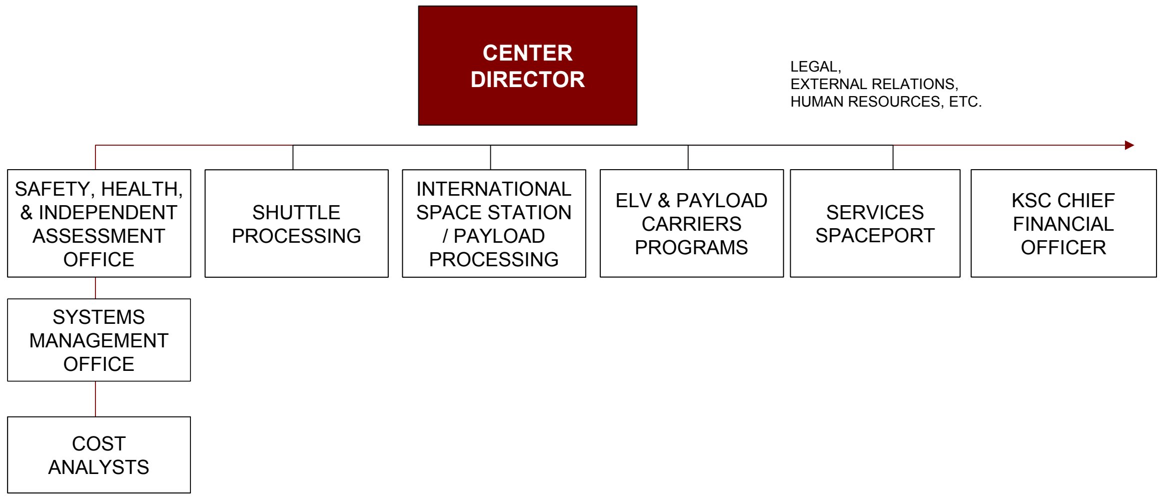


appendix

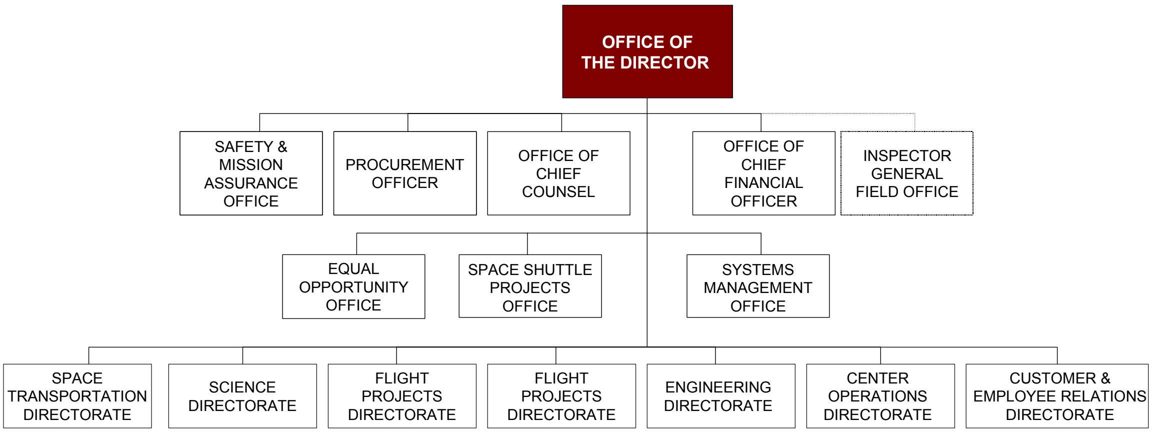
Kennedy Space Center Organizational Chart



Kennedy Space Center Cost Analysts Organizational Chart



Marshall Space Flight Center Organizational Chart



*MANAGERS OF LEAD CENTER PROGRAMS REPORT TO CENTER DIRECTOR

Marshall Space Flight Center Engineering Cost Office Organizational Chart

VS01

SYSTEMS MANAGEMENT OFFICE (SMO)

Office Of The Director

Axel Roth, Acting Director

William H. Nabors (Rip) (Asst. Center Export Control Administrator)
George M. Kozub (Export Control)
Vanita B. Brown (Export Control)
Helen P. Eddleman (Management Analyst)

VS10

Systems Engineering Office

Gerald Flanagan (Gerry), Manager

John W. Brunson
Michelle B. DeLay (Shelley)
Richard F. Gladwin (Rich)
Patrick B. McDuffee (Pat)
Robert L. McKemie (Bob)
Stephen F. Newton (Steve)
Neil E. Rainwater

Contractor Support Onsite

Rachael Thompson
Gene Whitaker
Paul Componation

VS20

Engineering Cost Office

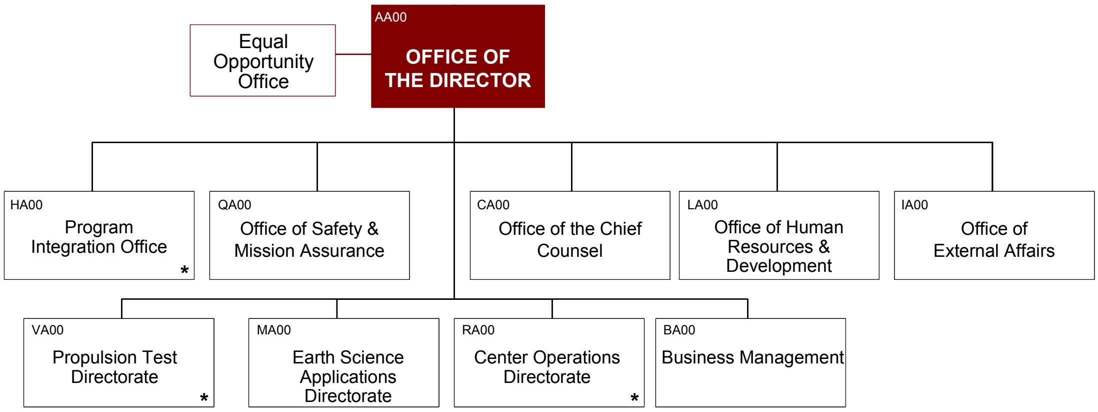
Joseph W. Hamaker (Joe), Manager

Carol A. Lovell (MSA)
Spencer M. Hill
Myron S. May (Scott)
Mahmoud R. Naderi
Frank A. Prince (Andy)
Linda A. Shackelford
Eric J. Shaw
Robert B. Shepard
Barbara A. Stone Towns
Michael E. Vanhook (Mike)
Charles Hunt (Co-op)

Updated 02/2002

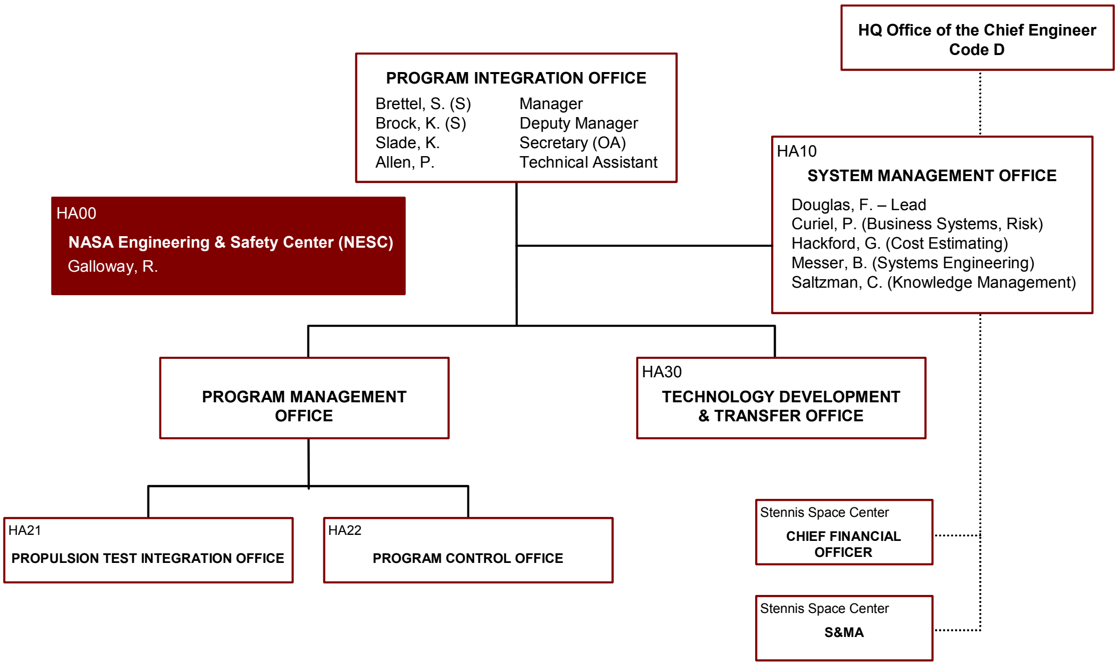
appendix d

Stennis Space Center
Systems Management Office Organizational Chart



*Cost Estimating Function is Distributed within Directorates

Stennis Space Center
Organizational Chart



appendix d

E. NASA Cost Analysis Steering Group (CASG)

The purpose of the CASG is to strengthen NASA's cost estimating standards and practices by focusing on improvement in tools, processes, and resources (e.g., training, employee development). Membership is comprised of senior cost estimating analysts from each NASA Center. The working group is also a forum to foster cooperation and interchange in areas such as sharing models and data across Centers and implementing "lessons learned". The CASG meets three times a year at different NASA locations.

The CASG also sponsors the annual NASA Cost Symposium Workshop which focuses on providing an opportunity for all NASA cost estimators, including support contractors, to present technical briefs on topics such as the status of cost model development, case studies, lessons learned, and other cost analysis research areas. The following section includes the NASA CASG Charter

NASA Cost Analysis Steering Group (CASG) Charter

Version 1.0

1. Purpose

a. This Charter establishes the purpose of the NASA Cost Analysis Steering Group (CASG) in the pursuit of the NASA Cost Vision and Mission. It is the Vision of CASG to be the Agency's forum for sharing space cost policy, standards, and information. Furthermore, it is the Mission of CASG to:

1. Provide the NASA cost analysis community a forum to share and jointly develop tools, methodologies, data, and training in order to make more effective use of scarce resources;
2. Provide decision-makers with credible cost information; and,
3. Promote professionalism, coordinated positions, and continuous improvement in cost analysis policies, standards, and disciplines.

b. Senior representatives from each of the NASA centers (including JPL) are the principal members of the CASG. The CASG is chaired by the Director, HQ Cost Division (Code BC). Membership is augmented as deemed appropriate by the chair.

2. Background

In the mid-90's, several NASA centers interested in resolving space cost analysis problems gathered to address mutual concerns faced by each center. The then-head of Cost Analysis at the Independent Program Assessment Office (IPAO) lead the efforts to create the CASG—addressing collectively the cost issues—that synergy of a corporate approach will bring about improvements and changes to the space cost analysis community.

3. Specific Responsibilities

As the CASG chair, Code BC Director has final approval authority on all matters of the CASG. As a general practice, unanimous consent of the Principals will be sought in the deliberation of the issues.

a. Each Center will fund its own participation under this charter.
b. Each Principal is responsible for sending representation to each scheduled CASG meeting.
c. Each Principal will periodically assume the responsibility of hosting and administering the conduct of CASG meetings. The CASG chair will coordinate the quarterly meetings and its host designation.
d. Principals may invite their support contractors and Federally Funded Research and Development Centers (FFRDCs) to attend CASG meetings and participate as advisors. Support contractors and FFRDCs may be excluded from CASG deliberations in any matters which could be perceived to offer competitive advantages to those firms or which may provide access to proprietary data protected under 18 U.S.C. §1905 unless the FFRDC or contractor has negotiated non-disclosure agreements with the owner(s) of the data as required.

4. Organizational Membership

HQ Cost Division-Chair	JSC
ARC	KSC
GRC	LaRC
GSFC	MSFC
IPAO	SSC
JPL	DFRC

F. NASA Career Development Guide (CDG)

The CDG is under development by Kelley Cyr in the JSC Cost Estimating and Assessments Office for the CASG. This section provides an overview of the CDG in its current draft form. The cost estimating guide is designed to be part of the Financial and Resources Management Career Development Guide available at http://cfoguide.net/cdguide/index.html.

Purpose

- To develop a Career Development Guide (CDG) for the NASA cost estimating community
- To develop the CDG in a format compatible with the Code B Financial and Resources Management CDG

Method

- The Code B Financial and Resources Management CDG was reviewed and the key data requirements were identified (tables in appendices B, D, E and F)
- A survey was conducted of existing training programs for cost estimators
- Data from the training survey was used to develop tables for the CDG

Survey Sources

- NASA CFO Financial and Resources Management Career Development Guide
- NASA Academy of Program and Project Leadership (APPL)
- Defense Acquisition Workforce Improvement Act
- Defense Acquisition University (DAU)
- GSA - Contract Specialist Training Blueprints
- JSC Onsite Course Catalog
- BLS Occupational Outlook Handbook: Cost Estimators
- SCEA Professional Development Program
- OPM Operating Manual for Qualification Standards;
- DOD Contract Pricing Reference Guides
- SCEA Professional Certification Program
- Cost Estimator's Reference Manual
- NASA Cost Estimating Handbook
- JSC Cost Estimating Announcements and Position Descriptions
- KSC Competency Management System

Process

- The intent is to develop documentation that will copy and paste directly into the Code B CDG as a revision, which will then be posted on the internet.
- The major revisions are in appendices B, and D through F.
- Once the appendices are complete, the whole documentation package will be sent out for review to the cost steering group.
- The comments from the review will be incorporated and a second draft will be completed.
- The second draft will be provided to the headquarters CFO for review and approval.
- Once approved, the revision package will be provided to the team responsible for maintaining the Code B CDG.
- They will make the necessary revisions and post the revised CDG on the IFMP web site.
- After the revised CDG is posted, we will notify the cost estimating community where to find it.

Overview

- One job category is defined: cost estimator.
- Four career stages are defined, consistent with the Code B CDG: entry, journey, senior, and executive.
- The four general competencies are defined in the Code B CDG
- Six technical competencies for cost estimating are defined
- For each career stage and technical competency, the knowledge/skills and learning objectives have been defined.

Career Stages

- The NASA financial and resources management career development model consists of four career stages, reflecting increased responsibilities and performance expectations. The career development model defines the technical competencies using these stages:
  - **Entry**: performs fundamental, basic and routine activities while gaining subject matter expertise.
  - **Journey**: functions independently and applies knowledge and experience to variety of complex situations.
  - **Senior**: senior specialist/analyst, team leader, or supervisors -- a recognized expert with broad scope of responsibility and high visibility.
  - **Executive:** executive position is responsible for installation or agency-level policy and implementation.

General Competencies

- General Competencies apply to the performance of all job categories, regardless of specific duties. Therefore, regardless of job position or organizational level, General Competencies apply to everyone in the NASA financial and resources management community.

- NASA has identified the following four broad General Competency categories that apply to all members of the NASA financial and resources management community as:
  - Leadership
  - Critical Thinking
  - Individual
  - Business Relationships

Technical Competencies Code B Model (Example)

- Business Resources Management
  - General Budgeting Concepts and Principles
  - Budget Preparation and Execution
  - Program/Project Management and Control
  - Internal Control Systems, Policies and Procedures
  - Automation Principles, Methods, Techniques and Systems

Technical Competencies Code B Model (Example)

- Financial Management
  - General Accounting Concepts, Principles and Business Practices
  - Federal Accounting Concepts and Standards
  - Agency Financial Accounting Policies and Procedures
  - Internal Control Systems, Policies and Procedures
  - Automation Principles, Methods, Techniques and Systems

Technical Competencies Cost Estimating

- Cost Estimating
  - Cost Estimating and Analysis
  - Business Management
  - Program/ Project Management
  - Science & Engineering
  - Personal & Professional Effectiveness
  - Computer & Information Technology

Plan Summary

Cost Analysis Career Development

Cost Estimating & Analysis

	1st Year	Fundamentals of Systems Acquisition Management
	2nd Year	Fundamentals of Earned Value Management

	1st Year	Intermediate systems Acquisition Management
	2nd Year	Intermediate Earned Value Management

	1st Year	Software Cost Estimating
	2nd Year	Cost Risk Analysis

	1st Year	
	2nd Year	

Business Management

	1st Year	Federal Budget
	2nd Year	Appropriations Law

	1st Year	Acquisition
	2nd Year	

	1st Year	Business Cost
	2nd Year	

	1st Year	
	2nd Year	

Program / Project Management

	1st Year	Foundations of Project Management
	2nd Year	

	1st Year	Project Management
	2nd Year	Systems Management

	1st Year	
	2nd Year	Advanced Project Management

	1st Year	Program Management
	2nd Year	

Space & Engineering

	1st Year	Understanding Space
	2nd Year	
	1st Year	Fundamentals of Orbital & Launch Mechanics
	2nd Year	Space Mission Analysis & Design
	1st Year	Human Spaceflight Mission Analysis & Design
	2nd Year	Space Launch & Transportation Systems
	1st Year	
	2nd Year	

Personal & Professional Effectiveness

	1st Year	Time Management
	2nd Year	Communication Skills
	1st Year	Teamwork Skills
	2nd Year	Teamwork Skills
	1st Year	Leadership & Supervisory Skills
	2nd Year	Leadership & Supervisory Skills
	1st Year	Management Education Program
	2nd Year	Managing the Influence Process

Computer & Information Technology

	1st Year	Basic Office Applications
	2nd Year	Hardware Cost Models
	1st Year	Advanced Office Applications
	2nd Year	Software Cost Models
	1st Year	
	2nd Year	Life Cycle Cost Models
	1st Year	
	2nd Year	

G. Standard Work Breakdown Structure (WBS) Examples

appendix g

JPL STANDARD FLIGHT PROJECT WBS

PROJECT NAME		
PM-01 Dictionary		
01	Program Management	
	01.01	Proj. Management
	01.02	Business Management
	01.03	Risk Management
PSE-02 Dictionary		
02	Project System Engineering	
	02.01	Project System Engineering
	02.02	Mission & New Design
	02.03	Proj SW Engineering
	02.04	Configuration Management
	02.05	Information System Engineering & Communication
	02.06	Configuration Management
	02.07	Planetary Protection
	02.08	Launch Approval Engineering
	02.09	Launch System Engineering
	02.10	Project V&V
MA-03 Dictionary		
03	Mission Assurance	
	03.01	Mission Assurance Management
	03.02	System Safety
	03.03	Environmental Engineering
	03.04	Reliability Engineering
	03.05	Parts Engineering
	03.06	QA Enginering
	03.07	SW IV&V
	03.08	Mission Operations Assurance

WBS 1 (black) WBS 2 (blue) WBS 3 (purple) WBS 4 (yellow)

SCI-04 Dictionary

04	Science	
	04.01	Science Management
	04.02	Science Implementation
	04.03	Science Support
	04.04	Education & Public Outreach

PL-05 Dictionary

05	Payload System	
	05.01	Payload System Management
	05.02	Payload System Engineering
	05.03	Payload System Product Assurance
	05.04	Payload System CC and MAP
	05.05	Inst 1
	05.06	Inst 2 (contract)
	05.07	?
	05.08 – 05.19	Reserved Inst.
	05.20	Technical Payload
	05.21 – 05.29	Reserved Payload
	05.30	Sci Inst Purge SS
	05.31	?
	05.32	?

FS-06 Dictionary

06	Flight System			
	06.01	Flight System Management		
	06.02	Flight System Engineering		
	06.03	Flight System Prod Asst		
	06.04	Flight System CC and M&P		
	06.05	Flight System Module 1 (in house)	Flight System Module 2 (sys contract)	
	06.05.01	Mgmt	06.05.01	Sys Contract
	06.05.02	System Engineering	06.05.2	Sys Contract Mgmt
	06.05.03			
	06.05.04			
	06.05.05			
	06.05.06			
	06.05.07			
	06.05.08			
	06.05.09			
	06.07 – 06.10	Reserved Flight System Modules		
	06.11	Flight System ?		
	06.12	Flight System I & T		

WBS 1 WBS 2 WBS 3 WBS 4

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MOS – 7 Dictionary		
07	Mission Ops Sys	
	07.01	Mission Ops Sys Management
	07.02	Mission Ops Sys Engineering
	07.03	? Data Sys
	07.04	? MOS & CDS
	07.05	Operations
	07.06	MOS V&V
LS – 08 Dictionary		
08	Launch Systems	
	08.01	Launch Services

WBS 1 WBS 2 WBS 3 WBS 4

NAFCOM LV SMALL

- Two Stage Vehicle
  - Stage 1
    - Stage 1 Subsystems
      - Structures & Mechanisms
        - Vehicle Structures & Mechanisms
        - Tank Structure & Mechanisms
      - Thermal Control
        - Operations
      - Main Propulsion Systems (less engines)
      - Electrical Power and Distribution
      - Command, Control & Data Handling
    - Stage 1 System Integration
      - Integration, Assembly and Checkout (IACO)
      - System Test Operations (STO)
      - Ground Support Equipment (GSE)
        - Tooling
        - M/E GSE
      - System Engineering & Integration (SE &I)
      - Program Management (PM)
      - LOOS

appendix g

- Stage 2
  - Stage 2 Subsystems
    - Structures & Mechanisms
      - Vehicle Structures & Mechanisms
      - Tank Structure & Mechanisms
    - Thermal Control
      - Environmental / Active Thermal Control
      - Induced Thermal Protection
      - Tank Thermal Control
    - Reaction Control Subsystem
    - Main Propulsion System (less engines)
    - Electrical Power and Distribution Group
    - Command, Control & Data Handling
    - Guidance, Navigation and Control
  - Stage 2 System Integration
    - Integration, Assembly and Checkout (IACO)
    - System Test Operations (STO)
    - Ground Support Equipment (GSE)
      - Tooling
      - M/E GSE
    - System Engineering & Integration (SE&I)
    - Program Management (PM)
    - LOOS

NAFCOM SPACECRAFT SMALL

- Unmanned Outer Planetary Spacecraft
  - Orbiter
    - Orbiter Subsystems
      - Structures & Mechanisms
      - Thermal Control
      - Reaction Control Subsystem
      - Electrical Power and Distribution
      - Attitude Determination & Control
      - Apogee Kick Motor
    - Orbiter System Integration
      - Integration, Assembly and Checkout (IACO)
      - System Test Operations (STO)
      - Ground Support Equipment (GSE)
        - Tooling
        - M/E GSE
      - System Engineering & Integration (SE&I)
      - Program Management (PM)
      - LOOS)
  - Probe
    - Probe Subsystems
      - Structures & Mechanisms
      - Thermal Control
      - Electrical Power and Distribution
      - Command, Control & Data Handling
    - Probe System Integration
      - Integration, Assembly and Checkout (IACO)
      - System Test Operations (STO)
      - Ground Support Equipment (GSE)
        - Tooling
        - M/E GSE
      - System Engineering & Integration (SE&I)
      - Program Management (PM)
      - LOOS
  - Scientific Instruments
    - Scientific Instruments Subtotal
      - Active Mirowave
      - Charge & X-Ray Detection

H. NASA Cost Data Requirement Descriptions (DRDs)

appendix h

Cost Analysis Data Requirement (CADRe)

In the upcoming era of ambitious space exploration projects, cost credibility with Congress and the Administration will play a critical role. NASA Project Managers and their staffs are the key members of the management team structure that will ensure that projects meet budget, technical and schedule constraints. Project Managers must receive more accurate, comprehensive, and timely data from their industrial partners in order to identify potential cost, technical and schedule risks at the earliest possible time and to initiate timely remediation activities.

The CADRe has been developed to combine and streamline the contents of several separate DRDs into one comprehensive and internally consistent data requirement in an effort to provide better information to both the Project Manager and to NASA Independent Assessment organizations. A further benefit derived from the CADRe is its built-in requirement for end-of-contract actual costs and technical parameters (by WBS element) used to update NASA cost models.

The CADRe is a hybrid requirement that is unique but equivalent to two previously used DRDs - the Cost Analysis Requirements Description (CARD) and Life Cycle Cost Estimate (LCCE) by combining their key elements in a single, coordinated report. The CADRe, like the CARD, is “owned” by the project manager, although populating most of its content can be a contractual requirement. While it does not incorporate the Work Breakdown Structure (WBS) DRD, the information contained in the CADRe DRD must conform to the approved project WBS in order to ensure that each and every element of the entire project is included.

Part A of the CADRe is a narrative description of the project including both technical and programmatic elements, supported by graphics and tables as appropriate. Part B is a tabular summary of technical parameters organized in accordance with the Work Breakdown Structure. Life Cycle Cost Estimate data is contained in Part C. The CADRe will be structured to allow physical separation of the LCCE data (Part C) when the intended use is to support an Independent Cost Estimate (ICE) where knowledge of the project LCCE is inappropriate for the IPAO (or other) team performing the ICE.

Initial delivery of the CADRe will occur at the end of Phase B, with subsequent deliveries at major milestones (PDR, CDR, FRR, etc.), but at least annually.

I. NASA Cost Estimate Briefing Template

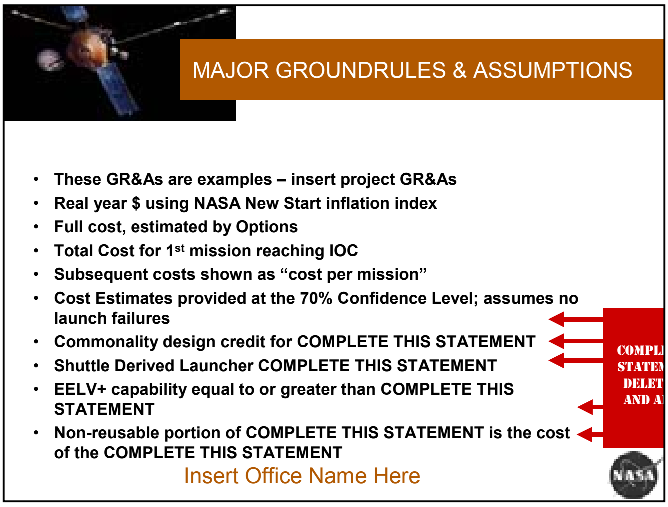
This 5-page template is provided for your use to increase the consistency of the way briefings are presented at NASA by standardizing the introduction. There are 5 standard slides that should be included at the beginning of a cost estimate briefing. This template provides the recommended standard format that can be customized. In this section a view of each slide is shown. In the actual Power Point template the instructions from each page can be deleted and you can double click on each item to customize the chart. The .ppt template is available for download on the ceh.nasa.gov web site.

Cover: This cover can be customized with the project details and an image of the product being estimated.

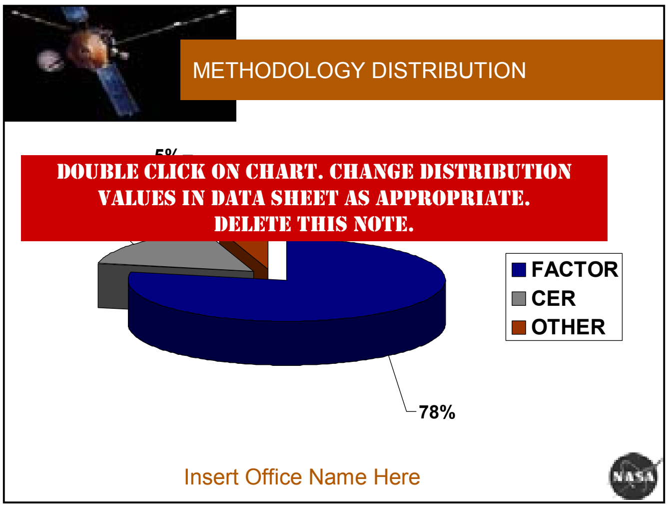
Slide 1: This slide should communicate the key points that explain the scope and purpose of the estimate.

appendix i

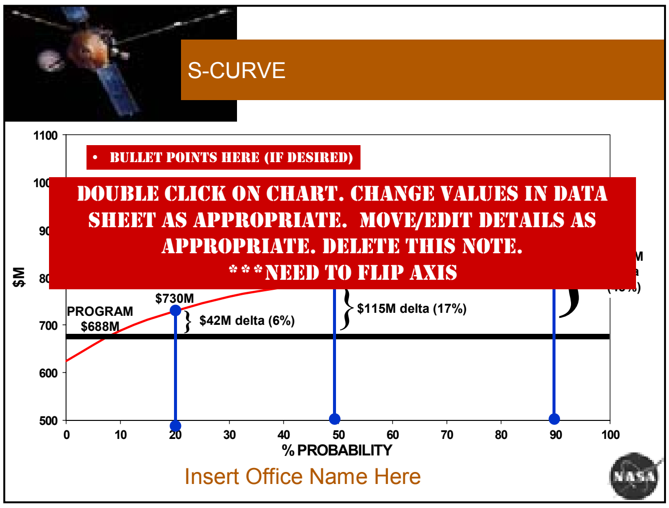
Slide 2: This slide should communicate the major Ground Rules & Assumptions for the estimate.



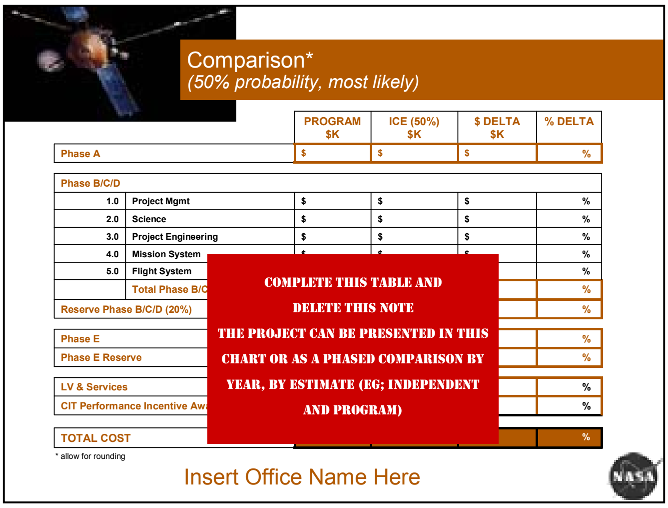
Slide 3: This slide should show the methodologies used for the estimate. For overview purposes, a graphical representation by percentage of the estimate in each methodology is acceptable.



Slide 4: This slide should show the S curve for the estimate, demonstrating the range values and can also include the CRL calculation results.



Slide 5: This chart shows the estimate summary and comparison to any other estimates such as an ICE, if applicable. Charts showing more detail in the estimate can be provided, depending on the purpose of the briefing. The idea with this chart is to show the bottom line overall estimate and comparison on one chart for quick reference and understanding.



J. IPAO Cost Estimate Sufficiency Review Checklist

Version 1a

This is a checklist to review project office cost estimate for reasonableness, completeness, consistency, and compliance with generally accepted estimating processes. The end result of the sufficiency review will provide decision makers with an assessment on the quality of the cost estimate. Attachment A is the sample report. Attachment B is a list of detail questions and it will serve as a repository of other questions and “lessons learned” matters.

Standards we look for:

1. Traceability. Information presented in a traceable fashion containing supporting documentation and technical data. IPAO cost estimator must be able to trace with the given information.
2. Reasonableness. Information presented in a logical manner with appropriate analogies and cost estimating relationships (CERs).
3. Soundness. Information, assumptions, and recommendations presented must be sound arguments. IPAO cost estimator will carefully consider expert judgments or assumptions.
4. Verification. Information presented must be verifiable by the IPAO cost estimator. The IPAO cost estimator will check databases that were used to verify the technical parameters on the cost elements.
5. Validity. Information presented must be logically correct, justifiable, and well-grounded. The IPAO cost estimator will review the groundrules and assumptions.
6. Accuracy/Consistency. Information presented is well organized, cohesive, supportable, and easily understood.
7. Completeness. Information presented must contain all necessary data, assumptions, and pertinent information.

How we assess cost estimates:

1. Receive the project cost estimate from the project office. What constitutes “project cost estimate”: documentation that contains the numeric tables with all supporting narrative (in softcopy).
2. Check the administrative information. Who prepared the estimate? For what purpose was the project office estimate generated? How much effort (staff months) did it take to do the estimate? What was the cost estimating schedule? Is this estimate a new estimate or an update of a prior estimate? Has anyone else reviewed this estimate or the prior estimate and what were the findings?
3. Review of the presence of the cost estimate documentation. This is to verify that in fact there are adequate “materials” to conduct the sufficiency review. Is the documentation organized according to the WBS—if not, a logical manner that will

provides structure for the IPAO cost estimator to follow. Are prior costs documented? Are the narratives explaining the estimating methodologies understandable? Are there pertinent historical information and project funding data? Are there supporting data or documentation available for those elements requiring further verification? Are the WBS definitions available? Can the IPAO cost estimator "replicate" what was done in the project office estimate—from the documentation?

4. Assuming a reasonable level of documentation is present, the next step is to conduct the traceability from the final cost estimate "rollup'ed" number to the appropriate level that show the basis of the estimate. The IPAO cost estimator will select a cost element and "drill down" to the basis of the estimate. The drill down process depends on the cost element and how it is "bucketed" and "estimated." Generally, the estimator will literarily track the number from one spreadsheet or chart to another and in the process "decompose" the summation number until we reach a satisfactory level where the estimate is understood.
   a. As a guideline, the IPAO cost estimator will target the high cost, high risk, and high interest cost elements. Depending upon the project, this may fall into the 80/20 rule, where 80% of the cost resides in 20% of the cost elements.
   b. Which cost elements are "pass through" elements?
   c. Once the cost elements are selected, the IPAO cost estimator will drill down each element tailored to its component or system.

5. There are many questions an estimator can ask to understand the cost estimate. These are suggested questions to be asked in a drill down exercise—this is not an inclusive list:
   a. Are the costs rational to prior actual costs?
   b. Are the ground rules and assumptions reasonable?
   c. Are the learning curve (if applicable) and slopes reasonable?
   d. Were historical data used?
   e. Were correct inflation rates used?
   f. Were appropriate methods used? Is the estimate reflecting analogies and databases that are within realm of reasonableness, such as technology, platforms, etc?
   g. Are the data points/range used in the cost estimate relevant?
   h. Are all pertinent costs included?
   i. Are costs time-phased over the fiscal years? Both inflated and non-inflated dollars? What is the method of time phasing the point estimate? Is the project schedule consistent with cost estimate schedule used in the phasing?
   j. Were analogous direct and overhead rates used?
   k. Did the estimate capture applicable full cost?
   l. Is appropriate cost risk analysis performed? Did the estimate capture the risks?
   m. Did the estimate cover the "scope" of the program in review?
   n. Did the estimate identify which cost elements were estimated and pass-throughs?
   o. Did the estimate provide a cumulative distribution curve (S-curve)?

6. The IPAO cost estimate will submit an IPAO Sufficiency Review Report (see appendix A). The report will consist of:
    a. Executive summary (1-page) which will provide the cost estimate confidence level, via the Cost Readiness Level (CRL) and the rationale accompanying the assessment.
    b. Detail report.

ATTACHMENT A

IPAO Cost Estimate Sufficiency Report (SR)

PART ONE:

Project Name:

IPAO Reviewer:

Purpose of the SR: (example) This SR was done in conjunction with the project NAR.

Executive Summary:

1. Cost Readiness Level (CRL) of the cost estimate:
2. Bullet summary of the SR.

PART TWO:

Detail report (the level depends on the scope of the cost estimate)

- Traceability. Assessment and justification.
- Reasonableness. Assessment and justification.
- Soundness. Assessment and justification.
- Verification. Assessment and justification.
- Validity. Assessment and justification.
- Accuracy/Consistency. Assessment and justification.
- Completeness: Assessment and justification

(This list should be expanded with other questions tailored to your project.)

ATTACHMENT B

Risk related questions:

Have costs for discrete, identified risks been captured?
How were inputs to cost-risk models (e.g., @Risk) developed?
Were engineers consulted in the definition of the level of risks?
Was CER, technical and correlation risk captured?
Was both probabilistic and discrete risk analysis performed?
Were the cost-risk distributions used justifiable?
Were provisions for unknown-unknowns made in the estimate?
Was schedule risk quantified along with cost-risk?
Can the cost-risk analysis answer the questions: How many dollars are included to cover discrete risks?
What are the risky WBS elements?
What is the likelihood of an overrun?
Schedule related questions:

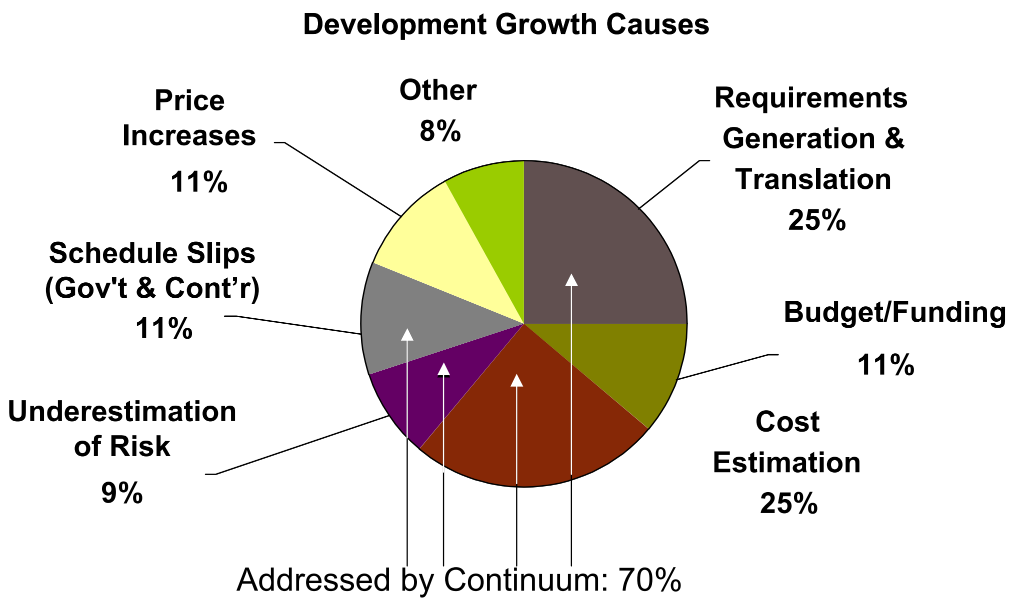
K. Cost Growth

Applying the triple constraint concept introduced in Section 2 of the NASA Cost Estimating Handbook, (see Exhibit K-1 below), the NASA cost estimator works with the project manager and other project representatives throughout the life cycle phases to identify project priorities and then balance those priorities to reach a solution that optimizes performance, benefits, and costs, while minimizing risks. Utilizing tools and techniques at his/her disposal, the NASA cost estimator performs trade-off studies, economic analyses, cost benefit analyses, etc., to demonstrate to the project team the optimum mix of costs versus risks, risks versus benefits, and costs versus technical and schedule constraints.

As shown in Exhibit K-2, the typical project's cost rise exponentially during life cycle phase D and phase D and E. Underestimation of risk is one of many factors that contribute to cost growth on projects. Exhibit K-2 also shows that another contributing cost growth factor is cost estimation. *This is not to say that 25% of cost estimates cause cost growth, but rather that after reviewing quantitative project data, it was found that 25% of the perceived cost growth in a project was due to cost estimates that did not fully capture the entire project's cost.*

Triple Constraint Concept

appendix k



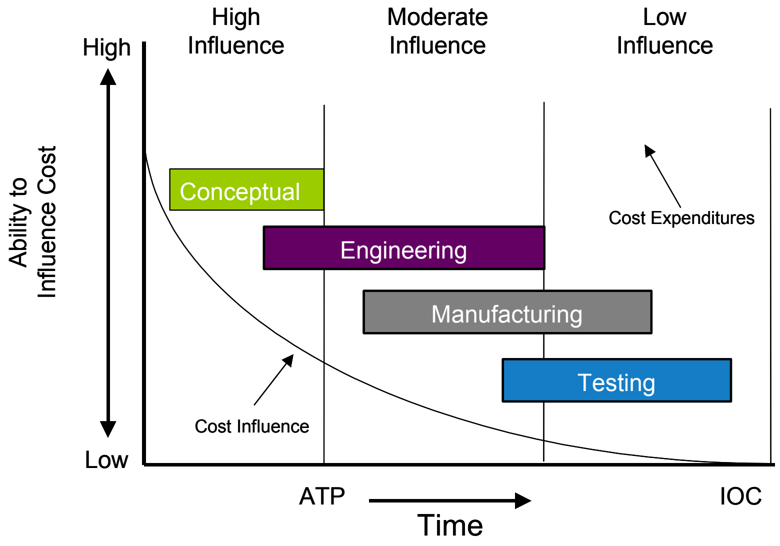
Quantitative Framework
"The Success Triangle of Cost, Schedule, and Performance: A Blueprint for Development of Large-Scale Systems in an Increasingly Complex Environment" (Booz Allen Hamilton, 2003)

Exhibit K-2
Typical Project Cost Trajectory Over Time

A thorough examination of risks is essential to identifying, managing, and controlling cost drivers. Exhibit K-3 illustrates the influence or leverage cost estimating has over the life cycle of a space program. In the long run, a risk adjusted cost estimate is more realistic and can be a more influential project tool.

NASA completed a cost growth study in early 2004. The analytic approach compared initial and final budget estimates of the development costs for 45 recent projects and computed percent budget growth as a surrogate for cost growth. Selected projects are predominantly Space Science projects, since these are the easiest projects for which one can develop a budget trace. "Recent" generally means missions flown since 1996. All projects were initiated in 1990 or later and four-fifths of the projects were initiated in the last ten years. Data came mostly from historical NASA budget documents; other data came from other NASA archives and Internet documents.

In determining the results of NASA cost growth, the analysis in the study did not correct for content change. Many NASA projects were and are able to constrain budget growth by eliminating science requirements. Thus, budget growth is not a true representation of cost growth. The analysis did not adjust for inflation. Cost growth is usually calculated using same-year constant-dollar estimates and actuals.



Most cost leverage exists prior to ATP

Exhibit K-3:
Cost Greatest Leverage is Early in the Life Cycle

Budget documents do not provide constant-dollar estimates, and inflation assumptions change yearly, making suspect any attempts to adjust budget dollars to constant dollars a posteriori, especially the initial budget estimate. The study attempted to capture only implementation budgets. In general, the budget data should be only for the implementation phase, although not all budget documents were clear on the content in budget lines. It is possible some growth represents an increase in content, e.g., including launch costs in development budgets.

The results of the study were that average cost growth at NASA is:

- 36% arithmetic mean - this statistic is the average of percent budget growth on individual projects.
- 45% dollar-weighted mean - this statistic is the average of percent budget growth on individual projects weighted by final budget amount. Thus, some of the more expensive projects experienced considerable budget growth.
- Median growth: 26% - 35 of 45 projects exceeded the initial budget estimate.
- Total growth: 28% - this statistic is the relative change from the total of the 45 initial budgets to the total of the 45 final budgets.
- Recent NASA cost growth is about *30%.*

Exhibits K-4 and K-5 show graphical representations of these budget growth results.

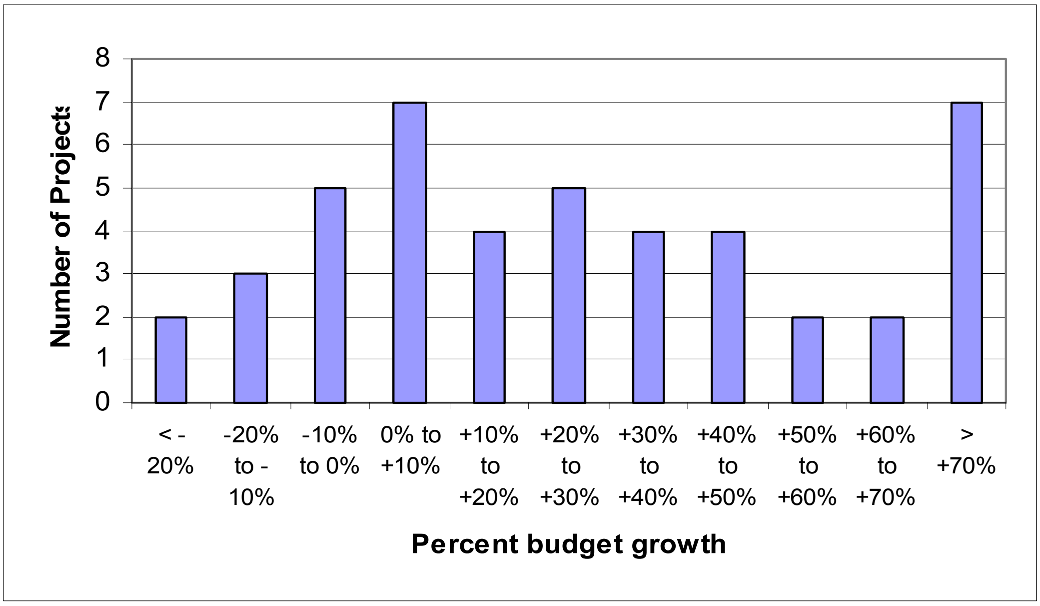


Exhibit K-4:
Distribution of NASA Budget Growth

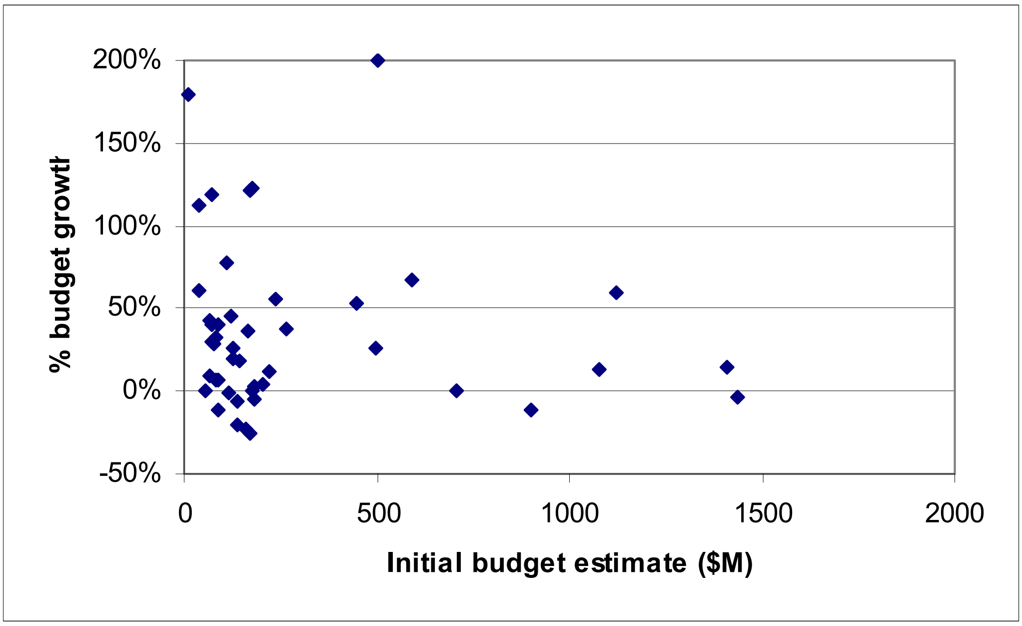


Exhibit K-5:
NASA Budget Growth Versus Project Size

appendix k

There are ways NASA can improve the process to help avoid cost growth. Some of the lessons learned and cost-estimating process changes instituted by DoD include:

- Establishment of an independent cost group with a mandate to develop independent estimates prior to program approval;
- Creation of a formal document for recording key technical, schedule, and programmatic assumptions—the CARD;
- Periodic collection of contractor cost data;
- Requirement of a rigorous cost-risk analysis to put the point estimate in perspective;
- Formal documentation of the process changes; and
- In addition, DoD has introduced program-management tools for better managing to cost estimates, such as EVM and CAIV.

Many changes are in the works:

- Independence - NASA already has an independent group in the IPAO. IPAO conducts independent assessments of both cost and technical aspects of the program.
- An update to NPR 7120.5C is nearing release that will codify the requirement for an IPAO project review prior to the two key project milestones: Phase A-to-B and Phase B-to-C transition.
- The new NPR 7120.5 will also codify requirements for a CARD, standardized work breakdown structures, cost-risk analysis, EVM, CAIV, and a full continuum of sound cost- and program-management practices in the form of Project Continuous Cost-Risk Management.
- CARD, Cost-Risk Analysis, and Cost Management
- Code H will develop training tools for program managers to understand these new requirements and practices.

What made this study of cost growth so difficult to conduct was the lack of a standardized format for recording (at a reasonable frequency) project cost, technical, and schedule data. Code BC is addressing this issue by developing consistent data requirements for contractor data that will be incorporated at contract award. The data must be consistent across the life of the program so that analysts can evaluate the data across the years without ambiguity. The depth at which the data will be required and collected (i.e., the level of WBS) will be dependent on the maturity of the program.

L. COTS, GOTS, & Center Unique Tools & Methods

Model Name (Title)	Description
Advance Missions Cost Model (AMCM)	Provides ROM estimates for the development and production of spacecraft, space transportation systems, aircraft, missiles, ships and land vehicles.
Aircraft Turbine Engine Cost Model (ATECM)	Estimates the development and production costs and time of arrival of aircraft turbine engines.
Airframe Cost Model	Estimates the development and production costs of aircraft airframes that is suitable for use in a program's conceptual stage when little detailed information is available.
AATe - Architectural Assessment Tool - enhanced	Combination database and knowledge base. A conceptual design phase tool best used in comparing multiple concepts with level assumptions.
Army Military-Civilian Cost System (AMCOS)	AMCOS is a user-friendly, PC-based tool used to support military and civilian cost estimation.
Ask Pete	http://osat-ext.grc.nasa.gov/rmo/pete/
Automated Cost Estimating Integrated Tools (ACEIT)	ACEIT helps analysts store, retrieve, and analyze data; build cost models; analyze risk; time phase budgets; and document cost estimates.
Best Estimate	Estimator for renovators & remodelors general contractors, design/builders, architects & designers.
Building Estimator's Reference Book	This manual covers updated construction methods, material and labor costs, labor productivity (man-hours), construction finance, scheduling, construction management, bidding, negotiating contracts, value engineering, types of cost estimates, overhead, insurance, profit, change orders, and more.
C Risk (A Cost Risk Analysis Tool)	Analytic (rather than a Monte Carlo simulation) risk analysis package. Requires minimal inputs compared to other risk models (best estimate, standard error of estimate, % of new technology).
Cobra	Wellcom system for managing schedules, measuring earned value and analyzing budgets, actuals and forecasts.

Model Name (Title)	Description
COCOPRO	Implements Boehm's COCOMO technique for estimating costs of software projects. It supports the intermediate COCOMO model, and allows automatic calibration of the model to a cost history database.
CODECOUNT(TM)	The CodeCount toolset is a collection of tools designed to automate the collection of source code sizing information. the CodeCount toolset spans multiple programming languages and uses one of two possible Source Line of Code (SLOC) definitions, physical or logical.
Composites Affordability Initiative Cost Analysis Tool (CAICAT)	Rapid cost evaluation system for an airframe structure.
Constructive Cost Model (COCOMO) II	An open box software cost estimating tool created by Barry Boehm and his staff.
Consumer Price Index (CPI) Inflation Calculator	Calculator for adjusting cost of living from one year to another using the Consumer Price Index (CPI) inflation index.
COOLSoft	Uses a hybrid of intermediate and detailed versions of COCOMO. This allows for the reuse of existing code, development of new code, the purchase and integration of third party code, and hardware integration.
COSMIC	Over 810 computer programs that were originally developed by NASA and its contractors for the U.S. space program.
Cost Analysis Strategy Assementment (CASA) Model	Life Cycle Cost (LCC) decision support tool. CASA can present the total cost of ownership depending on user selections: including RDT&E costs, production costs, and operating/support costs. CASA covers the entire life of the system, from its initial research costs to those associated with yearly maintenance, as well as spares, training costs, and other expenses.
Cost Estimating Cost Model	Estimates the cost of doing estimates for Deep Space Network (DSN) projects.
CostLink	A detailed cost estimating tool that can be customized to incorporate an organization's work breakdown structure and the detailed tasks associated with a project, enabling swift development of detailed estimates that can be converted to MS Project® Schedules. It has been customized to incorporate Stennis' WBS and used to establish a PTD Cost Book which defines available pools and task specific resources available at SSC. CostLink® is a product of Building Systems Design, Inc

Model Name (Title)	Description
Cost of Manpower Estimating Tool (COMET v2.0)	A software database and cost estimating tool which provide users with the O&S estimates for the cost of Navy manpower.
Cost Spreading Model	This is a simple online cost spreading calculator that can be used to spread the estimated cost of a program up to 8 years.
Cost Track	Integrated cost/project management software package.
Cost Xpert	Software costing tool calculates information including project costs, schedules, tasks, deliverables, maintenance, and support requirements.
Costar	To produce estimates of a project's duration, staffing levels, effort, and cost.
COSTIMATOR	Computerized cost estimating and process planning for manufacturing.
Crystal Ball	Choose a range for each uncertain value in your spreadsheet. Crystal Ball uses this information to perform hundreds of what-if analyses. These analyses are summarized in a graph showing the probability for each result.
DataFit	Performs data plotting, regression analysis (curve fitting), and statistical analysis
DeccaPro	Activity based cost estimating software.
Decision by Life Cycle Cost	A software package for automated life cycle cost evaluation and cost effectiveness analysis.
DecisionTools Suite (@RISK, BestFit, TopRank, and Riskview)	Provides a suite of integrated decision analysis programs running from a common toolbar in Microsoft Excel. (@RISK, PrecisionTree, TopRank, BestFit, and RISKview)
Dryden WBS Cost Model	WBS Cost Model developed at Dryden for Vehicle Systems for Advocacy and Budget Formulation, NAR, ICE, Program & Project Integration among the Enterprise
Employment Cost Index (ECI) Inflation Calculator	Calculator for adjusting costs from one year to another using the Employment Cost Index (ECI) inflation index.
Environmental Costs of Hazardous Operations (ECHO) Model	The model calculates the environmental cost incurred throughout a life cycle cost of a program.

Model Name (Title)	Description
European Space Agency (ESA) Cost Modeling Software (ECOM)	ECOM is a Software tool for collection, retrieval and processing of cost data from past ESA programmes and projects.
European Space Agency (ESA) Costing Software (ECOS)	European Space Agency (ESA) Costing Software.
Excel Estimate At Completion (EAC) Cumulative Distribution Function (CDF) Tool	37th DoDCAS Paper by Steven L. Van Drew, PhD, PE, Naval Air Systems Command and Gary J. Clor, PhD, Army Logistics Management College. Developed and demonstrated an analytical approach to calculating a probabilistic EAC.
FRISK (Formal Risk Assessment of System Cost Estimates)	Analytic (rather than a Monte Carlo simulation) risk analysis package. Inputs are assumed to have a triangular distribution while the total system cost is approximated by the lognormal distribution.
Highly Accurate Cost Estimating Model (HaCEM)	A hybrid fuzzy logic-neural network cost estimating system, used to obtain rough order of magnitude (ROM) estimates of the cost of performing component and engine tests at the John C. Stennis Space Center. It contains a small set of data of component and engine testing, taken from Project Requirements Documents (PRDs). The data were used to train the adaptive network-based fuzzy inference systems (ANFIS) which were then used to predict cost for future tests.
GDP Deflator Inflation Calculator	Calculator for adjusting costs from one year to another using the Gross Domestic Product (GDP) inflation index.
GEM-FLO	Generic simulation Environment for Modeling Future Launch Operations is a generic discrete event simulation of launch vehicle processing to analyze operational system performance.
International Price Index (IPI) Inflation Calculator	Calculator for adjusting costs from one year to another using the International Price Index (IPI) inflation index.
International Space Station Analytical Cost (ISSAC) Model	The International Space Station (ISS) Analytical Cost (ISSAC) Model is a bottoms-up, activity-based cost estimating tool developed for the ISS Program Office's Assessment and Cost Estimating Office (ACEO). It models cost according to the products/services outlined in the ISS CARD associated by WBS. It permits the calculation of the cost impact of changes to the flight schedule and program requirements and ties cost by ISS Organization.

Model Name (Title)	Description
Labor & Material	This document contains instructions for preparing labor and materials cost estimates. This type of cost estimating is also referred to as grass-roots or bottoms-up estimating.
Learning Curve Calculator	Uses the learning curve to estimate the unit, average, and total effort required to produce a given number of units.
MESSOC	The Model for Estimating Space Station Operations Cost (MESSOC) is another product specific model that is available to the estimator through the IPAO, Code B or the ISSPO. MESSOC covers all mature operations costs for Earth-orbiting space stations.
MICM (Multivariate Instrument Cost Model)	Multivariate cost model for use in estimating costs of scientific instruments proposed for candidate future missions with emphasis on GSFC missions.
Mission Operations Cost Model	Simple online mission operations cost model (MOCM) that provides a useful method for quick turnaround, rough-order-of-magnitude cost estimating.
Mission System Integration and Test (MSI&T) Cost Model	Parametric cost estimating relationships (CERs) for use in estimating all costs required to bring together a bare spacecraft bus and a complement of instruments to form a payload (i.e., "wraparound" or "observatory I&T" costs)
NASA Air Force Cost Model (NAFCOM)	NAFCOM is a parametric estimating tool for space hardware. The model is intended to be used in the very early phases of a development project. NAFCOM can be used to estimate hardware at the subsystem or component levels and estimates both development and production costs (acquisition costs). NAFCOM is applicable to various types of missions (manned spacecraft, unmanned spacecraft, and launch vehicles). Two versions of the model are maintained: a government version that is restricted and a contractor releasable version.
Navy Obligation Data Extraction System (NODES)	NODES is an unclassified database of historic Navy operating and support obligations. It contains Navy operations and maintenance (OMN) and military personnel (MPN) cost detail for 1995 through 2001. NODES obtains data from budget and account sources and is updated annually.
Operating and Support Cost Analysis Model (OSCAM)	OSCAM provides a means of analyzing operating and support (O&S) costs of various military systems. The objective of the OSCAM Program is to provide a tool for assessing the impact of alternative maintenance strategies and operating policies on cost and availability for these systems.
Parametric Cost Estimating Model (PaCEM)	PaCEM is a top down, parametric cost estimating model that uses test article thrust to correlate an estimate.

Model Name (Title)	Description
Parametric Construction Cost Estimating System (PACES)	Integrated PC-based budgeting and cost estimating system that prepares parametric cost estimates for new facility construction, renovation, and life cycle cost.
Parametric Mission Cost Model (PMCM)	The Parametric Mission Cost Model (PMCM) is a tool that estimates the cost of unmanned earth-orbiting and deep space missions that are flown by JPL. It is Microsoft excel-based and uses a relatively small number of technical inputs to generate a detailed and fairly accurate cost estimate by Work Breakdown Structure (WBS) element and project phase.
Risk Constrained Optimized Strategic Planning (RCOSP)	RCOSP is a simulation model designed to capture the relationship between resource-driven measures of effectiveness (such as direct maintenance time) and financial measures of effectiveness (such as equivalent uniform annual life cycle cost or return on investment). RCOMP was designed to support decision makers in choosing the most cost-effective maintenance acquisition packages within optimized mixes of corrective maintenance (CM) and preventive maintenance (PM) Its capabilities and modeling concepts can be used to simulate system availability, propulsion test-stand throughput and probabilities of success.
PRICE-H/HL/M (Parametric Review of Information for Cost & Evaluation of Hardware and Electronics)	Estimates cost and schedule for total life cycle of hardware systems - from systems concept phase through maintenance and support.
PRICE-S (Parametric Review of Information for Cost & Evaluation of Software)	Estimates cost and schedule for total life cycle of software systems - from systems concept phase through maintenance and support.
Primavera Enterprise	Suite of project management tools including metrics, project management and control, project data repository, project team collaboration, project process, and cost management and earned value management.
Producer Price Index (PPI) Inflation Calculator	Calculator for adjusting costs from one year to another using the Producer Price Index (PPI) inflation index.
Resource Data Storage and Retrieval System (REDSTAR)	NASA-wide repository of cost programmatic and technical data pertaining to space related projects and programs.

Model Name (Title)	Description
Revised Intermediate COCOMO (REVIC)	Estimates software development and maintenance costs: development costs from requirements analysis through completion of acceptance testing & software maintenance costs for 15 years.
SEER-DFM	Shows how specific design and process decisions will affect production cost.
SEER-H (System Evaluation & Estimation of Resources - Hardware Estimation Model)	Estimates hardware costs, schedule, and risk for the requirements, design, test, integration and test, and maintenance phases.
SEER-IC	Estimates custom integrated circuit development and production costs, generates specifications, and evaluates potential yields.
SEER-SEM (System Evaluation & Estimation of Resources - Software Estimation Model)	Estimates software costs, schedule, and risk for the requirements, design, test, integration and test, and maintenance phases.
SEER-SSM (System Evaluation & Estimation of Resources - Software Sizing Model)	Estimates the expected size of a software project (in lines of code) with minimal input.
Schedule and Activity Generator Estimator (SAGE)	Uses knowledge estimating relationships to estimate the time / activity associated with the sub-systems and overall collection of these which are specified by the user. For reusable space transportation "orbiter" like elements only.
Scientific Instrument Cost Model (SICM)	Parametric cost estimating relationships (CERs), grouped by instrument family, for use in estimating costs of scientific instruments proposed for candidate future missions with emphasis on GSFC missions.
Shuttle-Sim	A discrete event simulation of Shuttle processing to analyze operational system performance.
Small Satellite Cost Model (SSCM)	Estimates the development and production costs of a small satellite bus for Earth-orbiting or near-planetary spacecraft.
Small Spacecraft Mission Cost Model	Parametric cost estimating relationships (CERs), grouped by instrument family, for use in estimating the costs of spacecraft bus, instruments, and MSI&T for missions with a total payload dry weight less than 1,300 pounds (590 kg).

Model Name (Title)	Description
Space Operations Cost Model (SOCM)	The model estimates post-launch Mission Operations & Data Analysis (MO&DA) staffing and cost requirements and includes cost relationships for several Space Operations Management Office (SOMO) services (tracking network costs and others).
Spacecraft Equipment Cost Model (SPECM)	Parametric cost estimating relationships (CERs) for use in estimating costs of various subsystem bus components comprising spacecraft bus subsystems.
Spacecraft Subsystems Cost Model	Parametric cost estimating relationships (CERs), grouped by spacecraft bus subsystem, for use in estimating total costs of scientific buses proposed for candidate future missions with emphasis on GSFC missions.
Spacecraft/Vehicle Level	Provides ROM estimates for the development and production of spacecraft, launch vehicle stages, engines and scientific instruments.
SPSS Tools Suite	Toolkit of statistics, graphs, and reports for use in a variety of applications in commercial, academic and government settings. Applications include surveys, marketing and sales analysis, data mining, quality improvement, and statistical research of all types.
Unmanned Space Vehicle Cost Model 8th Edition	Contains Cost Estimating Relationships (CERs) for estimating subsystem and component cost of a space vehicle.
Visibility and Management of Operating and Support Costs (VAMOSC)	The Navy VAMOSC management information system collects and reports U.S. Navy and U.S. Marine Corps historical weapons system operating and support (O&S) costs.

Model Name (Title)	Source			Model Characteristics																	
	Commercial	Government	Other	Beta Curve	Cost Estimating	CER	Database	Evaluation	Full Cost	Inflation	Handbook	Hardware Estimating	Learning Curve	O&S	Parametric	Proposal	Risk	Schedule	Spreadsheet	Software Estimating	Software Program
Advance Missions Cost Model (AMCM)		X			X							X									
Aircraft Turbine Engine Cost Model (ATECM)		X			X							X									
Airframe Cost Model		X																			
AATe - Architectural Assessment Tool - enhanced		X			X		X		X					X							
Army Military-Civilian Cost System (AMCOS)		X			X																
Ask Pete		X																		X	
Automated Cost Estimating Integrated Tools (ACEIT)	X			X	X					X			X							X	
Best Estimate	X				X																X
Building Estimator's Reference Book	X				X		X				X				X						
C Risk (A Cost Risk Analysis Tool)			X														X				X
Cobra	X						X											X			
COCOPRO			X		X															X	X
CODECOUNT(TM)			X																	X	X
Composites Affordability Initiative Cost Analysis Tool (CAICAT)		X			X							X									X

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Model Name (Title)	Source			Model Characteristics																	
	Commercial	Government	Other	Beta Curve	Cost Estimating	CER	Database	Evaluation	Full Cost	Inflation	Handbook	Hardware Estimating	Learning Curve	O&S	Parametric	Proposal	Risk	Schedule	Spreadsheet	Software Estimating	Software Program
Constructive Cost Model (COCOMO) II			X		X									X						X	X
Consumer Price Index (CPI) Inflation Calculator		X								X											
COOLSoft			X		X									X						X	X
COSMIC			X				X														
Cost Analysis Strategy Assementment (CASA) Model																					
Cost Estimating Cost Model		X			X							X									
CostLink	X				X	X	X	X							X	X		X	X		
Cost of Manpower Estimating Tool (COMET v2.0)		X			X	X	X							X							X
Cost Spreading Model		X		X																	
Cost Track	X																	X			
Cost Xpert	X				X									X	X		X	X		X	X
Costar			X		X													X		X	X
COSTIMATOR	X				X																
Crystal Ball	X																X				X
DataFit	X					X															
DeccaPro	X				X											X					X

Model Name (Title)	Source			Model Characteristics																	
	Commercial	Government	Other	Beta Curve	Cost Estimating	CER	Database	Evaluation	Full Cost	Inflation	Handbook	Hardware Estimating	Learning Curve	O&S	Parametric	Proposal	Risk	Schedule	Spreadsheet	Software Estimating	Software Program
Decision by Life Cycle Cost	X							X													X
DecisionTools Suite (@RISK, BestFit, TopRank, and Riskview)	X																X		X		X
Dryden WBS Cost Model		X			X	X			X			X						X	X		
Employment Cost Index (ECI) Inflation Calculator		X								X											
Environmental Costs of Hazardous Operations (ECHO) Model		X			X																X
European Space Agency (ESA) Cost Modeling Software (ECOM)		X			X															X	X
European Space Agency (ESA) Costing Software (ECOS)		X			X															X	X
Excel Estimate At Completion (EAC) Cumulative Distribution Function (CDF) Tool		X						X											X		
FRISK (Formal Risk Assessment of System Cost Estimates)			X														X				X
Highly Accurate Cost Estimating Model (HaCEM)	X				X		X				X	X				X			X		

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Model Name (Title)	Source			Model Characteristics																	
	Commercial	Government	Other	Beta Curve	Cost Estimating	CER	Database	Evaluation	Full Cost	Inflation	Handbook	Hardware Estimating	Learning Curve	O&S	Parametric	Proposal	Risk	Schedule	Spreadsheet	Software Estimating	Software Program
GDP Deflator Inflation Calculator		X								X											
GEM-FLO		X					X	X						X				X			X
International Price Index (IPI) Inflation Calculator		X								X											
International Space Station Analytical Cost (ISSAC) Model		X				X	X	X			X										X
Labor & Material		X			X														X		
Learning Curve Calculator		X											X								
MESSOC		X					X			X	X		X	X			X	X	X		X
MICM (Multivariate Instrument Cost Model)		X			X														X		
Mission Operations Cost Model		X			X																
Mission System Integration and Test (MSI&T) Cost Model		X			X		X								X				X		
NASA Air Force Cost Model (NAFCOM)		X		X	X	X	X		X	X		X	X		X		X	X			
Navy Obligation Data Extraction System (NODES)		X					X														
Operating and Support Cost Analysis Model (OSCAM)		X												X							

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Model Name (Title)	Source			Model Characteristics																	
	Commercial	Government	Other	Beta Curve	Cost Estimating	CER	Database	Evaluation	Full Cost	Inflation	Handbook	Hardware Estimating	Learning Curve	O&S	Parametric	Proposal	Risk	Schedule	Spreadsheet	Software Estimating	Software Program
Parametric Cost Estimating Model (PaCEM)		X			X	X	X	X			X	X			X	X			X		
Parametric Construction Cost Estimating System (PACES)	X				X										X						
Parametric Mission Cost Model (PMCM)		X			X	X						X			X		X				
Risk Constrained Optimized Strategic Planning (RCOSP)	X	X			X	X	X	X		X	X	X	X	X	X	X			X		
PRICE-H/HL/M (Parametric Review of Information for Cost & Evaluation of Hardware and Electronics)	X				X							X		X	X						X
PRICE-S (Parametric Review of Information for Cost & Evaluation of Software)	X				X									X	X					X	X
Primavera Enterprise	X															X	X	X			X
Producer Price Index (PPI) Inflation Calculator		X								X											
Resource Data Storage and Retrieval System (REDSTAR)		X					X														
Revised Intermediate COCOMO (REVIC)		X			X									X						X	X

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Model Name (Title)	Source: Commercial	Source: Government	Source: Other	Beta Curve	Cost Estimating	CER	Database	Evaluation	Full Cost	Inflation	Handbook	Hardware Estimating	Learning Curve	O&S	Parametric	Proposal	Risk	Schedule	Spreadsheet	Software Estimating	Software Program
SEER-DFM	X							X							X						X
SEER-H (System Evaluation & Estimation of Resources - Hardware Estimation Model)	X				X							X		X	X			X			X
SEER-IC	X				X							X			X						X
SEER-SEM (System Evaluation & Estimation of Resources - Software Estimation Model)	X				X									X	X		X	X		X	X
SEER-SSM (System Evaluation & Estimation of Resources - Software Sizing Model)	X													X	X					X	X
Schedule and Activity Generator Estimator (SAGE)		X												X				X			X
Scientific Instrument Cost Model (SICM)		X			X		X								X		X		X		
Shuttle-Sim		X					X	X						X				X			X
Small Satellite Cost Model (SSCM)			X		X							X									X
Small Spacecraft Mission Cost Model		X			X		X								X				X		
Space Operations Cost Model (SOCM)		X			X														X		

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Model Name (Title)	Source: Commercial	Source: Government	Source: Other	Beta Curve	Cost Estimating	CER	Database	Evaluation	Full Cost	Inflation	Handbook	Hardware Estimating	Learning Curve	O&S	Parametric	Proposal	Risk	Schedule	Spreadsheet	Software Estimating	Software Program
Spacecraft Equipment Cost Model (SPECM)		X			X		X								X				X		
Spacecraft Subsystems Cost Model		X			X		X								X				X		
Spacecraft/Vehicle Level		X			X																
SPSS Tools Suite	X																				
Unmanned Space Vehicle Cost Model 8th Edition		X			X	X	X				X	X							X		
Visibility and Management of Operating and Support Costs (VAMOSC)		X					X														

Model Name (Title)	Author / Co. / Org.	Contact Information	
		Office Number	Web Address
Advance Missions	NASA		http://www.jsc.nasa.gov/bu2/AMCM.html
Aircraft Turbine Engine	NASA		http://www.jsc.nasa.gov/bu2/ATECM.html
Airframe	NASA		http://www.jsc.nasa.gov/bu2/airframe.html
Automated Cost Estimating Integrated Tools (ACEIT)	Tecolote	(805) 964-6963	http://www.aceit.com/
Best Estimate			http://www.ConstructionTradeShow.com/
Building Estimator's Reference Book	CSI Division (Jerrold Ratner)		http://store.frankrwalker.com/cgi-bin/frw/4
C Risk (A Cost Risk Analysis Tool)	Aerospace Corporation (P.L. Smith and S.A. Book)	(310) 336-5000	
Cobra	Welcom	(281) 558-0514	http://www.welcom.com/content.cfm/node/24
COCOPRO	Dr. Barry Boehm	(213) 740-8163	http://sunset.usc.edu/
Composites Affordability Initiative Cost Analysis Tool (CAICAT)	Office of Naval Research		
Constructive Cost Model (COCOMO) II	Dr. Barry Boehm	(213) 740-8163	http://sunset.usc.edu/
Consumer Price Index (CPI) Inflation Calculator	NASA		http://www.jsc.nasa.gov/bu2/inflateCPI.html
COOLSoft	Dr. Barry Boehm	(213) 740-8163	http://sunset.usc.edu/
COSMIC			http://www.cosmic.uga.edu/
Cost Analysis Strategy Assessment (CASA)			
Cost Estimating Cost Model	NASA		http://www.jsc.nasa.gov/bu2/CECM.html
Cost of Manpower Estimating Tool (COMET v2.0)	Naval Center for Cost Analysis		
Cost Spreading Model	NASA		http://www.jsc.nasa.gov/bu2/beta.html
Cost Xpert			

Model Name (Title)	Author / Co. / Org.	Contact Information	
		Office Number	Web Address
Costar	Dr. Barry Boehm	(213) 740-8163	http://sunset.usc.edu/
Crystal Ball	Decisioneering	(800) 289-2550	http://www.decisioneering.com/crystal_ball/index.html
DataFit	Oakdale Engineering	(724) 693-0320	http://www.curvefitting.com
DeccaPro	Deccan System Inc.	(812) 948-8726	http://www.deccansystems.com/DeccaPro.htm
Decision by Life Cycle Cost	Advance Automation Corporation	(800) 292-4519	http://www.aac-usa.com/
DecisionTools Suite	Palisade	(800) 432-7475	http://www.palisade.com/html/decision_analysis_software.html
Dryden ICE Cost Model	NASA DFRC Steve Sterk	(661)276-2377	
Employment Cost Index (ECI) Inflation Calculator	NASA		http://www.jsc.nasa.gov/bu2/inflation/eci/inflateECI.html
Environmental Costs of Hazardous Operations (ECHO) Model	Naval Air Systems Command/Tecolote		
Excel Estimate At Completion (EAC) Cumulative Distribution Function (CDF) Tool	Naval Air Systems Command /Army Logistics Management College	(301) 342-2798	
European Space Agency (ESA) Cost Modeling Software (ECOM)	Advantage Software B.V.	+31 20 6148649	http://www.estec.esa.nl:80/eawww/ecom/ecom.htm
European Space Agency (ESA) Costing Software (ECOS)	Advantage Software B.V.	+31 20 6148649	http://www.estec.esa.nl:80/eawww/ecos/ecos.htm
FRISK (Formal Risk Assessment of System Cost Estimates)	Aerospace Corporation (Phillip H. Young)	(310) 336-5000	
GDP Deflator Inflation Calculator	NASA		http://www.jsc.nasa.gov/bu2/inflateGDP.html

Model Name (Title)	Author / Co. / Org.	Contact Information	
		Office Number	Web Address
GEM-FLO	NASA (Martin Steele) / PAI (Mansooreh Mollaghasemi)	(321)867-8761 / (407)384-0800	http://www.productivityapex.com
International Price Index (IPI) Inflation Calculator	NASA		http://www.jsc.nasa.gov/bu2/inflation/ipi/inflateIPI.html
ISSAC Model	NASA (Richard Fox) / Booz Allen Hamilton (Mauricio Quintana)	(281) 244-8060 / (281) 488-2999	
Labor & Material	NASA		http://www.jsc.nasa.gov/bu2/instruct.html
Learning Curve Calculator	NASA		http://www.jsc.nasa.gov/bu2/learn.html
MESSOC	NASA JPL (Bob Shishko)	(818) 354-1828	
MICM (Multivariate Instrument Cost Model)	NASA (Cynthia Fryer)	(301) 286-7204	
Mission Operations	NASA		http://www.jsc.nasa.gov/bu2/MOCM.html
Mission System Integration and Test (MSI&T) Cost Model	NASA (Cynthia Fryer)	(301) 286-7204	
NAFCOM	NASA (Steve Creech)/ SAIC (Sharon Winn)	(256) 971-7275	http://nafcom.saic.com
NAFCOM96 Cost Model (Government & Unrestricted)	NASA/AirForce/SAIC (Keith Smith)	(256) 971-6571	http://www.jsc.nasa.gov/bu2/NAFCOM.html
Parametric Mission Cost Model (PMCM)	NASA JPL (Leigh Rosenberg)	(818) 354-0716	
PRICE-H (Parametric Review of Information for Cost & Evaluation of Hardware)	PRICE Systems	(800) 43-PRICE	http://www.pricesystems.com/
PRICE-S (Parametric Review of Information for Cost & Evaluation of Software)	PRICE Systems	(800) 43-PRICE	http://www.pricesystems.com/

Model Name (Title)	Author / Co. / Org.	Contact Information	
		Office Number	Web Address
Primevera Enterprise	Primavera	(8000 423-0245	http://www.primavera.com/
Producer Price Index (PPI) Inflation Calculator	NASA		http://www.jsc.nasa.gov/bu2/inflation/ppi/inflatePPI.html
Revised Intermediate COCOMO (REVIC)	Raymond Kile	(703) 604-0395	http://www.hq.af.mil/afcaa/models/REVIC92.EXE
SAGE	Edgar Zapata	(321) 867 6234	http://science.ksc.nasa.gov/shuttle/nexgen/Sage_main.htm
Scientific Instrument Cost Model (SICM)	NASA (Cynthia Fryer)	(301) 286-7204	
SEER-DFM	Galorath Inc.	(310) 414-3222	http://www.gaseer.com/
SEER-H (System Evaluation & Estimation of Resources - Hardware Estimation Model)	Galorath Inc.	(310) 414-3222	http://www.gaseer.com/
SEER-IC	Galorath Inc.	(310) 414-3222	http://www.gaseer.com/
SEER-SEM (System Evaluation & Estimation of Resources - Software Estimation Model)	Galorath Inc.	(310) 414-3222	http://www.gaseer.com/
SEER-SSM (System Evaluation & Estimation of Resources - Software Sizing Model)	Galorath Inc.	(310) 414-3222	http://www.gaseer.com/
Shuttle Sim	NASA (Martin Steele) / PAI (Mansooreh Mollaghasemi)	(321)867-8761 / (407)384-0800	http://www.productivityapex.com
Small Satellite Cost Model (SSCM)	Aerospace Corporation (Jim Summers)	(310) 336-6802	http://www.aero.org/software/sscm/
Small Spacecraft Mission Cost Model	NASA (Cynthia Fryer)	(301) 286-7204	
Space Operations Cost Model (SOCM)	Marc Jacobs		http://www.jsc.nasa.gov/bu2/SOCM/SOCM.html

Model Name (Title)	Author / Co. / Org.	Contact Information	
		Office Number	Web Address
Spacecraft Equipment Cost Model (SPECM)	NASA (Cynthia Fryer)	(301) 286-7204	
Spacecraft Subsystems Cost Model	NASA (Cynthia Fryer)	(301) 286-7204	
Spacecraft/Vehicle Level	NASA		http://www.jsc.nasa.gov/bu2/SVLCM.html
Unmanned Space Vehicle Cost Model 8th Edition	Airforce (Phu Nguyen)	(310) 363-0071	

M. Compilation of Models and Tools

This appendix is a glossary compilation of key tools and models available to the analyst for use in the early definition stages of space launch programs and projects. The listing includes information on each tool and model, without regard to the utilitarian value of the tool. However, key O&S tools have already been assessed recently in two NASA documents. The first document is a report titled “KSC Inventory of Applicable Operational Assessment Tools 2001 Report – ‘Final Report, Operations Assessment Tools 30 September, 2001’”. It assesses the metrics on key operational tools using a matrix that identifies input parameters required by the program or alternately output generated by the program.

The second document is a report titled “Launch System Operations Cost Model (LSOCM) Requirements Analysis Report”, dated 16 November 2001, prepared by ALE for Marshall Space Flight Center under Contract No. H-3458D. This report provides an assessment of whether existing/in-development operational tools met NASA requirements as defined by managers across the usage spectrum.

Architectural Assessment Tools-enhanced (AATe) – This tools is designed to focus on vehicle processing cost and cycle time estimation, landing to launch. The model is organized to be compatible with the classical modules of the launch process in order to provide visibility into the cost by module. A simple top-level Graphic User Interface (GUI) enables the analyst to evaluate the new concept in terms of classical characteristics and to weigh the importance of each characteristic. The model uses this data to estimate the cost of operations and the number of launches necessary to achieve a desired payload to orbit rate, an indirect indication of cycle time. The tool is structured to enable an experienced operator to access lower levels of detail. This tool is the tool of choice for KSC performing Space Launch Initiative assessments.

AATe is an Excel-based application using an intuitive and friendly graphic user interface to define the design of each stage (up to six) for a reusable launch system. The AATe works ideally for reusable boosters defined at a very conceptual level. The results are best used comparatively, such as relative to Shuttle and to other concepts assessed with the tool. However, absolute values may be used for a ROM cost estimate.

AATe requires 29 inputs per stage, though with optional additional inputs, the cost analyst can increase the fidelity of the results. Typical inputs include: degree of sub-systems integration, number of toxic fluids, vehicle reliability, payload mass per flight, concept physical dimensions, and operational margins.

In AATe, the cornerstone concept is the single vehicle productivity. The model captures design choices and generates estimates of single vehicle outputs (timelines, single string facility and operational costs, and single vehicle flight rate capability per year). The model then calculates fleet operations outputs (number of vehicles and major facilities) required to meet a yearly up-mass-to-orbit scenario.

Outputs types (for a reusable launch system) are: program-wide recurring yearly operations costs; operations yearly fixed costs; operations variable costs per flight; cycle times for landing, turnaround, integration and launch processing (calendar days); fleet size required to achieve a flight rate per year; and non-recurring (investment) costs for operations-related capabilities (facilities and GSE) required to achieve a particular flight rate per year.

Automated Cost Estimating Integrated Tools (ACEIT) – These suit of tools provide an architecture and framework for cost estimating and other analysis tasks. ACEIT helps analysts store, retrieve, and analyze data; build cost models; analyze risk; time phase budgets; and document cost estimates. ACEIT is a government-developed tool that standardizes and simplifies the Life Cycle Cost estimating process in the government environment. ACEIT's core features include a database to store technical and (normalized) cost data; statistical package specifically tailored to facilitate Cost Estimating Relationship (CER) development; and a spreadsheet that promotes structured, systematic model development, and built-in government approved proven inflation, learning, documentation, time phasing, sensitivity/what-if, risk, and other analysis capabilities. ACEIT integrates all the necessary cost estimating functions but allows you to enter the process at any level. In addition to the core features, ACEIT has several integrated tools including:

- Automated Cost Database development, search, and retrieval (ACDB)
- Statistical analysis (CO$TAT)
- Automated Information Manager for building CER libraries (AIM)
- Automated Cost Estimating, model creation and documentation (ACE)
- Risk analysis (ACE/RI$K)
- Operation from Excel and interfaces with other tools (ACEIT Executive)
- Custom Inflation Indices creation (Inflation Editor)
- Functions to obtain BY and TY OSD Inflation factors from any Excel spreadsheet (Inflation/Utility) [3]

Advance Missions Cost Model (AMCM) – This is a simple online advanced missions cost model that provides a useful method for quick turnaround, rough-order-of-magnitude estimating. The model can be used for estimating the development and production cost of spacecraft and space transportation systems. This simple model only has a few inputs such as an estimated system weight (empty), expected technical difficulty, and expected Initial Operating Capability (IOC). [1]

Airframe Cost Model – This is a simple on-line model for estimating the development and production costs of aircraft airframes that is suitable for use in a program's conceptual stage when little detailed information is available. The model provides separate CERs for major cost elements such as non-recurring engineering and tooling, development support, recurring manufacturing labor, and recurring quality assurance. Data was derived from 13 different aircraft between 1960-1978. The airframe cost covers the cost of the assembled structural and aerodynamic components of the air vehicle, but does not include training, support equipment, data, and spares.[1]

Best Estimate – A tool designed to estimate renovations and remodels if needed for new systems. The tool will model each project from a cost perspective and prepare a description of the work included in the price.[7]

Cost Analysis Strategy Assessment (CASA) – This tool is a LCC decision support tool. CASA can calculate the total cost of ownership depending on user selections, including RDT&E, production, and operating/support costs. CASA covers the entire life of the system, from its initial research costs to those associated with yearly maintenance, as well as spares, training costs, and other expenses.[1]

CoCoPro – CoCoPro estimates resources needed to complete a software development project. Using a set of exponential equations, the program produces both development cost and schedule estimates for a system based on lines of code, cost per month, and 15 project parameters. The modifiers cover personnel experience and capabilities, project complexity, product factors, and hardware limitations.[8]

C Risk (Cost Risk Analysis Tool) – An analytic risk analysis package (not Monte Carlo simulation) that provides best estimate, standard error of estimate, and the percent of new technology with minimal inputs.[9]

Constructive Cost Model (COCOMO II) – A model that allows estimation of cost, effort, and schedule when planning a new software development activity. The implemented tool provides a range on cost, effort, and schedule estimates, from best case to most likely to worst case outcomes. It also allows a planner to easily perform "what if" scenario exploration, by quickly demonstrating the effect adjusting requirements, resources, and staffing might have on predicted costs and schedules (e.g., for risk management or job bidding purposes). [10]

COOLSoft tm – This model utilizes a hybrid approach of intermediate and detailed versions of the Constructive Cost Model (COCOMO), which allows for the reuse of existing code, development of new code, the purchase and integration of third party code, and hardware integration. The output is then displayed as man-months of programming effort, calendar schedule, support costs and hardware costs.[1]

Conceptual Operations Manpower Estimating Tool/Operations Cost Model (COMET/OCM) – This model was developed for the Marshall Space Flight Center (MSFC) in 1994. The model is built on shuttle and ELV operations data, and enables the user to estimate the operations cost of shuttle derivatives, crewed reusable vehicles, unmanned reusable vehicles, crewed expendable vehicles, and unmanned expendable vehicles. COMET, which stands for Conceptual Operations Manpower Estimating Tool, estimates manpower requirements for two key elements: vehicle processing and flight planning. The Operations Cost Model (OCM) takes this manpower estimate, applies ratio factors, labor, and overhead cost factors, and performs other calculations to yield a total vehicle operations and support cost estimate.[2]

CORE - Commercial system engineering tool from Vitech, which helps provide product and process engineering solutions. Used by NASA, this tool is for discrete event modeling. The CORE product family provides a flexible combination of modeling and simulation tools supporting product and process engineering. CORE's object-oriented environment delivers the same functionality from a single user workstation to large, distributed, client-server teams. [20]

COSMIC – A database of over 810 computer programs that were originally developed by NASA and its contractors for the U.S. space program.[1] Previously run by the University of Georgia Research Foundation, the data has been transferred to Open Channel Software. This company has entered into an agreement with the National Technology Transfer Center (NTTC) to publish approximately 500 programs in the existing COSMIC software collection at their Internet site http://www.openchannelfoundation.org/cosmic.[11]

Cost Xpert – This is a software-costing tool, which calculates information including project costs, schedules, tasks, deliverables, maintenance, and support requirements.[1]

COSTIMATOR – This model provides computerized cost estimating and process planning for manufacturing.[1] Manufacturing data, standards, and extensive databases are used to produce cost estimates and process plans. The model has the ability to do instant estimating through its IQBuilder Database, consisting of parametric calculations that provide manufacturing times and costs. When limited data is available, the model can calculate time and cost per piece to manufacture based on historical data.[16]

Crystal Ball – Crystal Ball is a simulation program that helps you to analyze the risks and uncertainties associated with Microsoft Excel cost spreadsheets. Crystal Ball automates the cumbersome "what-if" process using Monte Carlo simulation, by applying a range of values or a probability distribution to each uncertain variable in a spreadsheet. The program generates random values from within the defined probability ranges, and then recalculates the model literally hundreds or thousands of times, storing the results of each "what-if" scenario. Analysis probabilities are graphed by the model.[12]

Decision Tools Suite (@RISK, BestFit, TopRank, Riskview) – This is an Excel based suite of tools for analyzing decisions and risk, which work together. @RISK is a spreadsheet add-in for Risk Analysis that lets you see the full range of possible outcomes for any spreadsheet model with Monte Carlo simulation. BestFit automatically finds the best distribution to fit your data sets, and may be used alone or with @RISK. Riskview allows you to quickly preview and create distributions for use in @RISK, and TopRank conducts an automated "what-if" analysis on any spreadsheet model.[13]

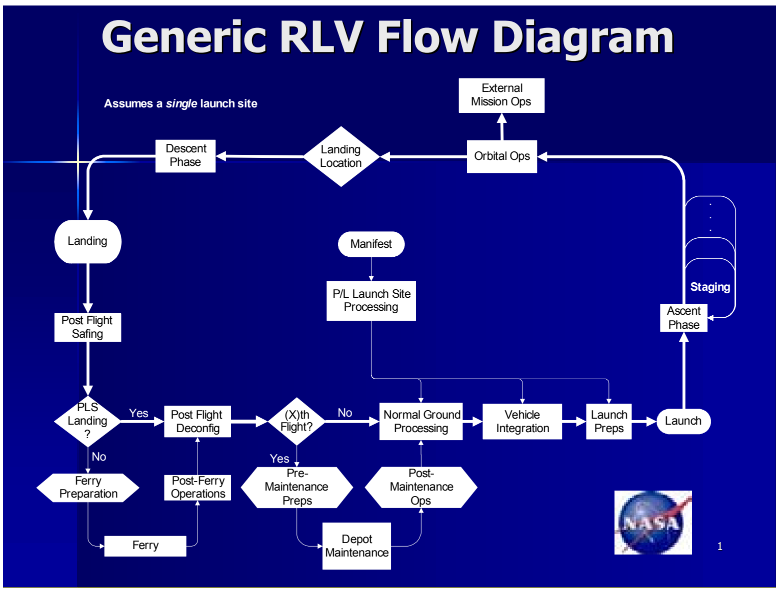
D4COST 2000 – This model provides building cost estimates beginning from conception. The model takes actual cost data on existing buildings (projects) and applies factors that allow the user to cost escalate (or depreciate, as the case may be) from one time period to another, and to regionally adjust for the local variances in construction costs from one place to the next. The system does this work in real time, not only providing the user with an actual number (not a range), but it also allows the user to run "what-if" scenarios that are useful in comparing the varying costs of different building types and construction materials.[14]

Expendable Launch Vehicles (ELV) International and US – This small database is a compilation of some basic payload and cost data from existing ELVs.[1]

Excel Estimate At Completion (EAC) Cumulative Probability Function (CDF) Tool - 37th DoDCAS Paper by Steven L. Van Drew, PhD, PE, Naval Air Systems Command and Gary J. Clor, PhD, Army Logistics Management College. Developed and demonstrated an analytical approach to calculating a probabilistic EAC. Given a constant such as BAC and an uncertain efficiency factor such as CPI_{cum} whose distribution is assumed to follow either a uniform or triangular distribution, approach provides earned value analysts with a set of equations capable of answering questions such as, What is the probability of under running the contractor's LRE?

European Space Agency (ESA) Cost Modeling Software (ECOM) – This is a software tool for collection, retrieval, and processing of cost data from past ESA programs and projects, used for cost estimation and proposal evaluation. The heart of ECOM is the database, which contains historical cost proposal data from past ESA projects. The items are grouped in classes and the data comprises the cost breakdown and the associated technical description. The technical description consists of the main technical performance parameters, number of models and design status. In addition, for some equipment, there are also comments and block-diagrams. Within the estimating part of ECOM, various cost estimation techniques are available. The methods applied are estimated by analogy, use of cost estimating relationships, and parametric cost modeling. The tool includes links to commercial parametric models such as PCM and PRICE-H.[15]

Generic Simulation Environment for Modeling Future Launch Operations and Shuttle Simulation (GEM-FLO) – GEM-FLO is a generic but powerful simulation of launch operations processing for space transportation systems, expendable or reusable, single or multiple stages. The basic concept is that the processing of a space transportation system has certain generic processes such as landing, turnaround, depot cycles, integration sequence, integration time, and time on pad. The facilities or other resources required, and the time probability distributions may vary, but the relationships are generic and applicable to many flight and ground system architectures. By means of a graphic user interface, an underlying Arena© discrete event simulation is populated with a description of the system being analyzed. The outputs include flights per year, facility utilization, and total resources demanded. A special version, called Shuttle-Sim, has also been developed to model STS processing specifically, and at higher fidelity. Web links for GEM-FLO and Shuttle-Sim can be found at:
http://science.ksc.nasa.gov/shuttle/nexgen/Tools1.htm. The diagram below shows the generic operational representations for Earth-to-orbit space transportation systems.



International Space Station Analytic Cost (ISSAC) Model – was developed to aid the ISS Program Office's ability to map costs by organization, contractor, ISS Program WBS, function, and according to whether costs are thought to be fixed or variable. ISSAC also provides the flexibility to run activity scenarios to determine the impact on program costs based on five simple cost drivers. The ISSAC model has a user-friendly GUI to help users run scenarios and generate other database reports. Developed in VBA and designed to run in Access 2000, it provides a budget accounting approach rather than an engineering analysis of costs.

Activities in the ISSAC model are defined as a task or job that is performed by an organization in support of the ISS Program. Activities are aligned with the products/services in the ISS CARD. When the cost analyst has selected a particular organization or WBS element, its associated activities appear automatically in the activities field. Activities may change from one fiscal year to another, so by selecting a particular year, the cost analyst may view that year's unique list of occurring activities. Examples of some of activities in ISSAC are: Assembly Validation, Development Activity, Flight Element Processing, Planning, and Facilities Support. The cost analyst can add a new activity, edit activity properties, edit the activities' cost drivers, or delete an activity.

Cost drivers determine the cost of an activity within an organization. The cost analyst can configure the cost-driver equations for an activity as necessary to model a specific ISS Program. There are currently five types of cost drivers identified in the ISSAC model: total dollars per year for the selected activity; total number of Equivalent Personnel (EP) per year for that activity; a step function that allows dollars or EPs to be assigned to a pre-determined unit range; dollars per unit; and EPs per unit for an activity. The "units" the analyst can select are: Document, Anomaly, Procedure, Flight, EVA, Element, Increment, Crew Member, Lbs, Kg, Hour, Shuttle Flight, Soyuz Flight, Progress Flight, ATV/HTV Flight, Pressurized Vehicle, SpaceHab, MPLM, Rack, KSLOCS, and PR. The cost type (fixed or variable) is also identified for each activity.

The use of a particular cost driver depends on the activity and level of information available. For each cost driver, the cost analyst may define an associated contract and contractor, and to choose whether or not the contractor is designated as Prime for the specific activity. The analyst can also import actual cost data from previous years.

The ISSAC model can also be used to create alternative scenarios and to assess their impacts on and changes to the ISS Program. The analyst can choose to run scenarios on flight rates, activity status, inflation rates, and the model's global variables.

Launch Systems Operations Cost Model (LSOCM) – LSOCM V1.0 is a combination of two models discussed previously: RMAT and COMET/OCM. RMAT is used to establish parametric expressions for maintenance times for subsystems of the future system. These data are used as an input to the COMET/OCM mode, an operation manpower estimating tool that uses differences in vehicle characteristics in an on-screen interview process to relate manpower for the future system to manpower required for shuttle. These data use standard cost factors such as cost per pound for propellant times estimated consumption rates to establish cost of operations at a given launch rate per year. The model provides opportunity for the user to adjust standard operating procedures for new ways of doing business. The final output of the process is an operating cost estimate at four launch rates. This tool set can be exercised with limited design detail related to the future system, provided expert opinion is available to properly define the differences between the future system and the shuttle.[2]

Logistics/Cost Model (LCM) – LCM primarily makes use of cost estimating relationships obtained by using multiple regression to fit historical cost data to one or more vehicle design or performance variables.[2]

Model for Estimating Space Station Operations Costs (MESSOC) – is a cost and resource estimating tool for the mature operations phase of the International Space Station (ISS). First developed for Space Station Freedom, MESSOC's roles now are to inform ISS decisions through the life-cycle cost management process, to provide an independent assessment of the ISS budget, and to identify long-term on-orbit resource envelopes.

Because operations cost estimates alone are not sufficient to address key design and operations issues, MESSOC provides the cost analyst with the ability to test the effect of changes in ISS design, operations, and policies on both estimated operations costs and Station performance metrics. These metrics include crew time available to Station users, on-orbit availability of critical Station equipment, and user-dedicated payload mass to orbit.

The heart of MESSOC is a set of integrated algorithms and equations, linking operations costs with performance. Inputs to the algorithms come from two sources: those variables entered or edited by the analyst directly in dialog boxes and spreadsheets, and those data contained in the MESSOC's engineering and operations data tables. Variables entered in dialog boxes and spreadsheets create a Space Station scenario. In constructing a scenario, the analyst essentially tells the algorithms what the Station configuration is over time, what operations are being conducted aboard the Station over time, and what overall Space Station program and policy variables are in effect. The scenario spreadsheets provide a natural mechanism by which to capture Station evolution and growth.

From a Space Station scenario, the cost algorithms calculate costs in 20 functional cost elements. These costs, when summed, give total operations costs in a given year. The calculations are performed for each year of the Station's operational life, taking into account changes in its configuration, on-orbit and ground operations, as well as certain other intertemporal variables. Because of the nature of the algorithms, considerable detail is also available within the 20 cost categories and three operations performance categories for each year.

Two levels of cost analysis can be performed: simple scenario changes in which the analyst changes dialog box inputs, or through the spreadsheets, changes the Station configuration and/or operations profiles; or, more complex applications in which the analyst changes the detailed engineering data in the data tables. Because logistics costs, for example, are built up from engineering data at the ORU/SRU level, detailed supportability trades are possible.

MESSOC software is written entirely in Visual Basic for Applications (VBA), and is designed to run as an Excel file within Office '97 (or better). The user interface employs modern GUIs (Graphical User Interfaces) familiar to Excel users. Help topics and key assumptions (in the standard Microsoft help file format) can be displayed from the Help menu. Each of MESSOC's equations and algorithms is documented in great detail; the documentation is accessible through an included html file.

Mission Operations Cost Model (MOCM) – MOCM is a very high-level estimating tool available through the JSC Cost Estimating and Models website for a quick turnaround, ROM cost estimate for the mission operations of manned, unmanned and planetary spacecraft. This is a simple online MOCM that provides a useful method for quick turnaround, rough-order-of-magnitude cost estimating. The MOCM provides an estimate of the basic mission operations and data analysis (MODA) cost for a given spacecraft, including the cost of: maintaining and upgrading ground systems; mission control; tracking; telemetry; command functions; mission planning; data reduction and analysis; crew training and related activities. The MOCM does not include the cost of launch vehicles or launch services. The model estimates the average annual MODA based on the type of mission and the investment cost of the spacecraft. The investment cost is defined as the total development and production cost of the spacecraft, experiments, and ground systems. The MOCM is based on NASA data for spacecraft flown between 1962 and 1990.[1] MOCM is a calculator/estimating relationship for mission operations.

NASA/Air Force Cost Model 2002 (NAFCOM 2002) – The NAFCOM 2002 Cost Model is an automated parametric cost-estimating tool that uses historical space data to predict the development and production costs of new space programs. It uses parametric relationships to estimate subsystem or component level costs for any aerospace hardware including: earth orbital spacecraft, manned spacecraft, launch vehicle, upper stages, liquid rocket engines, scientific instruments, or planetary spacecraft. NAFCOM uses a template selection wizard to configure a default WBS consistent with the type of spacecraft or launch vehicle to be estimated. As with previous releases of NAFCOM, additional historical data has been added to the database resident in the cost estimating equations. Resident capabilities include time phasing of cost, schedule estimating, a direct link to collaborative environments, and improved printed output.[4]

NROC – The iNtegrated – RMAT – OCM/COMET model is the tool of choice for performing the Space Launch Initiative 2ND Gen Program technology assessments. As much of a process as a tool, the model combines the capabilities of the RMAT and COMET/OCM with an estimating worksheet and operations expertise from Kennedy Space Center. Enhancements to the model include facilities and GSE cost estimating capability and a rough order of magnitude cycle time estimator.[2]

On-Line Calculators – These include simple tools such as:

> **Inflation Calculators** – Calculators using the index from one year to another using the GDP Deflator, the Employment Cost Index (ECI) Inflation Calculator, or the Consumer Price Index (CPI). [1]
>
> **The CPI calculator** adjusts the cost of living from one year to another using the CPI inflation index. This inflation calculator is based on the average inflation index during the calendar year, and will currently compute inflation rates for any years between 1913 and 1998.[1]
>
> **The ECI calculator is** an inflation calculator for adjusting costs from year to year using the ECI inflation index. This calculator is based on the average inflation index during the calendar year. This inflation calculator will compute inflation rates between 1981 and 1998 and measures changes in wages, salaries, and benefits for civilian workers (private industry plus state and local government).[1]

The GDP Deflator Calculator is an inflation calculator for adjusting costs from one year to another using the Gross Domestic Product (GDP) Deflator inflation index. This inflation calculator is based on the inflation rate during the US Government Fiscal Year, which begins on October 1 and ends on September 30. This inflation calculator will currently compute inflation from 1940 to 2005.[1]

Cost Spreading Calculator – This is a simple online cost spreading calculator that can be used to spread the estimated cost of a program up to eight years. The calculator uses a beta curve to determine the amount of money to be spent in each year based on the fraction of the total time that has elapsed. The user enters the total cost to be spread.[1]

Labor and materials worksheets – Analysts have access to manpower and materials worksheets developed by NASA in Excel format.[1]

International Price Index (IPI) Inflation Calculator – This is an inflation calculator for adjusting costs from one year to another using the IPI inflation index. This inflation calculator is based on the average inflation index during the calendar year and will compute inflation rates between 1982 and 1998. IPI is based on the export, import price indexes, measures the transaction prices of goods, and services exported from or imported into the United States.[1]

Learning Curve Calculator – This is a calculator providing learning curves to estimate the unit, average, and total effort required to produce a given number of units. These curves are derived from a basic theory developed by T.P. Wright, for obtaining cost estimates based on repetitive production of airplane assemblies. For the Wright learning curve, the underlying hypothesis is that the direct labor man-hours necessary to complete a unit of production will decrease by a constant percentage each time the production quantity is doubled. The learning percent is determined by statistical analysis of actual cost data for similar products or guidelines from “Cost Estimator’s Reference Manual- 2nd Ed.,” by Rodney Stewart. The calculator uses the learning curve to estimate the unit, average, and total effort required to produce a given number of units. Effort can be expressed in terms of cost, man-hours, or any other measure of effort. The calculator can be set to compute the Wright learning curve or the Crawford learning curve, which requires a quantity of 1,000 or more.[1]

Product Price Index (PPI) Inflation Calculator – This is an inflation calculator for adjusting costs from one year to another using the PPI inflation index. This inflation calculator is based on the average inflation index during the calendar year. This inflation calculator will compute inflation rates between 1947 and 1998. The PPI measures changes in the wholesale prices of finished goods.[1]

Operations Cost Model/Conceptual Operations Manpower Estimating Tool (OCM/COMET) – is a merger of OCM and COMET into a single Excel file, hereafter called OCM. The two models taken together are used to estimate launch vehicle operations costs for both reusable and expendable systems. OCM organizes launch vehicle operations into four primary segments: Program Segment (P), Vehicle Segment (V), Launch Operations (L) and Flight Operations (F). Within these categories are 28 OCM cost elements. (See Appendix A for element definitions.) Not all elements apply to all vehicles. For example, L3 Recovery Operations and F7 Crew Operations would not apply to expendable vehicles).

A key input to OCM is the type of launch vehicle, entered in terms of one of four possible rating sets: manned/reusable, unmanned/reusable, manned/expendable, or unmanned/ expendable. The assumption, embodied in OCM, is that manned/reusable is the most costly and unmanned/expendable, the least. The other two are in between, with unmanned/reusable generally assumed to be more costly than manned/expendable. The model is calibrated to historical data for the manned/reusable rating using Shuttle data and for the unmanned/expendable rating using EELV (Delta IV or Atlas V) data. The type of vehicle, particularly the reusable/expendable designation, is used as a gross surrogate definition for several second-tier operational complexity questions, such as reusable TPS system, crossrange/alternate landing sites, flight certification requirements, on-orbit payload operations, piloted versus crew-as-payload, and flight software size.

In using OCM, the analyst selects one of three types of Cost Estimating Relationships (CERs) for each element, with some exceptions. The three CER choices are Direct, Ratio, and Parametric. A choice of Direct means the analyst inputs directly values for fixed costs per year, variable costs per flight, and step functions values for incremental costs and flight rate breakpoints. The second choice is Ratio CERs, in which a ratio is applied to the value of another element to calculate the cost of the desired element. The third choice, Parametric CERs, uses some non-cost characteristic(s) of the system, a system hardware cost such as the theoretical first unit cost of the system hardware, or the cost of some other element to calculate the cost of the desired element.

If the analyst selects Ratio CERs, OCM estimates the manpower required to perform the Flight Planning (an element of Flight Operations) and Vehicle Processing (an element of Launch Operations), based on user-defined vehicle and mission concepts. The resulting manpower estimates become inputs to other OCM spreadsheets, which fill out the balance of the Launch and Flight Operations resource requirements to develop a complete operations cost estimate for those segments based on ratios. The ratios are determined by the rating set. All four ratio sets assume Standard Operating Procedures (SOP) for current launch vehicles, and were updated in 2003/04.

If the analyst selects parametric CERs, the rating set determines the complexity factor values for some of the parametric CERs. Parametric CERs are a new addition to OCM.

OCM is based on historical data for existing systems. The historical data is allocated to various vehicle characteristics such as reusability, manned, number and type of events in the mission profile, etc. Calibration points are calculated for Shuttle and existing Expendable Launch Vehicles (ELV) at a rate of six flights per year to provide an anchor for the estimate. Additionally, the characteristics of the relationships representing manpower as a function of flight rate are based on analysis of the historical data combined with analysts' judgment.

Other OCM inputs include the cost per man-year, other rates and wrap factors (e.g., contractor fee and contingency). These cost factor inputs transform the manpower estimates for each of the four flight rates to a cost estimate. At this point, cost adjustment factors to recognize such things as New Ways of Doing Business (NWODB) may be introduced. NWODB examples could be new technologies, new organizational management techniques, etc.

OCM output includes point estimates for each cost element at each of the four input flight rates and, based on best-fit regressions, two flight rate-sensitive CERs for each cost element, one each in linear and logarithmic forms.

Operations Impact Assessor (OIA) – The OIA tool defines a component as an object or assembly of parts that have processing tasks and resources and facility requirements. The tool can model a conceptual component and its processing tasks to help evaluate both operability and processing requirements such as support equipment, facility utilization, labor, and processing schedules.[17]

Parametric Mission Cost Model (PMCM) - is a tool that estimates the cost of unmanned earth-orbiting and deep space missions that are flown by JPL. It is Microsoft excel-based and uses a relatively small number of technical inputs to generate a detailed and fairly accurate cost estimate by Work Breakdown Structure (WBS) element and project phase. It can accept probabilistic inputs and perform Monte Carlo simulations to find the likely statistical range around a most-likely project cost.

PRICE (Parametric Review of Information for Costing and Evaluation) Estimating Suite – PRICE Parametric Cost Estimating Tools may be used for estimating the cost of hardware, software, microcircuits, and life cycle costs. Pertinent tools include:

> **PRICE H** – Hardware Estimating Model – Used to estimate costs, resources, and schedules for hardware projects such as electronic, electro-mechanical, and structural assemblies. It can be used to estimate hardware projects of any scale, from the smallest individual component to the complex hardware assemblies of a complete aircraft, ship, or space station.[5]
>
> **PRICE HL** – Hardware Life-Cycle Estimating Model – Used for analysis at the system, subsystem, major assembly, and subassembly levels, and can be rapidly tailored to reflect specific support conditions. While it can be used independently, PRICE HL is also often used in conjunction with PRICE H, the Hardware Estimating Model. Together, these models produce comprehensive cost and schedule estimates for entire programs, from initial concept to multi-year, multi-theater deployment, and field support.[5]
>
> **PRICE S** –Software Development Estimating Model – Used to estimate the cost and schedule of software development. Designed to handle all types of software from business systems and communications to command and control, avionics, and space systems.[5]

PCM – This model is used with ECOM discussed above. The model calculates cost using a mass and complexity factor. The complexity factor is derived by a reverse calculation with a similar type of equipment where the costs are known. Since the user has no access to the formula, this method is considered a black-box approach. This requires an experienced estimator in order to receive reliable cost figures.[1]

Reusable Launch Vehicle (RLV) Repair Cycle Simulator (RCCS) – This is a simulation tool designed for the evaluation of alternative resource strategies for the RLV program. The model considers two classes of RLV parts that undergo regular maintenance and include the basic components for modeling maintenance cycle patterns and the ground maintenance schedule.[17]

Resource Data Storage and Retrieval (REDSTAR) – NASA-wide repository of cost, programmatic, and technical data relating to space related projects and programs. The Marshall Space Flight Center's Engineering Cost Office established the repository in 1971.[1]

Reliability, Maintainability Analysis Tool (RMAT) – RMAT is a discrete event simulation tool requiring failure rate and criticality data, maintenance times and manpower requirements, and characteristic life and shape parameters for each assembly/part. RMAT is a general purpose simulation so that a variety of proposed vehicles (space transportation systems as well as space stations) and operational scenarios can be modeled. Given detailed operational reliability and maintainability input data, RMAT estimates aggregate logistics characteristics for a new concept vehicle under study. Insight into the effects of uncertainty in the inputs can be gained, if the uncertainty is defined or estimated as a probability distribution for use with the model. RMAT is used to estimate reliability and maintainability characteristics of new launch concepts based on support requirements derived from both military aircraft and Shuttle program information. It estimates both the scheduled and unscheduled work required to determine the maintenance burden of a future system or a new technology. This analysis can be applied at the subsystem level. The results can then be used to estimate the manpower, processing times, and fleet sizes needed to support the turnaround process for a new concept and the impact of alternate technologies and support strategies. Although RMAT can be used as a standalone tool, it can also be used to pass major support drivers to the Logistics/Cost Model (LCM) for estimating O&S costs. The Cost Element Structure addresses costs for operational processing, plus the logistic, base, and program support required. The input to RMAT/LCM consists of concept description plus the annual flight rate required. Additional input choices require the user to select between scenarios that reflect either the Shuttle or aircraft characteristics for support.[2]

Schedule and Activity Generator / Estimator (SAGE) – SAGE will be released to limited distribution in April 2004. SAGE is a visual basic application employing a friendly graphic user interface to assist in estimating the time it would take to turnaround a reusable space transportation system. Parting from the Shuttle Root Cause Analysis (RCA) database, a user defines the sub-systems that comprise the vehicle of interest. For example, the user would specify an on orbit propulsion system by “adding” a certain number of tanks of oxidizer, a number of tanks for fuel, a series of thrusters of certain thrust, and multiple other applicable sub-system details (such as reliability, among others). Based on this piece by piece system definition, including some Spaceport definition, a series of timelines are generated as the tool automatically matches these chosen objects to a database of associated activities.

This software: Adds detail to operations analysis to estimate turnaround times for reusable space transportation system elements, maintains ease of analysis, leverages off of the Shuttle RCA Operations Database, allows innovative sub-system and system definition, explore improved maintainability, integration of parts, shared sub-systems architectures, and simpler, reduced parts count designs, explore improved reliability and supportability and integrates with existing simulation tools. SAGE was developed specifically to explore creative design options for flight and ground systems as an analyst seeks to trade and understand the balance between system complexity and maintainability, as in parts count, system reliability, and system operational support. For more information, see http://science.ksc.nasa.gov/shuttle/nexgen/Sage_main.htm

SEER – The SEER tools derive cost, schedule, and staffing estimates by assessing the impact of product, organizational, and even operational variables parametrically, using comprehensive knowledge bases. [6]

> **SEER-H** – Predicts the resources required for developing new hardware, including that based on new technologies. These tools provide estimates and analyses of

the cost of labor and materials support regimes for development, production, and fielding.[6]

SEER-S – Estimates costs, labor, schedules, reliability, and risks associated with information technology, embedded system, and commercial software development projects.[6]

Shuttle Root Cause Analysis (RCA) Database - The Shuttle RCA is a user friendly ©MS Access Database which incorporates a front end graphic user interface to present Shuttle processing operations data. The data can be viewed along multiple fields, such as by sub-system, as well as by function, such as turnaround, launch, flight element assembly, or vehicle integration. The database contains operational data such as the duration of thousands of activities, by title, for 8 flows of Shuttle systems that have been selected as especially representative of system throughput capacity. The data can be manipulated, filtered, and used to gain valuable insight into the operations of highly complex systems.

Bottoms up analysis for O&S cost estimating, such as when considering the hours and man-loading of activities can be highly assisted by the duration data base approach of this type tool. The use of such data is limited to the direct and more visible activity that comprises O&S activity. The entire public database as well as summary information is available for download at: http://science.ksc.nasa.gov/shuttle/nexgen/RCA_main.htm

Spacecraft/Vehicle Level Cost Model – This is an online cost model that provides a useful method for quick turnaround, rough-order-of-magnitude cost estimating. The model can be used for estimating the development and production cost of spacecraft, launch vehicle stages, engines and scientific instruments. The SVLCM is a top-level model derived from the NAFCOM database.[1]

Space Operations Cost Model (SOCM) – is an evolving, multi-level, constructive model that estimates the costs and staffing for space operations projects by a comparison of mission characteristics to an advancing "State of the Practice" (SOP) for planetary and Earth-orbiting mission types.

Two level of cost estimates can be made, depending on how much information is available to the cost analyst. High-level project characteristics are used to generate a Level 1 estimate with a ±30% accuracy. Level 1 estimates can be performed with little more than conceptual mission data, tailored to specific mission types. The basis for the Level 1 estimates is a large and diverse database of completed and planned missions (the Reference Mission Set). A more detailed characterization of the project's operations implementation strategy can then used to refine the Level 1 estimate into a Level 2 estimate with improved accuracy.

Workforce estimates in terms of FTEs are derived based on values of operations cost drivers and are not constrained to a specific WBS. The cost analyst can specify output options that include a traditional functional WBS that corresponds well with historical data (see Appendix A below), an activity/process-based WBS that distributes estimates across six general activity classes (Plan/Command/Monitor/Analyze/Develop/Provide) and four major project elements (Spacecraft/Payload/Ground System/Tracking System), and summarized high-level requirements without a WBS.

Input cost drivers are arranged in five categories: mission, programmatics, GDS/MOS, spacecraft, payload. Under each of these five categories is a set of alternatives arranged in order of lowest to highest cost approach. For each operations epoch, the model calculates an estimate of FTEs based on the cost analyst's selections for the Level 1 cost drivers. Each cost driver selection has an associated weighted multiplication factor. These factors are based on the expected contribution from each cost driver category relative to the other categories. The weighting factors for each of the five categories (and for each operations epoch) are based on analyses of historical and projected cost data in the Reference Mission Set.

This FTE estimate for each epoch is then allocated among each element of a WBS using distribution functions derived from analyses of historical data and the relative operations complexity of the mission (which is determined by how close the Level 1 estimate is to the maximum cost operations approach). After this distribution is complete, FTEs can be converted to cost using a Staff Wage Rate Database to assign government/industry/university people with various levels of experience to each WBS function/activity. This completes the Level 1 estimate and generates a cost report showing FTEs and costs for each WBS function in each mission epoch. This estimate is based on top-level requirements imposed on the project and selected high-level implementation decisions made by the project to meet the requirements.

A Level 2 estimate incorporates impacts from specific detailed mission/system implementation inputs. The types of cost drivers included here are usually generated by a project operations team as they refine the implementation strategy and define details of the hardware system designs for the spacecraft, instrument, and ground data/mission operations system to meet the top-level requirements used to generate the Level 1 estimate.

Two key features of the Level 2 estimation methodology are the Operations Cost Driver Database and the Input Influence Tables. These model elements are used to support derivation of Level 1 estimate adjustment factors based on more detailed project inputs relating to the specific implementation strategy chosen to meet project requirements. The Operations Cost Driver Database contains detailed information covering cost drivers for mission design, spacecraft design, GDS/MOS design, and risk mitigation strategy. The database includes a description of the driver, the mission types it applies to, and representative value ranges for the state-of-the-practice, low-, and high-cost approaches. The low-cost field includes operations techniques that allow low-cost operations and the high-cost field represents a more challenging problem or lower risk approach. Input Influence Tables map the cost driver values to the WBS functions/activities. These tables include a row for each cost driver. The columns in the table correspond to each WBS element and each mission operations epoch. The values in these tables are assigned HI/MED/LOW based on the potential impact of a cost driver on a WBS element in a specific operations epoch. If the cost driver value has been determined to be more challenging than the SOP, costs increase from the Level 1 estimate. Likewise, if the cost driver value is less challenging than the SOP, the Level 1 estimate is reduced. If all Level 2 cost drivers are defined to be "nominal," the Level 2 estimate will be the same as the Level 1 estimate independent of the values in the Input Influence Tables (which are only used to capture Level 2 cost driver impacts).

A SOCM update will shortly be released as an integrated feature within NAFCOM (http://nafcom.saic.com/home.html). Changes include new input definitions characterizing current operations technologies and practices, and calibration to an updated Reference Mission Set.

SPSS Tools Suite – Toolkit of statistics, graphs, and reports for use in a variety of applications in commercial, academic, and Government settings. Applications include surveys, marketing, and sales analysis, data mining, quality improvement and statistical research of all types.[9]

Toolkit for Enabling Adaptive Modeling and Simulation (TEAMS) - A decision support tool designed to provide current and future spaceport designers with a knowledge-based infrastructure to develop, maintain, and reconfigure simulation models.[19]

Unmanned Space Vehicle Cost Model - Model containing Cost Estimating Relationships (CERs) for estimating subsystem and component costs of an unmanned space vehicle.[1]

Vision Spaceport - Vision Spaceport is a joint Industry/NASA endeavor to develop a model that enables the user to estimate the cost and cycle time for a wide range of launch system concepts during the concept development phase. The tool is designed to enable design teams to assess the cost and cycle times for the launch site and related infrastructure.[2]

Notes

[1] Reproduced with minor changes from Johnson Space Center cost estimating information Internet page, URL http://www.jsc.nasa.gov/bu2/models.htm.

[2] Reproduced with minor changes from the "Launch Systems Operations Cost Model (LSOCM) Requirements Analysis Report" dated November 16, 2001, by ALE under Contract No. H-34658D, paragraph 2.1, Review of Existing Tools.

[3] Reproduced with minor changes from the ACEIT Internet Homage, http://www.aceit.com/.

[4] Reproduced with minor changes from SAIC's NAFCOM Internet page http://nafcom.saic.com/welcome.asp

[5] Reproduced with minor changes from Price Systems Internet page on the Price Estimating Suite of Tools, http://www.buyfs.com/productservice/priceh.html, and http://www.buyfs.com/productservice/prices.html.

[6] Reproduced with minor changes from Galorath's Internet pages on SEER, http://www.galorath.com/tools_soft.shtm and http://www.galorath.com/tools_hard.shtm.

[7] Reproduced with minor changes from BestEstimate's Internet page, http://www.best-estimate.com./

[8] Reproduced with minor changes from CoCoPro's Internet pagehttp://www.iconixsw.com /Spec_Sheets/CoCoPro.html

[9] Reproduced with minor changes from Appendix K, NASA Cost Estimating Handbook dated Spring 2002.

[10] Reproduced with minor changes from COCOMO's Internet page, http://sunset.usc.edu/ research/COCOMOII/index.html.

[11] Reproduced with minor changes from Open Channel Foundation's Internet page http://www.openchannelfoundation.org/cosmic.

[12] Reproduced with minor changes from Crystal Ball's Internet page, http://www.decisioneering.com/crystal_ball/info_index.html.

[13] Reproduced with minor changes from Palisade's Internet page, http://www.palisade.com/html/decision_analysis_software.html.

[14] Reproduced with minor changes from D4COST's Internet page, http://www.d4cost.com./

[15] Reproduced with minor changes from ESA's Internet page, http://www.estec.esa.nl/eawww/ecom/article/ecom.htm#Chap1.

[16] Reproduced with minor changes from MTI System's Internet page, http://www.costimator.com/costimator.htm.

[17] Reproduced with minor changes from the "Final Report Operations Assessment Tools" dated September 30, 2001, from Kennedy Space Center, paragraph 3.

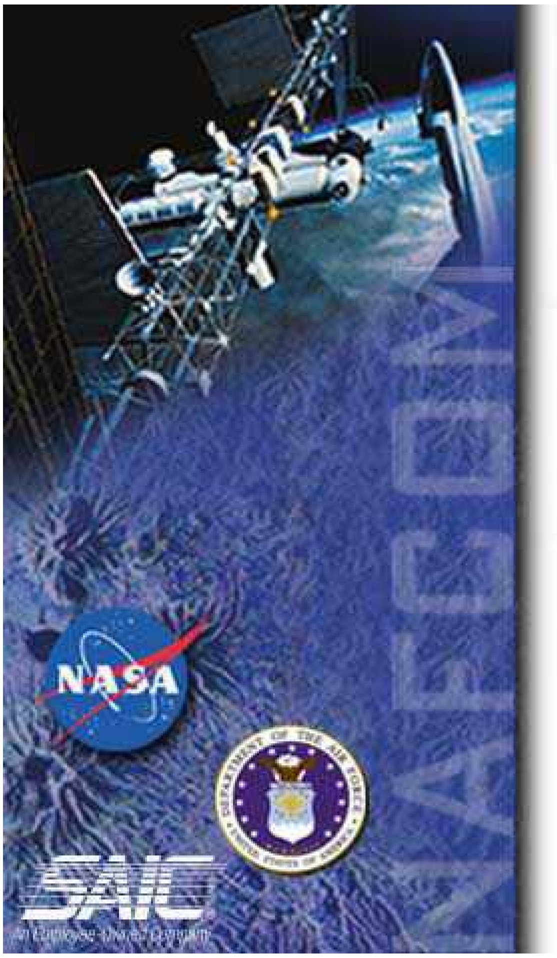
[18] Information from interview with Edgar Zapata, Kennedy Space Center, dated 9 July 2002.

[19] Reproduced with minor changes from KBSI, information provided by Dr. Perakath Benjamin, http://www.kbsi.com/software/smartcost.htm.

[20] Reproduced with minor changes from Vitech's website at http://www.vtcorp.com/ productline.htm

N. NAFCOM Overview

The following is taken, by permission, from the NAFCOM website: http://nafcom.saic.com/



The NASA/Air Force Cost Model (NAFCOM) is an automated parametric cost-estimating tool that uses historical space data to predict the development and production costs of new space programs. It uses parametric relationships to estimate subsystem or component level costs for any aerospace hardware including: earth orbital spacecraft, manned spacecraft, launch vehicle, upper stages, liquid rocket engines, scientific instruments, or planetary spacecraft. This release of NAFCOM includes a major redesign of the user interface for the model. Users of NAFCOM no longer must create their cost estimates by building up a work breakdown structure one element at a time. NAFCOM now uses a template selection wizard to configure a default WBS consistent with the type of spacecraft or launch vehicle to be estimated. As with previous releases of NAFCOM, additional historical data has been added to the database resident in the cost estimating equations and several new capabilities have been added (including time phasing of cost, schedule estimating, a direct link to collaborative environments, and much improved printed output).

NAFCOM introduces several new features, as well as enhancements to existing features that increase the capability and convenience of the model.

New Graphical User Interface – the entire interface has been completely redesigned to improve accessibility and limit the number of input screens that must be accessed to complete an estimate

WBS Template Selection Wizard – a graphical interface wizard provides quick estimate startup by posting questions that set up the most appropriate estimating template; a single screen dynamically changes based on mission and vehicle type selections providing the capability to estimate hundreds of possible vehicle configurations when engine types, re-usability, crew transfer vehicle, upper stages, etc. are considered

Expert knowledge of database embedded in template selection process – all technical data for all subsystems for each template has been pre-loaded to help with estimate set up

Subsystem Level Complexity Generators – nine new complexity generators have been developed including solid rocket motor, propulsion (less engines), orbital maneuvering system, thrust vector control, recovery, landing, thermal control, crew accommodations, and environmental control and life support

Process-based Schedule Estimating – allows the user to view schedules by subsystem and then by the processes required to develop and produce the hardware for each of those subsystems

Time Phased Cost – using the schedules generated in the process-based module, time phasing of cost at the subsystem level has been included

Cost Trades – allows the user to perform "what if" scenarios based on global changes to factors including weight, manufacturing management, engineering management, new design, and STH

Enhanced Engine Estimating – fully integrated versions of Rocketdyne's updated liquid rocket engine cost model, a combined cycle propulsion engine model, and algorithms from the U.S. Air Force jet engine cost model have been included

Integration into Collaborative Environments – NAFCOM estimates are now saved as Excel spreadsheets allowing easy manipulation of model inputs external to the application

Increased Database – the database has been expanded to include to a total of 122 missions

Redesigned Hard Copy Printouts - all printouts have been redesigned and can be sent to a printer or MS Word; printouts include Cost, FBS, Globals, Learning, PRICE Calibration Factors, Technical Inputs, Time Phasing Inputs, and Time Phased Cost

This sheet provides the NAFCOM Input sheet for the global parameters. The full NAFCOM input sheets are available at ceh.nasa.gov

NAFCOM Global Input Parameters

Estimate Name: ____

Preparer's Name: ____

Revision Number: ____

Output Fiscal Year Dollars: ___________________________________

Launch Month: ____________________________________

Launch Year: _____________________________________

Database Normalization: ____ **NASA** ____ **Air Force**

Dollar Units: ____ **Millions** ____ **Thousands**

Learning Curve Type: ____ **Unit (Crawford)** ____ **CUM Average (Wright)**

Decimal Places: ____ **0** ____ **1** ____ **2** ____ **3**

Weight Display: ____ **kgs** ____ **lbs**

Year Type: ____ **Fiscal** ____ **Calendar**

Learning %: _________

Production Rate Per Year: _________

LRIP Step Down %: _________

Production Starts at Unit: _________

Rate %: _________

LRIP Quantity: _________

appendix

O. JUMP START PROGRAM

JUMP START Program

"Where do I start?"

To provide a running start on estimating at any Center by any new/experienced analyst (not just estimators), JUMP START will answer the common predicament faced by a new estimator challenged with a new project. Because of this situation, the estimator may end up asking a familiar question, "Where do I start?" Offering an immediate solution to these recurring situations, IPAO has provided the contractual vehicle for parametric model users to help setup the minimum required project-estimating task, allowing one to two days effort of expert help. The end results, in a relatively short time, are the new estimators--walking alone doing their own estimates.

The use of PRICE or SEER products requires the NASA user to setup the PRICE or SEER files by work breakdown structures and meaningful configuration of the estimating task. To facilitate this initial effort, each user requires a minimum effort that must be augmented by PRICE and SEER consultants to establish the first few steps of creating PRICE or SEER files. PRICE or SEER consultants will "Jump Start" the estimating and programmatic tasks.

Objective: The objective of JUMP START is to provide minimum technical assistance to NASA cost analysts throughout the Agency in conducting cost estimates and other programmatic tasks using PRICE or SEER products. This is a level of effort (labor-hours only) deliverable. Furthermore, each sub-task cannot be more than $3K each or 24 hours of expert consultation.

Task: The contractor will provide support to the NASA PRICE or SEER Model analyst in creating the cost estimate. The support will be in the form of mentoring the NASA PRICE or SEER Model analyst in creating model data files, data collection and evaluation, and model output evaluation.

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appendix O

P. Galorath Incorporated Overview

Galorath Incorporated is the developer and distributor of the SEER™ suite of advanced modeling tools. Project managers, engineers and costing personnel throughout the world turn to Galorath for the industry's most comprehensive set of decision-support and process management tools. Complemented by extensive consulting and support services, Galorath's SEER estimation and analysis tools define, analyze and manage software, hardware and DFM projects, from early concepts through upgrade and maintenance phases. Many of today's major programs utilize the SEER suite of tools as a powerful aid to systems trade offs and project management decisions throughout development, integration, and test to simplify and enhance the management of multiple Integrated Product Teams.

Knowledge Bases

One of the most unique aspects of the SEER tools is their powerful knowledge bases. Establish a baseline estimate specific to your unique project by selecting knowledge bases (Kbases) that best describe your development environment. SEER's Kbases are the most extensive "library" of projects available in a tool. They are created from real, completed estimates that are detailed, quantified and repeatable, providing users with an instant baseline to define, refine and measure against. With more than 100 Kbases to choose from, thousands of scenarios are possible. You can also create your own knowledge base tailored to your environment from historical data to further fine tune your estimating process.

Galorath offers a variety of tools in its suite:

Software Project Control

1. **SEER-SEM™** (Software Estimation Model; Version 7.0 released in 2003)
2. **SEER-Accuscope** (Advanced Sizing; Version 1.0 Released in 2004)
3. **The SEER-SEM™ Client for Microsoft Project** (Converts SEER-SEM Estimates directly into Microsoft Project Plans; Version 1.0 Released in 2003)

These tools are used to build realistic schedule, project cost and staffing estimates; Evaluate quality and reliability potential; Gauge maintenance, upgrade and life-cycle costs; Compare costs and benefits of reuse, off-the-shelf software, or modern development methods.

Example Knowledge Bases for SEER-SEM Aerospace/Defense

Covers all aerospace applications (commercial and defense), weapons systems, space systems, and ground-based mission critical systems.

SEER-SEM Sizing Inputs

- ❑ WBS Description: ______________________
- ☐ Program
- ☐ Component
- ☐ Unit

Platform

	Avionics
	Manned Space
	Missile and Unmanned Airborne

	Shipboard
	Unmanned Space

Application

	Flight Systems
	Mission Planning & Analysis

	Radar
	Signal Processing

Acquisition Method

	Automated Language Conversion		Integrate with Configuration		Minor Rehost
	Concept Reuse		Major Modification		New Development
	Full CASE Environment		Major Reengineering		Redocumentation
	Full Complete Maintenance		Major Rehost		Salvage Code
	Full Design Reuse		Manual Language Conversion		Subsequent Incremental Build
	General		Minor Modification		Sustaining Maintenance
	Generate Code Automatically		Minor Reengineering		
	Integrate As-Is				

Development Method

	Ada Development
	Ada Development with Incremental

	Ada Full Use
	Ada Object Oriented

Development Standard

	1679 With IV&V (Independent Verification & Validation)		498 Business Systems
	2167A		498 Support Systems
	2167A Full Set		498 Weapons Systems
	2167A Minimal Set		DOD 7935

Hardware Project Control

1. SEER-H™ (Hardware estimation & life-cycle cost analysis; Version 6.0 released in 2004)
2. SEER-IC™ (Custom Integrated Circuit Development)

These tools can be applied to all hardware products from simple structures and mechanical devices to hydraulics, electronics, and even complex aerospace or integrated circuit programs. They are used to resolve make-versus-buy decisions; Gauge operations support and life-cycle costs; Analyze complex and interdependent design and production trade-offs.

SEER-H Inputs Electronics Work Elements

WBS Description: ______________________

Selected Knowledge Bases			
Application		Acquisition Category	
Platform		Development Standard	
O&S Description		Class	

Parameter	Least	Likely	Most	Rationale
+ PRODUCT DESCRIPTION				
- Total Printed Circuit Boards				
+ CIRCUITRY COMPOSITION				
- Percent Analog				
- Percent Digital				
- Percent Hybrid				
- Discrete Components Per PCB				
- Surface Mount Discretes				
- Integrated Circuits Per PCB				
- Surface Mount ICs				
- Input/Output Pins Per PCB				
- Clock Speed (MHz)				
- Packaging Density				
- IC Technology				
- Custom Chip Usage				

SEER-H Inputs Mechanical/Structural Work Elements

WBS Description: ______________________

Selected Knowledge Bases			
Application		Acquisition Category	
Platform		Development Standard	
O&S Description		Class	

Parameter	Least	Likely	Most	Rationale
+ PRODUCT DESCRIPTION				
- Weight (lb|kg)				
- Volume (cubic feet|meters)				
+ MATERIAL COMPOSITION				
- Percent Aluminum/Malleable Metal				
- Percent Steel Alloy				
- Percent Commrcl Available Exotic				
- Percent Other Exotic				
- Percent Composite				
- Percent Polymer				
- Percent Ceramic				
- Complexity of Form				
- Complexity of Fit				
- Construction Process				

Recent Additions to SEER-H

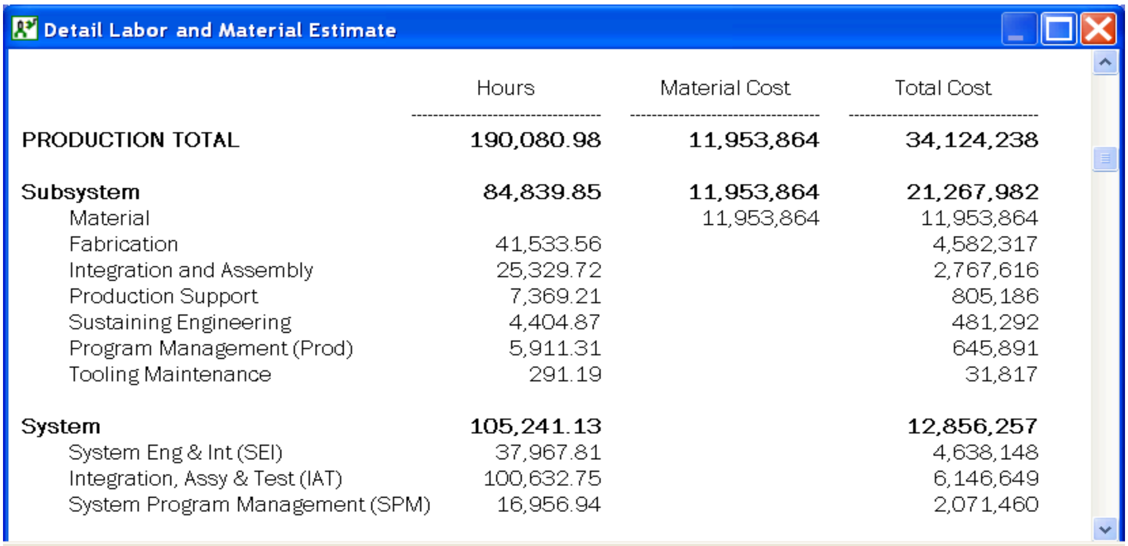
System Level Cost

In 2003, partially funded by the NASA Independent Program Assessment Office (IPAO), Galorath conducted a study on System Level Costs, to improve the ability of our parametric models to estimate them. The result is a system level cost (SLC) capability which ahs been added to our suite of cost models.

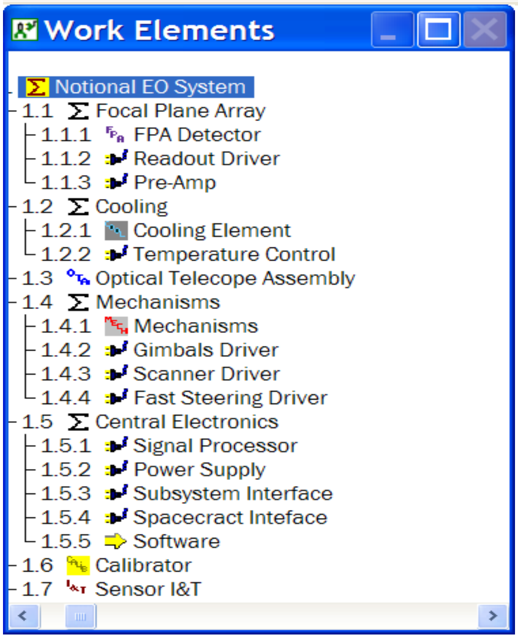
We proceeded in several steps. Data was studied from NASA/Air Force Cost Model (NAFCOM), together with limited data from other sources, to identify system level costs and characterize their statistical relationships to other project costs and project parameters. From the study, we developed cost estimating relationships based on the statistics and ultimately modified our SEER-H (hardware) model to output costs at system level for the first five of the following six NAFCOM cost categories:

- Systems Engineering and Integration
- Integration, Assembly and Checkout
- Ground Support Equipment
- Program Management
- System Test Operations
- Launch and Orbital Operations Support

The following snapshot is an example of a System Level Cost estimate report:


Detail Labor and Material Estimate

	Hours	Material Cost	Total Cost
PRODUCTION TOTAL	190,080.98	11,953,864	34,124,238
Subsystem	84,839.85	11,953,864	21,267,982
Material		11,953,864	11,953,864
Fabrication	41,533.56		4,582,317
Integration and Assembly	25,329.72		2,767,616
Production Support	7,369.21		805,186
Sustaining Engineering	4,404.87		481,292
Program Management (Prod)	5,911.31		645,891
Tooling Maintenance	291.19		31,817
System	105,241.13		12,856,257
System Eng & Int (SEI)	37,967.81		4,638,148
Integration, Assy & Test (IAT)	100,632.75		6,146,649
System Program Management (SPM)	16,956.94		2,071,460



SpyGlass

This SEER-H Plug-in will substantially improve the capability of SEER-H to estimate development and production costs of space-based electro-optical sensor devices (EOSDs). The following is a list of the new work element types for the plug-in.

- Optical Telescope Assembly
- Focal Plane Array
- Cooler
- Mechanism
- Calibrator
- Integration, Test, & Calibration

SEER-DFM™

(Design for Manufacturability) with Composites Plug-in. This tool allows you to evaluate any part, process or assembly alternative; Analyze manufacturing trade-offs; Build realistic labor, materials and tooling estimates. You can make smart decisions about trade-offs and alternative approaches before manufacturing begins, because you can choose the most efficient production and assembly methods.

Contract Information

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appendix

Q. PRICE Systems LLC Overview

PRICESystems, LLC is the developer and distributor of the PRICE Estimating Suite of parametric modeling tools to be used by engineers, estimators, and project managers for Risk Analysis, Independent Assessment, Contractor Validation, Early Concept Evaluation, Structure and Material Studies, Mission Affordability Studies, What If Analysis, and Total Life Cycle Cost.

PRICE provides training and consulting services that include PRICE For You custom courses, access to the PRICE KnowledgeNetwork, better planning, budgeting and estimating training and mentoring programs, data collection and collaboration process implementation as well as the integration of collaborative PRICE Estimating Suite engineering centers.

About The PRICE Estimating Suite

The PRICE Estimating Suite is a dynamic hardware and software project development solution used to estimate cost and schedules, assist in product planning, and improve project control. The PRICE Estimating Suite consists of the following applications: The PRICE Hardware Estimating Model, PRICE Hardware Life Cycle Estimating Model, PRICE Software Development and Support Cost Model, PRICE Electronic Module, and Microcircuit Estimating Model. As part of the PRICE Estimating Suite, the PRICE KnowledgeNetwork delivers industry benchmark metrics to jumpstart estimates and process improvement, and the PRICE Solution for Microsoft Excel provides a two-way interface that automates what-if analysis, trade-offs, calibration efforts, reports, and proposals.

About the PRICE KnowledgeManager

The PRICE KnowledgeManager is a companion application to the PRICE Estimating Suite that facilitates the process of converting data into knowledge. While supporting qualitative keywords, attributes and structural hierarchy in a collaborative web-enabled environment, the PRICE KnowledgeManager also empowers PRICE Estimating Suite customers to harvest, store, and reuse PRICE hardware project cost elements through the use of powerful trend analysis capabilities.

About PRICE Systems

PRICE Systems is a global leader of integrated planning and estimating solutions that provides software licensing and professional services to Fortune 1000 companies. After 25 years of valuable service and experience to the Aerospace and Defense Industry, PRICE Systems was independently purchased from Lockheed Martin in 1998. Today, PRICE Systems is headquartered in Mt. Laurel, New Jersey with global offices in Dayton, OH, Lexington Park, MD, Los Angeles, CA, Hampshire, UK, Paris, FR, Ruesselsheim, GR and Seoul, KR. Visit PRICE Systems at www.pricesystems.com.

Success with NASA

- NASA has expanded its license to include KnowledgeManager.
- PRICE has added NAFCOM 99 to the KnowledgeBases for KnowledgeManager.
- PRICE has designed custom training courses for NASA and a Jump Start and Turnkey programs to assist analysts with estimates and implementation of the PRICE Estimating Suite.
- PRICE has assisted JPL and MSFC with calibration.
- Anthony DeMarco, President of PRICE Systems, was a member of the International Space Station Management and Cost Evaluation Task Force. "Through our framework of innovative solutions and services, PRICE Systems will provide NASA with the tools and methodologies needed to meet fiscal year success."

Contact Information

PRICE Systems, LLC
17000 Commerce Parkway, Suite A
Mt. Laurel, NJ 08033
Tel: 1-800-43-PRICE Fax: 856-608-7247

appendix q

PRICE H INPUT SHEET

1. NAME OF UNIT	2. NAME OF CONTRACTOR	3. WORK BREAKDOWN STRUCTURE ELEMENT NO.

4a. CONTRACT LINE ITEM NO.	5. QTY OF THIS UNIT USED IN AND NAME OF NEXT HIGHER ASSY
4b. REFERENCE TECH VOL.	6. NAME OF SYSTEM OR SUBSYSTEM

7a. SOURCE OF UNIT	7b. IF MANUFACTURED, ENTER % NEW DESIGN REQUIRED & % DESIGN REPEAT			
☐ NEW DEVELOPMENT	PERCENT OF TOTAL STRUC/MECHANICAL		PERCENT OF TOTAL ELECTRONIC	
☐ PURCHASED (SEE NO. 8)	% New Design		% New Design	
☐ - *OFF THE SHELF*	% Des Repeat		% Des Repeat	
☐ -*CUSTOM MADE*	7c. IF PURCHASED OR GFE, ENTER % MODIFICATION REQUIRED			
☐ GFE	PERCENT OF TOTAL STRUC/MECHANICAL		PERCENT OF TOTAL ELECTRONIC	

8. IF PURCHASED	PROTOS UNIT COST $	PROD. UNIT COST $		☐ FIXED ☐ TO BE ESCALATED	YEAR $
9. WEIGHT AND VOLUME	TOTAL UNIT WEIGHT (LBS)		STRUCTURE WEIGHT	UNIT DIM OR VOL	

10. STRUCTURAL INTEGRATION & TEST DESCRIPTION

☐ **Simple interface** Integration: Simple boltdown, flange or mounting feet utilized; up to 6 fasteners; minimal tools Test: Inspection, but no actual testing required	☐ **New, but familiar & routine interface** Integration: Medium precision alignment/fit between items; some special tools used; multiple surfaces; some adjustment of surfaces Test: Performance meets specifications
☐ **Routine interface** Integration: Alignment and bolt-down; up to 12 fasteners; standard tools Test: Clearances and dimensions; observe any mechanical ac	☐ **Moderately difficult interface** Integration: Requires medium precision alignment; requires specials tools and/or fixtures Test: Includes dimension and performance measurement; needs some special gauges and custom tests
	☐ **Difficult interface** Integration: Requires precision alignment using special jigs & tools, possibly monolithic; matching and/or timing adjustment Test: Requires full specification testing; requires set of test gauges and special test facilities

11. ELECTRONIC INTEGRATION & TEST DESCRIPTION

☐ **Simple Interface** Integration: Plug-in electronic connection Test: If testing is required, then auto-test; no calibration	☐ **Moderately difficult interface** Integration: Several plug-in connections; number of wire connections Test: Requires adjustment and calibration of several items
☐ **Routine Interface** Integration: Plug-in connections; possible wire connections Test: Some auto/semi-auto tests; some adjustments	☐ **Difficult interface** Integration: Multiple connectors/connections Test: Significant testing with adjustment and calibration required; probable interaction with other items, Vendor, or CFE integration
☐ **New, but familiar & routine interface** Integration: Plug-in electronic connection; some wire conne Test: Semi-auto tests, adjustments, possible simple calibrations.	☐ **Advanced State-of-the-Art interface** Integration: Many connectors/connections Test: Heavy auto and manual testing; full calibration and adjustments with many other Vendor or CFE items; lengthy time and documentation requirements.

PRICE H INPUT SHEET (CONT.)

12. ENGINEERING COMPLEXITY

12a. SCOPE OF ENGINEERING DESIGN EFFORT

☐ **Simple mods:** Simple modifications to an existing design	☐ **New product:** New design different from established product line. Uses existing materials and/or electronic components.	☐ **Advance SOTA:** State of the Art being advanced or multiple design paths required to reach goal.
☐ **Extensive mods:** Extensive modifications to an existing design	☐ **New technology:** New design that is different from established product line. Requires in-house development or new electronic components or new materials and processes.	
☐ **New design:** New design within established product line; continuation of existing state of the art.		

12b. EXPERIENCE OF ENGINEERING DESIGN TEAM

☐ **Very experienced:** Extensive experience with similar type designs. Many experts in field. Top talent leading effort.	☐ **Average:** Normal experience. Engineers have completed similar type designs	☐ **Inexperienced.** Engineers are unfamiliar with the design. Many are new to the job.
	☐ **Mixed Experience:** Some are familiar with this type design, others are new to the job.	

13. HARDWARE/SOFTWARE INTEGRATION COMPLEXITY

13a. SCOPE OF SOFTWARE/HARDWARE INTEGRATION EFFORT

☐ **Existing + New (Simple)** Existing HW with new SW or new HW with existing SW. Simple interfaces, normal timing.	☐ **Mod + New (Complex):** Modified HW with new SW or new HW with modified SW. Complex interfaces and critical timing.	☐ **Purchased/Furnished:** HW or SW is purchased or furnished. Timing and communications problems are anticipated.
☐ **Mod + New (Normal):** Modified HW with new SW or new HW with modified SW. Normal interfaces and timing.	☐ **New + New.** New HW and new SW design. New interfaces with normal timing and transfer rates.	

13b. EXPERIENCE OF SOFTWARE/HARDWARE INTEGRATION TEAM

☐ **Very experienced.** Personnel with extensive experience in integration. Some top talent. Control/Change Procedures (C/CPs) are in place	☐ **Average.** Normal Crew, some experience. C/CPs are in place	☐ **Inexperienced.** Crew is inexperienced. Many new hires. No procedures.
	☐ **Mixed Crew.** Some experience in integration. Some new hires. C/CPs are inadequate	

14. UNIT QUANTITY AND SCHEDULES

PROGRAM PHASE	QUANTITIES		SCHEDULE		
	IN ENGINEERING SHOP (Include non-deliverables)	IN PRODUCTION FACILITY (Include non-deliverables)	PHASE START DATE	FIRST UNIT COMPLETE DATE	LAST UNIT COMPLETE DATE
DEVELOPMENT					
PRODUCTION					

15a. DESCRIBE PRODUCTION PROCESS (Automated-Skilled Labor, Etc.)	15b. DEGREE OF AUTOMATION	MECHANICAL	ELECTRONICS	15c. INDICATE LEARNING CURVE- INDUSTRIAL (Material, Labor and Type of L/C)
MECHANICAL	MAXIMUM	☐	☐	
	NORMAL	☐	☐	
ELECTRONICS	MINIMUM	☐	☐	

16. REMARKS (Use additional pages as necessary)	17. NAME AND PHONE NUMBER OF PREPARER

appendix q

CONCEPTUAL COMPLEXITY GENERATOR

1. NAME OF UNIT	2. NAME OF CONTRACT	3. WORK BREAKDOWN STRUCTURE ELEMENT NO.

4a. CONTRACT LINE ITEM NO.	5. QTY OF THIS UNIT USED IN AND NAME OF NEXT HIGHER ASSY
4b. REFERENCE TECH VOL.	**6. NAME OF SYSTEM OR SUBSYSTEM**

MCPLXS - CONCEPTUAL COMPLEXITY GENERATOR FOR STRUCTURAL ITEM

7. CONSTRUCTION AND FUNCTION

☐ Sheet Metal	☐ Machined	☐ Laminated construction
☐ Support, no moving parts	☐ Machined parts for support/containment	☐ Laid up flat surface with stiffness
☐ Containment under static forces	☐ Precision machined parts in assembly	☐ Structural frames, supports, bulkheads
☐ Bears significant dynamic forces	☐ High precision optical components	☐ Cylindrical shaped, filament wound

8. PRIMARY MATERIAL	9. PLATFORM	
☐ Aluminum alloys, bronze	☐ Manned Space	☐ Mobile Ground - Military
☐ Steel alloys, yellow brass	☐ Unmanned Space	☐ Mobile Ground - Missiles (Grd-Air, Grd-Grd)
☐ Tungsten, copper alloys	☐ Airborne Missiles (Air-Air, Air-Grd)	☐ Ground - Military
☐ Titanium, Ni-based alloys	☐ Airborne Military	☐ Ground - Commercial
☐ Matrix composites, glass, ceramics	☐ Airborne Commercial	☐ Other

10. NUMBER OF STRUC PARTS	11. MACHINABILITY, Enter material to be machined (e.g., Al 2024)

MCPLXE - CONCEPTUAL COMPLEXITY GENERATOR FOR ELECTRONIC ITEM

12. ELECTRONIC DESCRIPTION BY PERCENTAGE OF CONTENT

TYPE	%DISC	%SSIC	%MSIC	%LSI	%VLSI	VHSIC GA	VHSIC MEM
ANALOG AUDIO							
ANALOG RF/VIDEO							
DIGITAL							
DISPLAY							
DISPLAY NO CRT							
TRANSMITTER							
POWER SUPPLY/VLSI MEM							

13. QUALITY ADJUSTMENT

	Parts Qual	Description/Examples
☐	S	QPL spacecraft and other very long life projects
☐	S1	Very, very high rel proj; e.g., manned spacecraft
☐	B	Very high rel parts; used in inaccessible places
☐	B1	High qual parts; e.g., civil aircraft; safety eqmt
☐	B2	Rel chosen to reduce maint costs of long-life eqmt
☐	D	Brand names, quality components
☐	D1	Commercial grade; some infant mortality allowed
☐	Other	

14. NAME AND PHONE NUMBER OR PREPARER

15. REMARKS

(Adjustments to inputs, computation of MCPLXS/E calibration factors, comparisons to PRICE or NAFCOM calibrated table values, etc.)

R. NASA Lessons Learned Information System (LLIS)

http://llis.nasa.gov/

NASA Lessons Learned Information System (LLIS)

Lessons learned are often spoken about, however, they are not documented and shared often enough. They are important to build consistency and to ensure credibility. Methodology, assumptions, etc., may prove to be invalid, incomplete, or right on target. This section should highlight those areas. Additionally, the results of the cost estimate should provide lessons learned in the area of general cost information. For example, a lesson learned might be that system costs can be reduced or eliminated by ordering in scale. Learning curve lessons learned are those cost savings lessons that are achievable and applicable regardless of the program. Customer feedback is also important to incorporate in the lessons learned. Most importantly, lessons learned should be shared with the cost estimating team and the NASA CEC to ensure better estimates in the future.

The NASA Lessons Learned Information System (LLIS) can be consulted before and during an estimate. At the completion of the estimate, the LLIS should be populated with lessons learned from the estimate. As in the case of documenting the estimate, it is important to document lessons learned during the process. It is also advisable and beneficial to have a team meeting at the end of an estimate to brainstorm and identify lessons learned for future estimates.

See Appendix Z for a different view of NASA cost estimating and analysis lessons learned.

S. Process-Based Modeling

Process-based modeling is a recent innovation in cost modeling. It is the result of the desire for a greater level of fidelity than current state-of-the-art weight-based estimating models provide. Weight-based models estimate the “what” of cost, while process-based models estimate the “how.” Process-based models estimate cost by relating cost drivers such as management complexity, inheritance, and engineering management, to the processes involved in the design, development, testing, evaluation, and production of a project. The cost drivers affect cost in one of three ways: adding or removing a process, changing the number of times a specific process occurs, or by changing the amount of time required to perform a specific process. For example, the amount of testing to be performed for a project may determine whether or not qualification testing is performed. Also, design is an iterative process, and the amount of new design for the project will help determine the number of iterations required in the design process. The level of detail results in the ability to determine why a project costs a certain amount and which processes are driving the cost. Thus a process-based model, in addition to providing an estimate, also serves as a communication tool with management and with project personnel. Process-based models are not meant to replace traditional parametric models, but rather they supplement traditional models.

Process-based models can have as much or as little detail as desired. Highly-detailed, bottoms-up process-based models may be preferred if the end user is an engineer, while top-down, intermediate-level models may be preferred if the end user is a cost analyst or a manager.

Process-based models can be created using Excel spreadsheets and run using standard desktop PCs. Process-based model development requires interaction with subject-matter experts to help determine the correct process flows for each hardware element and for systems engineering and management functions. The process flows form part of the logic of the model. There are two ways to develop the cost of the model – engineering equations and physical limits, and statistically based models. Statistically based models offer the ability to calibrate a process model to one or more analogous projects by subsystem, such as Space Shuttle, Space Station, or Cassini. In order to build a statistically based model that is calibrated to one or more projects, a great deal of data acquisition is required. For the NAFCOM process-based model, detailed WBS- and function-level time-phased cost and schedule data were collected for Shuttle, Apollo, Gemini, Cassini, Chandra, and Galileo.

T. REDSTAR DATABASE

The Resource Data Storage and Retrieval (REDSTAR) Library is a NASA-owned and controlled repository containing over 28,000 documents dating back to the early 1960's related to spacecraft cost, technical, and programmatic information. The physical library is located at Science Applications International Corporation's (SAIC) Research Park facility in Huntsville, Alabama and is supervised my a Masters-degreed librarian. REDSTAR contains the source data for many of NASA's modeling efforts, including NAFCOM. Data from over 540 companies, government agencies, universities, and aerospace societies is represented within the library. Information from total program to subcomponent levels can be found for spacecraft buses, attached payloads, engines, launch vehicles, upper stages, scientific instruments, and aircraft. The library also holds many other types of documents and data resources including cost models, cost estimating tools, schedules, ground and launch operations data, mission operations data, POPs, 533s, and documents related to Lessons Learned and New Ways of Doing Business (NWODB).

The REDSTAR Library Website (redstar.saic.com) contains approximately 1,000,000 pages of information from 7,500 of the 27,000+ documents in the REDSTAR Library. Search routines allow simple to comprehensive searching and documents can be downloaded for local viewing, printing, or distribution. SAIC hosts, administers, and maintains the website which is accessible to approved NASA employees, other Government employees, and non-prime space contractor personnel only. All non-government employees are required to obtain a NASA sponsor who is responsible for verifying both the need to know and citizenship of the requester. The MSFC VS20 Director, or his designee, has final approval on all user requests. The REDSTAR Library website was recently modified to provide more secure protection of potentially sensitive data. Due to this, all users have been required to re-apply for passwords. The REDSTAR Library Website is now considered to have the potential for containing ITAR restricted data and therefore the Export Control Laws are applicable.

Users are approved for access to the REDSTAR Library Website by completing a REDSTAR Website User Access Request Form which can be obtained at redstar.saic.com and obtaining the proper approval signatures on-file with the Systems Management Office (SMO) at MSFC. Once a user is approved, a login and password are assigned and activated which will allow the user access to the REDSTAR Library Website. When logging in, the user is authenticated by the system before access is granted.

U. JPL's Parametric Mission Cost Model (PMCM) Introduction and Summary

Leigh Rosenberg, JPL

Chris Swan, JPL

February 12, 2004

Introduction

The Parametric Mission Cost Model (PMCM) is a tool that estimates the cost of unmanned earth-orbiting and deep space missions that are flown by JPL. It is Microsoft excel-based and uses a relatively small number of technical inputs to generate a detailed and fairly accurate cost estimate by Work Breakdown Structure (WBS) element and project phase. It can accept probabilistic inputs and perform Monte Carlo simulations to find the likely statistical range around a most-likely project cost.

History

In 1995, as a way to make JPL competitive with commercial spacecraft contractors, and also to deal with the large number of proposals being generated, JPL formed an Advanced Projects Design Team (APDT), also known as Team X. Using concurrent engineering tools and processes, Team X performs rapid and thorough designs and reviews of varying space missions. These analyses can also demonstrate feasibility and provide cost estimates of future missions and assess the potential of new technologies. To date, Team X has conducted over 600 studies.

Even with the accelerated pace of mission design that Team X brought to JPL, the increasing number of proposals being produced at JPL made it worthwhile to develop a new cost-estimating tool that could emulate the Team X cost process with a high degree of accuracy. This led to the development of PMCM v.1 in 1998 by Leigh Rosenberg. Currently PMCM v.3 is the most recent model and version 4 is presently under construction.

Background

PMCM is comprised of a series of cost estimating relationships (CERs) that represent the cost of each WBS element. The CERs were derived via regression from about 150 Team X studies. These cost relationships take into account the key engineering drivers that affect the cost of the mission. True to its name, PMCM can accept probabilistic inputs and use them to generate a probable cost with its statistical range. This is done using a Monte Carlo simulation that randomly generates each the cost of each independent variable and tabulates the results.

Benefits

PMCM gives an accurate picture of the cost of an unmanned space mission, and it does this relatively quickly (within a few hours after the inputs are obtained). The estimates have proven to be quite accurate when compared to historical, actual costs of recent JPL missions and as compared to pre-project grass roots estimates. The model's results are useful in all planning and early implementation stages of a project.

Limitations

A model is only as good as the data it is based on and PMCM is no exception. It is important to remember that this model was built using data from the types of missions that are implemented at JPL. PMCM is not suitable for use on manned missions and its accuracy is reduced for missions that lack heritage to JPL and Team X missions.

V. NASA New Start Inflation Indices

TO: All Cost and Budget Personnel

FROM: Deputy, Chief Financial Officer (Resource Management)

SUBJECT: NASA New Start Inflation Index

Many of you use the NASA New Start Inflation Index (latest version attached) to make adjustments to cost numbers to reflect different “base-year dollars”. Code BC maintains this index. In the past, it has been derived using a weighted average of commercially available inflation indices that represent the “market basket” of goods and services that NASA purchases. As such, it is meant to reflect price changes for the composite group of contractors, vendors and suppliers with whom NASA deals.

As a result of recent discussions with OMB, we have decided to modify the way the out-years portion of the index is developed. Instead of commercially available projections of future inflation, we will begin using OMB projections of future inflation. We are not changing the way we calculate the past-years portion of our index—it will continue to be based on actual inflation data we obtain from commercial sources.

This approach will make the out-years portion of the index consistent with OMB inflation projections and will keep the past-years portion of the index consistent with actual historical inflation. Code BC will continue to distribute the index annually.

Two other points of guidance relative to inflation: (1) For situations where a project has existing contracts, the use of those contractors’ DCAS forward pricing rates should probably be preferred over the general index being discussed here. (2) We recommend that for long-term trade studies (more than 5 years out) that are comparing options and are not being used directly for a budgetary input, there is no need to inflate to future year prices—staying in constant dollars generally makes the comparisons more understandable in terms of today’s yardstick of prices.

If you have any questions about this index or its use, please contact Joe Hamaker in Code BC at 202.358.2495 (or joe.hamaker@nasa.gov).

NASA New Start Inflation Index

The "new start" inflation index should be appropriately used. It is intended to estimate escalation when contractor forward pricing rates are not known. It should not be used if better (contractual) information is available. This index should be used for new R&D developments only and does not apply to either operations or support service contractor costs.

	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	
	2.0%	1.9%	2.0%	2.1%	2.1%	2.0%	2.0%	2.0%	2.0%	2.0%	
FROM	1.020	1.019	1.020	1.021	1.021	1.020	1.020	1.020	1.020	1.020	FROM
1990	1.465	1.493	1.523	1.555	1.588	1.620	1.653	1.686	1.720	1.755	1990
1991	1.414	1.441	1.470	1.501	1.533	1.564	1.595	1.627	1.660	1.694	1991
1992	1.344	1.370	1.397	1.427	1.457	1.486	1.516	1.547	1.578	1.610	1992
1993	1.290	1.315	1.341	1.370	1.398	1.427	1.456	1.485	1.515	1.546	1993
1994	1.251	1.276	1.301	1.328	1.356	1.384	1.412	1.440	1.470	1.499	1994
1995	1.220	1.243	1.268	1.295	1.322	1.349	1.376	1.404	1.432	1.461	1995
1996	1.190	1.213	1.237	1.263	1.290	1.316	1.343	1.370	1.397	1.426	1996
1997	1.173	1.196	1.220	1.246	1.272	1.298	1.324	1.351	1.378	1.406	1997
1998	1.161	1.183	1.207	1.232	1.258	1.284	1.310	1.336	1.363	1.391	1998
1999	1.138	1.160	1.183	1.208	1.233	1.258	1.284	1.310	1.336	1.363	1999
2000	1.102	1.123	1.145	1.169	1.194	1.218	1.243	1.268	1.294	1.320	2000
2001	1.066	1.087	1.109	1.132	1.156	1.179	1.203	1.228	1.252	1.278	2001
2002	1.040	1.061	1.082	1.104	1.128	1.151	1.174	1.198	1.222	1.247	2002
2003	1.020	1.040	1.060	1.083	1.106	1.128	1.151	1.174	1.198	1.222	2003
2004	1.000	1.019	1.040	1.062	1.084	1.106	1.128	1.151	1.174	1.198	2004
2005		1.000	1.020	1.041	1.063	1.085	1.107	1.129	1.152	1.175	2005
2006			1.000	1.021	1.043	1.064	1.084	1.107	1.130	1.152	2006
2007				1.000	1.021	1.042	1.062	1.084	1.106	1.129	2007
2008					1.000	1.020	1.041	1.062	1.083	1.105	2008
2009						1.000	1.020	1.041	1.062	1.083	2009

Note: Use 2.0% for out years

W. Spreading Model (Based on Beta Curve)

The beta curve, also known as the normal distribution curve, was developed at JSC in the 1960s. It is used for spreading parametrically derived cost estimates and for R & D type contracts whereby costs build up slowly during the initial phases, and then escalate as the midpoint of the contract approaches.

A beta curve is a combination of percent spent against percent time elapsed between two points in time (see exhibit below). For example, if an analyst was interested in estimating the software for a satellite program, a rule of thumb is to use a beta curve 60/40 (60% of the funds spent in the first half of the project and the other 40% in the second half) for space cost spread and 40/60 (40% of the funds spent in the first half of the project and the other 60% in the second half) for ground cost spread between two designated dates (e.g., January 1, 2002 to December 31, 2006).

Beta Curve Cost Spread Factors

Spread Factor Categories

(First Half / Second Half)

50:50

60:40 for 40:60 or 30:70, use percents in reverse sequence

70:30

		Annual Factor (percent) By Year									
OGIVE	Yrs	1	2	3	4	5	6	7	8	9	10
50:50	1	100									
	2	50	50								
	3	21	58	21							
	4	10	40	40	10						
	5	6	26	36	26	6					
	6	4	17	29	29	17	4				
	7	3	12	22	26	22	12	3			
	8	2	9	17	22	22	17	9	2		
	9	1	7	13	19	20	19	13	7	1	
	10	1	5	11	15	18	18	15	11	5	1
60:40	1	100									
	2	60	40								
	3	31	53	16							
	4	19	41	32	8						
	5	12	31	33	20	4					
	6	9	23	28	24	13	3				
	7	6	17	24	24	18	9	2			
	8	5	14	20	22	19	13	6	1		
	9	4	11	16	19	19	15	10	5	1	
	10	3	9	14	17	17	16	12	8	3	1
70:30	1	100									
	2	70	30								
	3	45	42	13							
	4	28	42	23	7						
	5	18	38	25	14	5					
	6	12	32	26	17	10	3				
	7	9	26	25	18	12	7	3			
	8	7	21	24	18	13	9	6	2		
	9	5	16	23	18	14	10	7	5	2	
	10	4	13	21	18	14	11	8	6	4	1

Beta Curve Cost Spreading

Another way of spreading costs using the beta curve is to express the cumulative cost fraction as a function of the cumulative time fraction, T:

Cum Cost Fraction = $10T^2(1 - T)^2(A + BT) + T^4(5 - 4T)$ for $0 \leq T \leq 1$

Where:

- A and B are parameters (with $0 \leq A + B \leq 1$)
- T is fraction of time
- A=1, B= 0 gives 81% expended at 50% time
- A=0, B= 1 gives 50% expended at 50% time
- A=0, B= 0 gives 19% expended at 50% time

This formula and methodology was extracted from the NASA Systems Engineering Handbook (http://ldcm.gsfc.nasa.gov/library/NASA%20Syst%20Eng%20Handbook.pdf).

Finally, a simple online cost spreading calculator is located at http://www.jsc.nasa.gov/bu2/beta.html. This online tool can be used to spread the estimated cost of a program up to eight years. The calculator uses a beta curve to determine the amount of money to be spent in each year based on the fraction of the total time that has elapsed.

X. Orbital Space Plane (OSP) Cost Credibility Team (CCT)

The Cost Credibility Team (CCT) was organized to provide cost estimating and analysis support to the Orbital Space Plane (OSP) program. The motivation for establishing the CCT was provided by the Office of Management and Budget, who gave an action to NASA to provide consistent, credible OSP life cycle cost estimates that were validated by independent review. The Engineering Cost Office (ECO) at MSFC was tasked by the OSP Program Manager to formulate a team to address the OMB action.

In response to the OSP program request, the ECO established a team consisting of cost analysis professionals from MSFC, JSC, and KSC under the leadership of Andy Prince. The ECO also formulated the outlines of a Cost Credibility Plan (CCP) to address the issues raised in the OMB action. The plan outlined by the ECO and expanded by the CCT consisted of three distinct, but interrelated tasks: Benchmarking; Process Discipline; and Innovation.

Benchmarking was an in-depth look at how well our models estimated the cost of historical spaceflight systems. Government and contractor data was used in this analysis. Several cost model shortcomings were identified that defined requirements for improvements to our models.

Process Discipline was focused on performing cost estimates for the program, interfacing with contractor cost organizations, and performing reconciliation activities with the life cycle cost estimates delivered by the OSP study contractors. A central tenet of process discipline was the establishment and maintenance of supportable, defendable, credible, and documented cost estimating processes that were followed to ensure consistency in all program estimates.

Innovation was the improvement of existing and development of new costing capabilities. Using the lessons learned from the Benchmarking activity, improvements to NAFCOM were identified and implemented. In addition, a process based model for NAFCOM was developed to address the data gap that has resulted due to the time lag since the last development of a human rated launch system (Shuttle).

All CCT activities were closely coupled to ensure that the cost estimates were based on the best knowledge and tools available. Because high quality cost estimates were important to meeting program milestones, a detailed schedule was developed and linked into the program schedule. Finally, the program provided funding to enable the execution of the CCP.

Following the cancellation of the OSP program, the CCT was requested to document the lessons learned from our activity. The following is a summary of our submission.

Delineating the activities of the CCT into Benchmarking, Process Discipline, and Innovation proved to be an effective way of organizing the work. However, in the future, Data Collection should be addressed as a separate task.

Benchmarking of our cost models, both by the contractors and internally, was an excellent way to discover strengths, weaknesses, and areas for improvement. However, the benefits were reduced by inconsistencies in how the models were used and a lack of data from the contractors.

The team approach to cost estimating was a good way to even out the biases and leverage the experience and knowledge that each person brings to the group.

Multi-center involvement was beneficial for capturing perspectives and knowledge from across the Agency, as well as providing additional resources to accomplish the task.

Working directly with the contractors enabled the Government to gain insights into their cost estimating approaches, and fostered a sense of common purpose.

Having a single point of contact into the program proved to be a good way to stay integrated. However, as the work evolved the need to interface with other program managers and keep multiple program customers happy made coordination and integration a challenge.

Review of the CCT's processes and products by an independent, outside expert provided valuable insight and helped keep the team focused on supportable, defendable, and credible cost estimates.

Y. IPAO Seven Principles

By Mike Benik

Good morning everyone. I'm delighted to have this opportunity to address this distinguished audience.

Joe, thank you for the kind introduction. I hope that I can bring to the table something that all of you can take with you and use.

Last week Admiral Steidle rolled out the new NASA Office of Exploration Systems (Code T) organization. In the Q&A session that followed he mentioned that he needs to find some independent cost estimators. It seems like he could have his pick this week in Houston. This is a great turnout for this symposium.

I admit upfront that I am not a practitioner of cost estimating. However, I am an informed consumer of the products you deliver. I and senior NASA decision makers depend on the cost estimates you bring forward. So, I have more than a casual interest in cost estimates and what goes into them.

As you heard, my organization is the Independent Program Assessment Office, otherwise known as the IPAO. Some project managers might label my folks as "boarding parties." You know the cliché: "we're from Headquarters and we're here to help." Occasionally we get the courteous reply "I could use all the help you bring…" I can assure you though that when my people say—I'm here to help—they mean it.

The IPAO mission is to support Mr. Sean O'Keefe regarding the approval of program development and activities such as conducting independent, multidisciplinary analyses and assessments of evolving aerospace systems—designs moving from an advanced concept to those warranting consideration as a fully approved project or program.

In a nutshell, the mission of IPAO is to assure the Administrator that the development efforts and mission operations are being planned and conducted on a sound engineering basis with proper controls and management of risk. This is where you come in as an important member of the team.

In any review performed by IPAO the technical and programmatic aspects are given a thorough assessment. But in the end it always seems to come down to the familiar question, "…but what will it cost?" I will not attempt today to opine about the nature of this important question—"what will it cost?"

Your illustrious leader, Joe Hamaker, has a whole dissertation that deals with that question. In that particular presentation, Joe takes you on a voyage starting with the origin of the art of estimating, the birth of NASA, the early NASA years, the Shuttle era rife with the promise of low cost, then the declining budgets and rising costs, and to almost today—he ends the presentation at year 2000. Joe, we're looking forward to your update.

I would like to highlight one of the concluding observations Joe made in his presentation. He emphatically states "NASA cost estimators have played a crucial role in every major historical program." I couldn't agree with him more. And I extrapolate further—you will continue to play a crucial role in NASA—make no mistake about it. Just last week Admiral Steidle emphasized the need for good cost estimating in the ventures ahead.

Have you been reading the papers? As NASA forges ahead with our exploration vision to the cosmos, it has provoked a lot of discussion in the media. Much of the editorial reaction is favorable, but some is not. A spirited discussion is expected and warranted, but some conclusions are based on misinterpretation of the facts or even misinformation. When that happens, we have a responsibility to provide clarification.

The majority of the discussion is about the "cost". I put the word—cost—in quotes because it has a life of its own. It's an entity, it's alive, it moves, it breathes; it makes people happy, sad, angry! It brings out the best and worst in people.

I'd just like to briefly quote a couple paragraphs from the March 1 Aviation Week. (Read Av Week quotes.)

On January 22, 2004 there was an article in the LA Times, "Is This Really A Cheaper Way to Go To Mars?" saying that the President's vision and these long-term goals could be accomplished with a 20-billion dollar door prize. This notion has been proposed by Robert Zubrin and advocated in the LA Times by Max Boot.

Well, NASA sent back a letter to LA Times stating that this notion of a $20B door prize is not realistic. Gary Martin, our NASA Space Architect, wrote to the LA Times and provided a more rational perspective. He pointed out that we must be realistic.

Let me quote in part: "The costs of extending human civilization well beyond Earth will require meaningful governmental support. While commercial and private sector participation will certainly help fuel this endeavor, it is not realistic to believe that commercial enterprise is capable of mounting the long-term, complex and technologically daunting endeavor the initial exploration missions to the Moon and beyond will require. Of course, the quicker commercial interests can find ways to make a profit in space the easier it will be for the nation to sustain exploration. However, the dream of private enterprise taking the lead in the human exploration of the solar system is not feasible today." End quote.

The reason I cited the article is to point out clearly that cost is a major driver for national space investment policy; hence, it is center stage for policy debate. And you, my brave cost estimators, are at the center of it all!

Given this dynamic landscape that I just described, I would like to offer some personal insights that may be of practical value for cost estimators faced with important decisions.

I consider myself somewhat a student of leadership principles, and there are many principles and examples out there. One in particular that I am fond of is Colin Powell's seven laws of power. If you've read his autobiography or other leadership books you are probably familiar with them.

Colin Powell has commanded armies and is now U.S. Secretary of State. Colin Powell is in every sense a world leader. Through the years, in each position of growing authority, he has followed a code of leadership that inspires confidence, trust, and admiration.

I'm going to take these seven laws of power and apply them to your business of cost estimating. So, I say this as an informed consumer and a customer of what you deliver.

Joe, what was the business principle…the customer is always right. We have to remember that when you and I have discussions…that I'm a customer.

1. Dare To Be The Skunk

I exhort you to dare to be the "Skunk." Every NASA office, program, project, and organization should tolerate rebels who tell the emperor he has no clothes… and this particular emperor expects to be told when he is naked.

Soon after Colin Powell became the Chairman of the Joint Chiefs of Staff in 1989, he huddled with President George Bush's senior staff, debating how best to respond to the invasion of Kuwait by Iraq. The group agreed that the United States should continue to defend Saudi Arabia from invasion. But what about pushing the Iraqis out of Kuwait? Only Powell was willing to bring up that potentially devastating question.

How many times have we've been told by others, "that it was not the correct thing for you to ask nor bring it up…" Are you the cost estimator that brings to the table the truth, and nothing but the truth, and dares to be the skunk at the picnic, take a deep breath?

You have a responsibility to persuade the public that you're doing your best to tell them the truth, regardless of the consequences to yourselves. That's counter-intuitive. It's not easy for people to believe that. Because of that, cost estimators must go out of their way to do things that will give people the confidence that you really do behave that way.

Cost estimators must also do everything they can to avoid even the appearance of a conflict of interest—or any other kind of impropriety—involving their executives, people, program, and institutions they cover. That's why cost estimators in the government/industry and throughout the country have this enormous responsibility—upholding the truth.

Now, you don't have to be rude or mean about it. It's not the "so, take this" attitude that you bring to the table. As a good estimator, I ask you to methodically and professionally build a consensus, prodding people while simultaneously listening, learning, and involving them. But in the final analysis, you may say to yourself, "being responsible sometimes means to be the skunk at the picnic."

2. To Get The Real Dirt, Head For The Trenches

According to Powell, "the people in the field are closest to the problem, therefore, that is where the real wisdom is." On the eve of the Desert Storm campaign, Powell solicited enlisted men and women for advice on winning the war. "When a captain came to see me," he recalls, "I would tell him to sit down. I'd say, 'Talk to me, son. What have you got?'

And then I'd let him argue with me, as if he were arguing with an equal. After all, he knew more about the subject than I did."

Powell knew also that that Captain would tell his friends that he had argued with the Chairman of the Joint Chiefs of Staff. Word would spread, and people would understand that when they came into Powell's office, he really wanted to hear what they thought. And that he trusted their opinions.

As cost estimators, I assume you are talking to the engineers and the project leads who are down in the trenches actually executing the programs. And if you're not, you should be. That's where you find out if the Master Schedule briefed at the Senior Staff Project Review is mere politics or it's doable. You have to prod, poke, nudge, elbow, dig, jab, and push the project!

When you're doing cost data collection, and as you are visiting that project lead for the "n-th" time, if he or she says to you, with their hands up and in utter surrender, "you AGAIN!" You've arrived!

3. Share The Power

"Plans don't accomplish work," says Powell. "It is people who get things done." He adheres to two basic leadership premises: 1) people are competent and 2) every job is important.

"Everybody has a vital role to play. And it is my job to convey down through every layer to the last person in the organization the valuable role they perform." This is what Powell told his State Department staff when he became Secretary of State.

As you perform your cost estimates, you also have the responsibility to convey to people around you that they perform a valuable role as much as you do.

The cost models and variety of estimating tools you have are great, but it's only as good as the inputs you obtain. You know the old adage – "garbage in, garbage out." You have the responsibility to communicate to the people from whom you obtain these inputs that they are part of the process and the cost estimate is affected by their inputs.

4. Know When To Ignore Your Advisors

Experts, advisers, and consultants will only get you so far. Eventually you must make the final decisions. According to Powell, "experts often possess more data than judgment and elites can become so inbred that they produce hemophiliacs who bleed to death as soon as they are nicked by the real world." The best leaders, he believes, should never ignore their own hard-won experience.

As cost estimators, you are responsible for the cost estimate and expected to understand why the numbers came out the way they did. This may sound so elementary, but I have seen that "blank" look on people when they followed the advice of an expert not knowing why they did.

Knowing when to ignore your advisors (with tact, I may add) is when you take ownership of the final decision and the final cost estimate.

5. Develop Selective Amnesia

By this I don't mean… "I can't remember how I got that number."

Too many people get so trapped in fixed ways of seeing things that they can't cope when the world changes. In the spring of 1988, Powell flew to Moscow to prepare for a presidential summit. Sitting across the table, Soviet Premier Mikhail Gorbachev delivered momentous news, saying, in effect: "I'm ending the Cold War, and you're going to have to find a new enemy."

As Powell recalls it, his initial mental reaction was, "But I don't want to!" After investing 28 years in seeing the Soviet Union as an enemy, he realized that "everything I had worked against no longer mattered." But he regained his footing, adjusted to the new world order, and helped guide modern U.S. foreign policy.

While we all have preconceived notions, Powell says, "Never let ego get so close to your position that when your position goes, your ego goes with it."

NASA is moving. The President's exploration vision is reshaping the NASA landscape, institution, people, processes, and policy. Technologically, we always have challenges.

I challenge you. Do you have the cost tools, cost models, cost databases, and resources to estimate emerging technologies and associated projects and programs?

Apply selective amnesia to that part of you that will hinder you from moving forward.

6. Come Up For Air

Powell demands excellence from his staff, but he also insists they have lives outside the office. Again, he leads by example: He has always devoted as much time as possible to Alma, his wife of 39 years, and their children. "I don't have to prove to anybody that I can work sixteen hours a day if I can get it done in eight," he told his State Department staff. "If I'm looking for you at 7:30 at night and you are not in your office, I'll consider you a wise person. Anybody who is logging hours to impress me, you are wasting time."

Now this is where we caveat the statement with… "there are special circumstances when we have to work through the night to deliver." What I am saying is this: when you're doing your cost estimates, your prevailing and constant disposition is tempered by a balanced life.

Trust me. There is another life outside of cost estimating.

7. Declare Victory and Quit

"Command is lonely," says Powell. And so is the decision to withdraw from the position of authority—a choice he says not every leader makes soon enough. His own retirement from the military was, in his word, "traumatic."

Let me be very specific about this when it comes to cost estimates. You can keep on estimating, keep on fine-tuning, tweaking, adjusting, and analyzing your cost estimate. Remember there is a time, an hour and a day when you stop estimating and declare it victory. Call it quits. Your estimate is done. I know you poured your heart and soul in it…but you have to declare victory

Likewise with keynote speakers, we need to know when to quit!

The men and women of NASA and their contractor partners continue to develop the leading-edge technology required to turn the President's vision into reality. The Nation, through NASA, will lead the way for humanity to realize the promise of extensive human space exploration in the 21st century. In the long run, the investments from the pioneering efforts of NASA will be the foundation for the blossoming of sustainable commercial enterprise in space in the coming decades.

Ladies and gentlemen, I wish you all great challenges ahead! Thank you.

Z. NASA Cost Estimating and Analysis Lessons Learned

By Andy Prince

1. Everyone is an expert on cost. Get used to it.
2. Understand your customer's requirements. We provide a service to the Agency and that service must always in consonance with the customer's needs.
3. The cost breakdown structure (also called the work breakdown structure) is the foundation of the estimate. Put it together carefully to ensure that nothing is left out and that nothing is double counted.
4. Carefully document all of your ground rules and assumptions. These are the heart and soul of the estimate. Many cost estimates have been misunderstood and misused because the ground rules and assumptions were not explicit.
5. A cost estimate is by definition a subjective analysis. Seek as much independent input and review as time and circumstances allow in order to counteract your particular biases.
6. The design engineers are your friends. Work closely with them to understand the complexities of their subsystem, as well as the uncertainties. If you have not met with every lead designer on a project and captured their knowledge and understanding into the estimate, your results are no better than a ballpark guess.
7. Use all cost models with an ounce of skepticism. They are guides based on past experience and are at best a fuzzy predictor of the future.
8. The only thing that can be said with certainty about a cost estimate is that the final cost will be different. The real question is not how right you are but how wrong you are.
9. Make sure your work is logical and defendable. If you cannot explain how you arrived at your results based on the evidence in hand, past experience, and expert judgment you will not be taken seriously.
10. Presentations should be clear and concise. Provide sufficient information to ensure that people understand how you arrived at your results, but don't get bogged down in detail (put that in the backup charts for the occasional person who wants a core drill).
11. Be careful with statistics and statistical analyses. NASA management often does not have the background to understand statistics and how they are used.
12. Every estimator gets bloodied now and then. Don't take it personally and don't be defensive. Listen carefully for the message behind the attack, there may be something that you need to hear and act upon.

13. I use what I call the "half rule" to tell if my cost estimates are reasonably accurate. The "half rule" says that if half the people in the audience think your estimate is too high, and half the people think your estimate is too low, you are probably about right.
14. All cost estimates should be evaluated with a sensitivity analysis. The sensitivity analysis will tell you what is and is not important to the results, and can sometimes produce interesting surprises.
15. A cost estimate is just that, an estimate. Perform a probabilistic risk assessment to understand the level of uncertainty in the estimate as well as defining a range of probable outcomes.
16. A good cost estimate cannot overcome bad management. A cost estimate is just another piece of information that goes into the management puzzle. You cannot (and you should not) dictate how management chooses to use that information.
17. You will often get pressure to produce a specific result. Be aware of that pressure and responsive to it, but don't let it override what the data and your knowledge and experience tell you.
18. Consistency before truth. If you have not established a consistent, logical process to achieving the estimate, then you can neither explain your results nor do you have a basis for improvement.
19. The first test of any estimate is credibility. Credibility can only be established with the help of others. Independence is determined by who provides the assessment of credibility.
20. Producing a good cost estimate is an iterative process. Anyone who thinks that they can get it right the first time is naïve.
21. This profession is not for sissies and wimps. Integrity and courage are required to stand up for your work.
22. Question everything. Question the inputs, the models, the assumptions, and the logic of the estimate. Question everything in the search for truth. But, be careful that the questioning doesn't turn into an inquisition; you will loose credibility with your customer

AA. Sample Customer Feedback Form

The Customer Feedback Form was developed by Robert Sefcik at GRC.

SYSTEMS MANAGEMENT OFFICE

ENGINEERING COST/RESOURCE ANALYSIS OFFICE

CUSTOMER SURVEY

Project: ____________________ Date: ____________

The Systems Management Office is always looking for ways to improve the quality of its services. Please take a few minutes to answer the following questions. Your comments and suggestions will be used to improve processes and our ability to respond to your future requests for services.

		Never 1	2	3	4	Always 5
1.	Did we effectively communicate with the project team to gain a good understanding of the project?					
2.	Were any data collection forms and related preparation instructions clear and understandable?					
3.	Was our final product clear and documented at the level of detail that you required?					
4.	Did we provide appropriate supporting information to facilitate your understanding of the analysis, scope, and the methodology used?					
5.	Were all your concerns/questions answered in a timely manner?					

6. Please provide us your ideas or suggestions which may help us develop better methods that you think will improve the quality of our response.

7. Is there a service that we currently do not provide that you would find helpful? If yes, please describe and be as specific as possible.

		Poor 1	2	3	4	Excellent 5
8.	How would you rate the overall service provided?					

Thank you for your comments and suggestions.

Please return this form to: AE3/Manager, Engineering Cost/Resource Analysis Office

appendix aa

One NASA MIS

As part of the One NASA goal, NASA has instituted a management information system (MIS) with a common portal for access to specific information on NASA's major programs, all Centers, Headquarter Offices, Enterprises, International Space Agencies, major contractors and the CAIB.

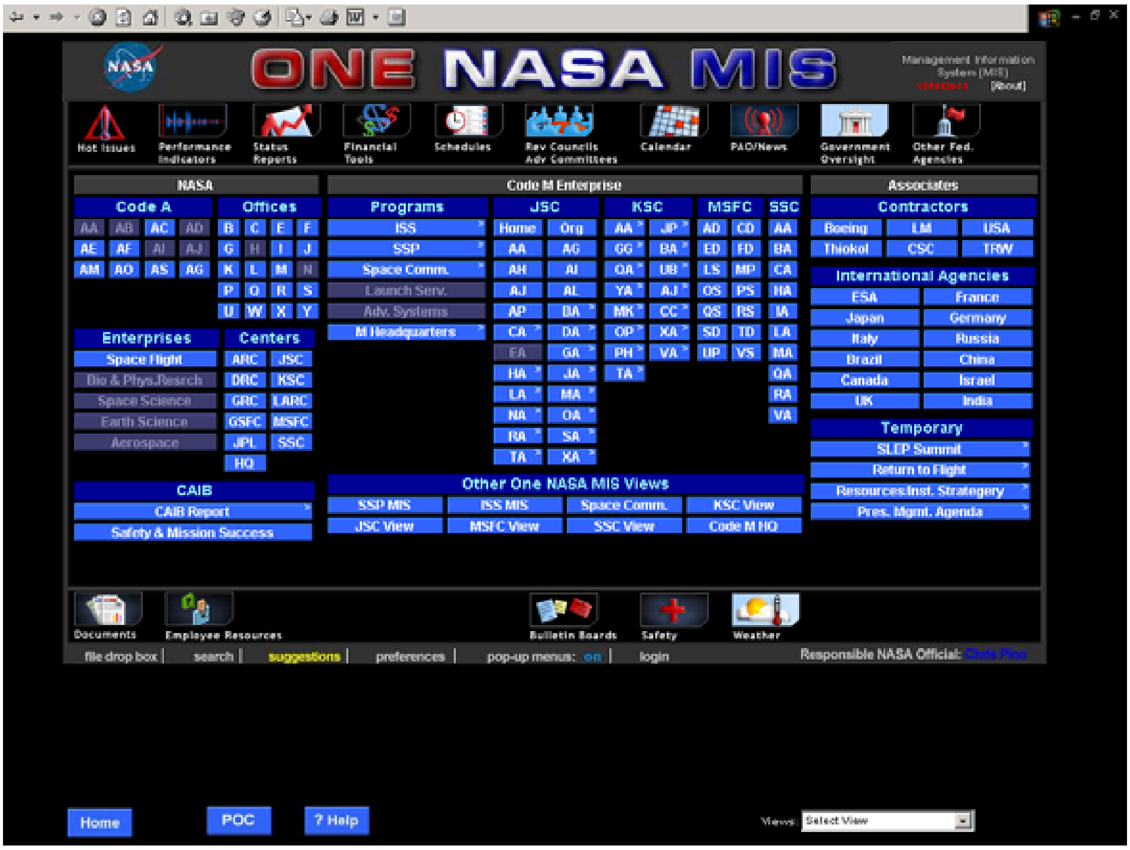


Exhibit BB-1: One NASA MIS

As shown in Exhibit BB-2, the look and feel of the One NASA MIS is carried over to the lower levels as one navigates through the site. The ISS MIS is shown as an example. It puts key management information in an easy to read menu and makes it available at the click of a mouse. Whether a member of the ISS community wants to track business information, go to an ISS Program Office site or check a flight preparation status document, it is all readily available.

Exhibit BB-2: MIS

For example selecting the Avionics & Software Office (Mail Code OD) from the ISS CAM list brings up a listing of available information organized by boards, panels, teams and associated links.

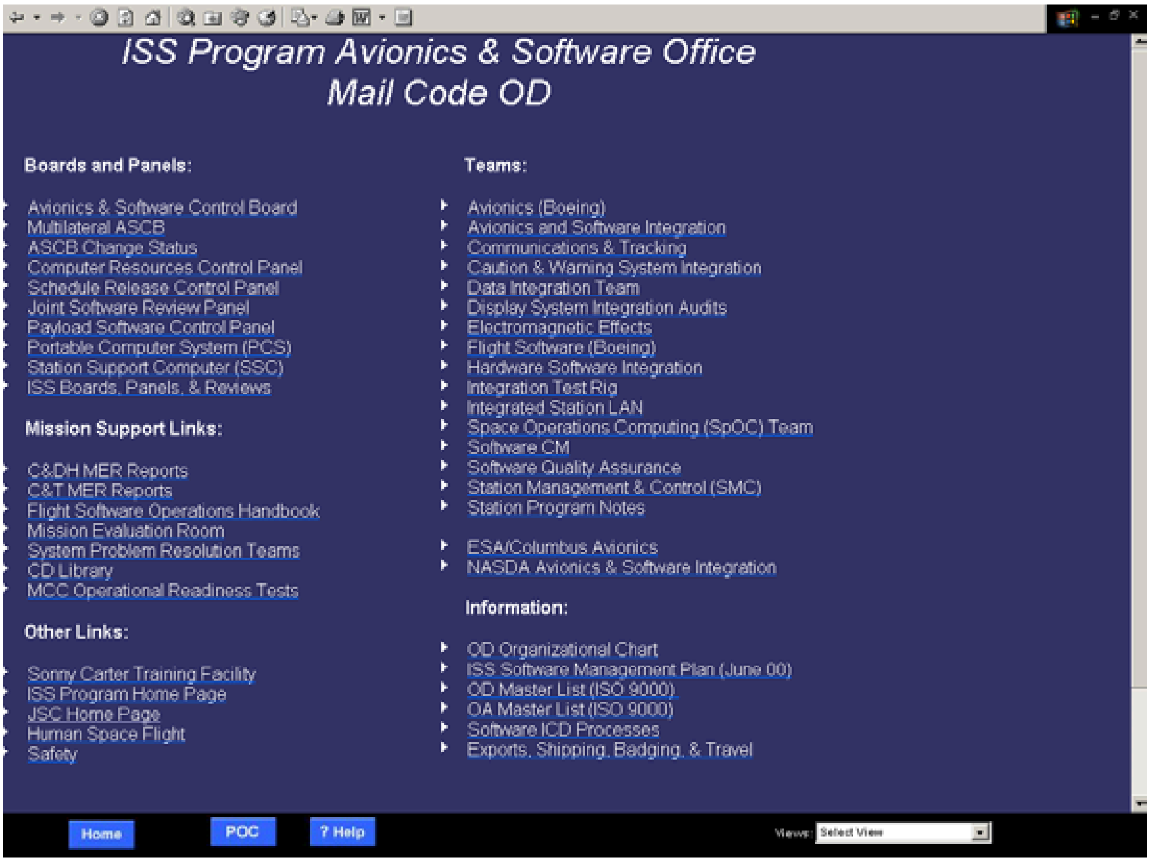


Exhibit BB-3: OD

As an example the level of detail available from the OD MIS portal includes the Command & Data Handling (C&DH) Mission Evaluation Room (MER) daily report under Mission Support Links:

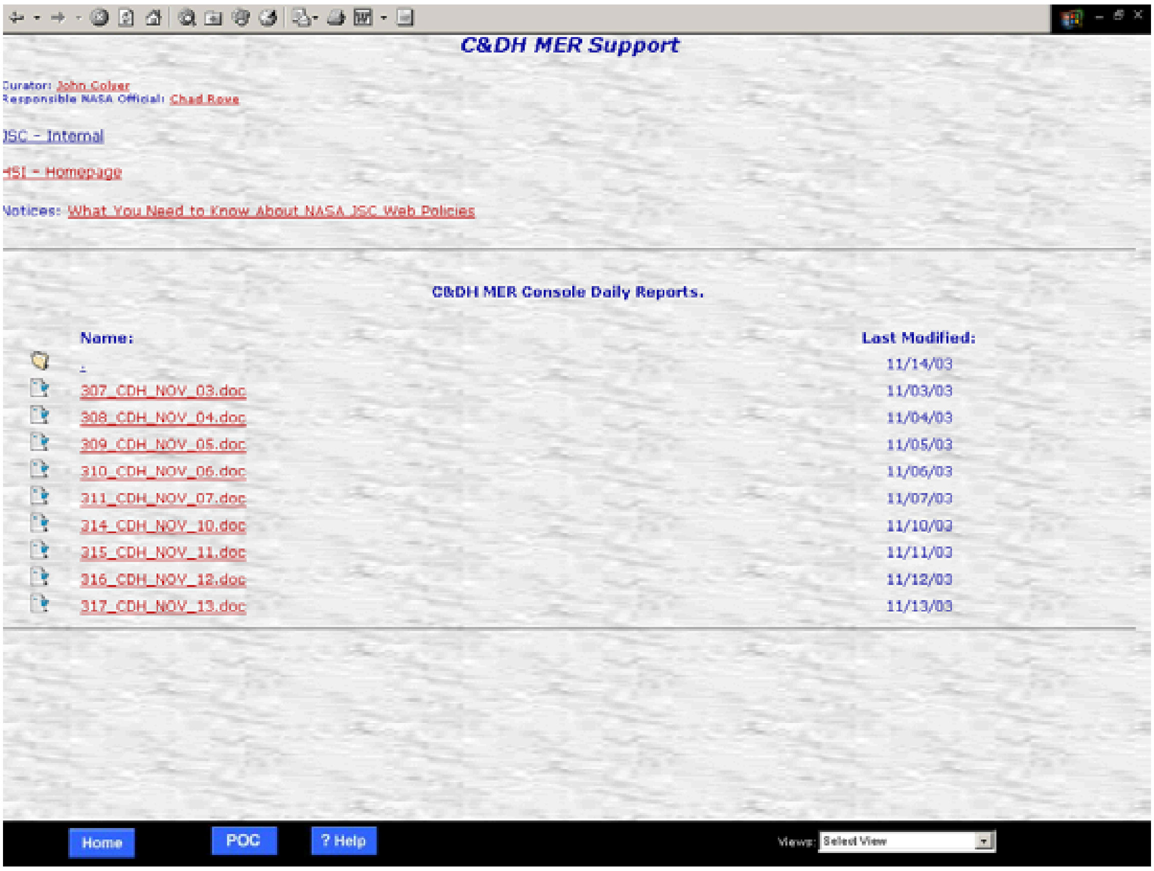


Exhibit 4: C&DH MER Support Report

Another example from the main ISS portal are the Key Performance Indicators (KPI) that may be selected from under the grouping ISS Program Indicators. This allows NASA management and ISS managers to see snapshots of current KPI with easy access to the details behind the indicators.

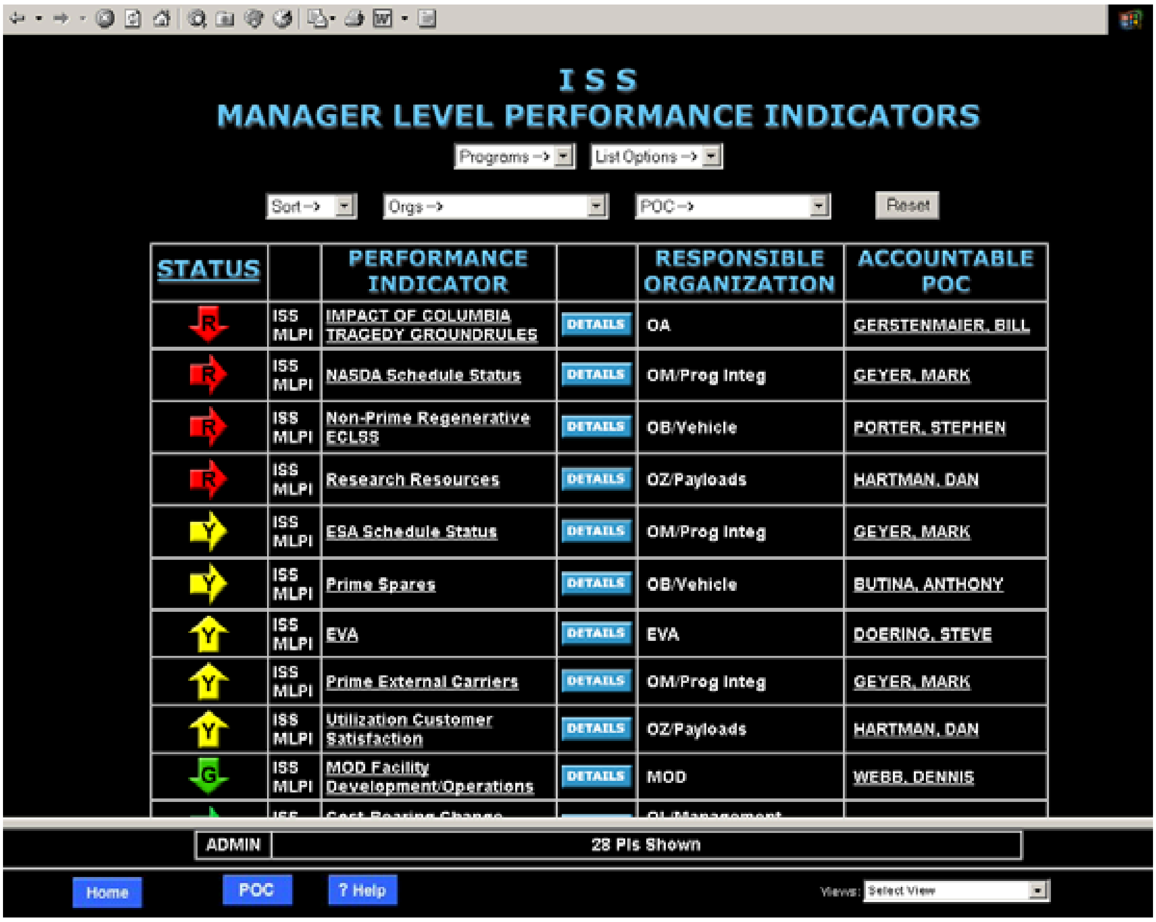
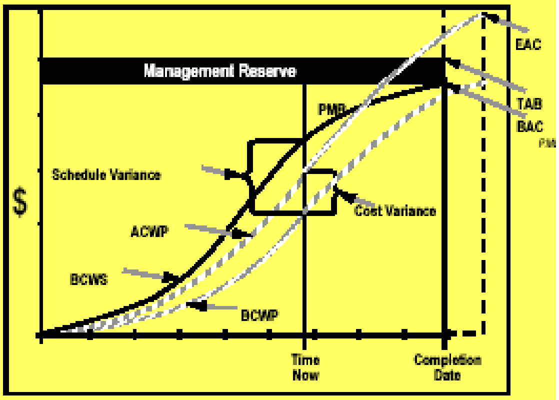


Exhibit BB-5: Management PI

The NASA MIS is a NASA internal web site and may not be accessed externally. Some links will require a log in ID and a password for additional access. Cost and Assessments from the Business Management grouping on the ISS MIS portal are an example of links that have secured access due to the proprietary nature of the information contained within.   For the NASA CEC, however, the One NASA MIS not only contains a wealth of information that may be appropriate to use for cost estimating (whether to develop a CER or base an estimate on historical cost), but it also is a repository for specific cost estimates for reference and review.

CC. Defense Systems Management College Earned Value Management Gold Card

Defense Systems Management College
Earned Value Management Gold Card



PERFORMANCE INDICES

(Favorable > 1.0, Unfavorable < 1.0)

Cost Efficiency $CPI = \dfrac{BCWP}{ACWP}$

Schedule Efficiency $SPI = \dfrac{BCWP}{BCWS}$

OVERALL STATUS

Percent Complete $= \dfrac{BCWP_{CUM}}{BAC}$

Percent Spent $= \dfrac{ACWP_{CUM}}{BAC \ (\text{or } EAC)}$

TO COMPLETE PERFORMANCE INDEX

$$TCPI_{EAC} = \frac{\text{WORK REMAINING}}{\text{COST REMAINING}} = \frac{BAC - BCWP_{CUM}}{EAC - ACWP_{CUM}}$$

ESTIMATE AT COMPLETION

(EAC = ACWP + Estimate for Remaining Work)

$$EAC_{CPI} = \frac{BAC}{CPI_{CUM}}$$

$$EAC_{Composite} = ACWP_{CUM} + \frac{BAC - BCWP_{CUM}}{(CPI_{CUM}) \bullet (SPI_{CUM})}$$

Cost Variance

$CV = BCWP - ACWP$

Cost Variance %

$CV\ \% = \dfrac{CV}{BCWP}$

Schedule Variance

$SV = BCWP - BCWS$

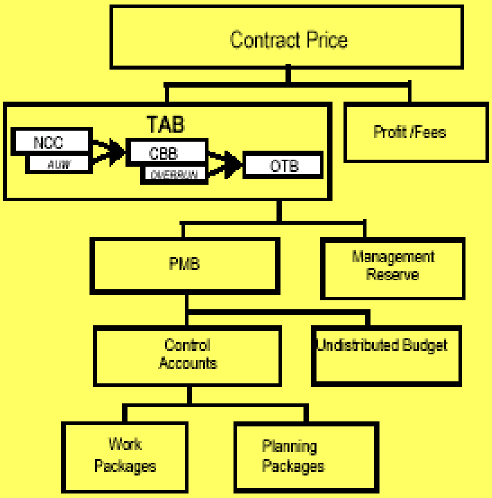
Schedule Variance%

$SV\ \% = \dfrac{SV}{BCWS}$

Variance At Completion

$VAC = BAC - EAC$

EVM Home Page — http://www.acq.osd.mil/pm/
DSMC EV E-Mail Address — EVM@DSMC.DSM.MIL
DSMC EV Phone No. — (703) 805-2848/2968 (DSN 655)
Oct 1997



TERMINOLOGY

NCC	- Negotiated Contract Cost	*(Contract price less profit/fee(s))*
AUW	- Authorized Unpriced Work	*(Work approved, but not yet negotiated)*
CBB	- Contract Budget Base	*(Sum of NCC and AUW)*
OTB	- Over Target Baseline	*(Sum of CBB and recognized overrun)*
TAB	- Total Allocated Budget	*(Sum of all budgets for work on contract-NCC, CBB or OTB)*
BAC	- Budget At Completion	*(Total budget--for total contract thru any given level)*
PMB	- Performance Measurement Baseline	*(Contract time-phased budget plan)*
MR	- Management Reserve	*(Budget withheld by contractor PM for unknowns/risk mgt)*
UB	- Undistributed Budget	*(Broadly defined activities not yet distributed to CAs)*
CA	- Control Account	*(Lowest CWBS element assigned to a single focal point to plan and control the scope/sched/budget)*
WP	- Work Package	*(Near-term, detail-planned activities within a CA)*
PP	- Planning Package	*(Far-term CA activities not yet defined into WPs)*
EAC	- Estimate At Completion	*(Est. of total cost--for total contract thru any given level)*
BCWS	- Budgeted Cost of Work Scheduled	*-- PLAN (Value of work planned to be done)*
BCWP	- Budgeted Cost of Work Performed	*-- EARNED VALUE (Value of work accomplished)*
ACWP	- Actual Cost of Work Performed	*-- ACTUAL COST (Cost of work accomplished)*

EVM POLICY (as defined in DOD 5000.2-R)

EVMS Criteria Approach *(Management control system must meet Criteria):*

- Required for non-FFP contract exceeding $70M RDT&E or $300M in procurement *(CY96$)*.
  - Below-threshold use may be appropriate—consider benefits, risk and criticality.
- Contractor must establish, maintain, and use a system that meets the intent of the 32 Criteria.
- Cost Performance Report (CPR) is delivered as a CDRL item.
  - 5 Formats *(WBS, Organization, Baseline, Staffing, and Explanations)*.

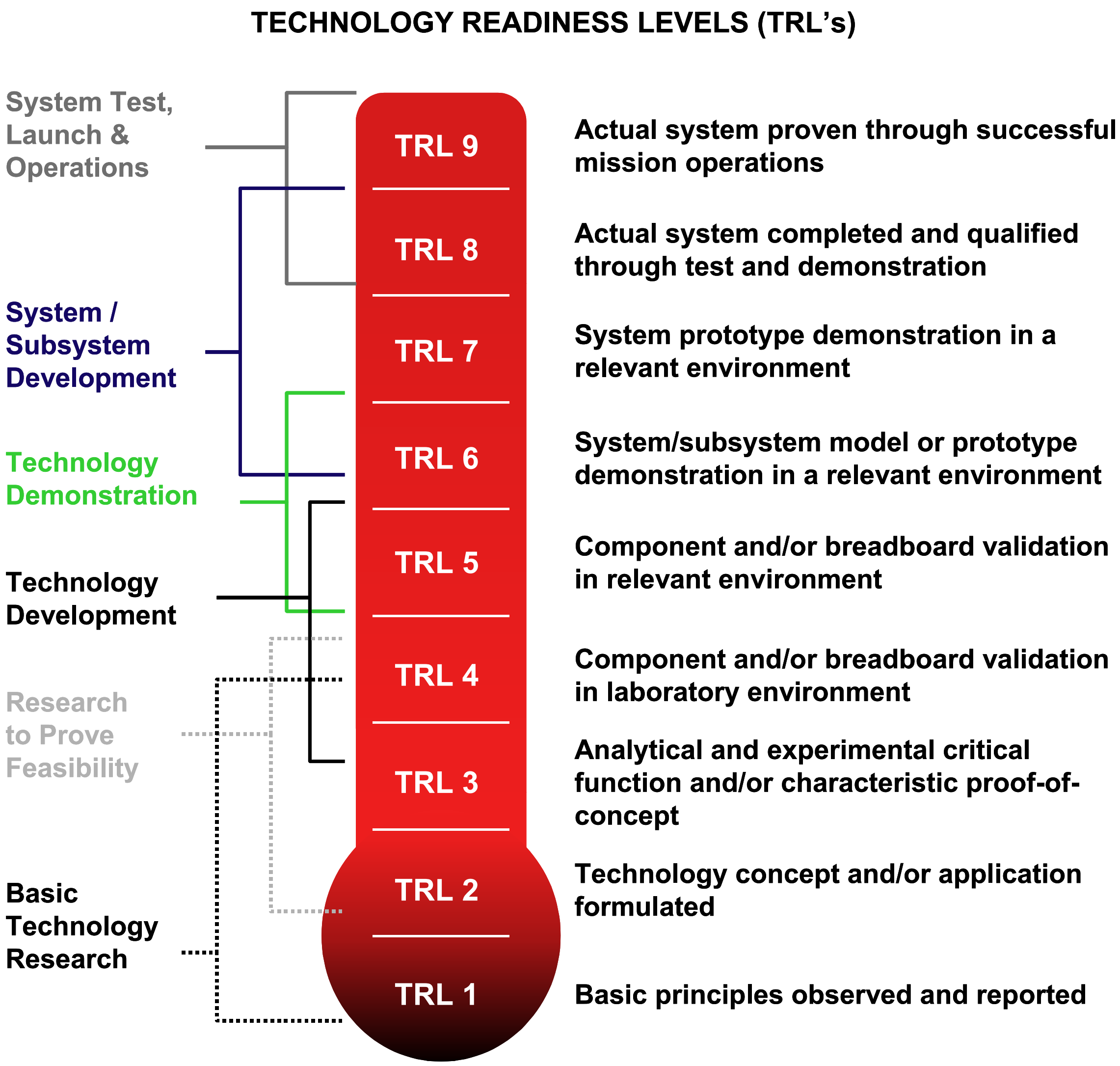
C/SSR Approach *(Management control system not required to meet Criteria):*

- Required for non-FFP contract exceeding $6M *(CY96$)* and 12 months in length.
- Contractor system with reasonably objective earned value methods is adequate.
- Cost/Schedule Status Report (C/SSR) is delivered as a CDRL item.
  - 2 Formats *(WBS and Explanations)*

appendix CC

DD. Technology Readiness Level (TRL)

Here's the link: http://www.hq.nasa.gov/office/codeq/trl/trlchrt.pdf



EE. White Paper (A Parable of Cost Estimating in Aerospace?)

A Simple Calculation of Cost of an Aerospace Facility Compared to a Data Point

By Ester Mator, NASA KSC

The phone rings…

Question: How close would an expert cost estimator, or the tools they use, come to a more detailed, backed up cost figure if trying to estimate the cost of a major aerospace facility such as the Kennedy Space Center (KSC) Space Station processing Facility (SSPF)? They need an answer by 2pm. It's 1pm.

An estimator sometime in the past has been asked to predict, with very little information, the "kind of cost" that might be incurred to build a Space Station Processing Facility at KSC. The estimator is given very little information, as the project is still in its conceptual phases, which is to say that only vague notions of what the building is and what it will do are known. Many inches of paper already abound about the project, none of it of any use in figuring out what the thing will cost. It will process space station elements. This is akin to processing payloads. It will handle anywhere from one to a few of these elements, possibly more, per year, of varying size, function and complexity. These payloads will be launched on the Space Shuttle.

The estimator (being an expert, and knowing that he/she is skilled enough to estimate anything, even in the absence of data or detail) begins by reducing the known to plainly a few factors. After all they want a 1 hour answer.

1. The business will not re-invent itself too far from what it may have done in any similar case recently. Seek a data point.
2. It's payloads.
3. It's Shuttle payloads.
4. Shuttle payloads must fit in a bay that measures 15 ft X 15 ft X 60 ft, so the size of the "things" is known. Size must be a factor.

Historical data?

The estimator (being an expert, here "expert" meaning knowing where to find the answer and claim credit as if one invented it oneself) is aware of a cost estimating relationship (CER) that was documented some years before.

For Payload/Cargo Processing:

(Equation 1)
CofF (Construction of Facilities) $M= 11.99*(202+L)*(56+W)*(45+H)/10^6*Esc
Where:
L=Length of Payload
W=Width of Payload
H=Hieght of Payload
Esc=Escalation for inflation as required, starting at 1987 Year $.

(Equation 2)
GSE (Ground Support Equipment) $M=CoF*2.06

The estimator reads on about the CER and finds that the CER relationships come from a Vertical Processing Facility (VPF) built at KSC many years earlier. Historical data had been used to make up the CER. This data was:

VPF=$19.4M to construct a facility that was 217 ft X 71 ft X 105 ft in dimensions, and that outfitting the facility with GSE had cost $39.96M (all in fiscal year $1987 dollars).

Hence, the Shuttle having a known payload set of dimensions would allow one to reverse engineer the CER factors. The CER of "11.99" is actually just a cost per cubic foot of $19.4M divided by the buildings volume [19.4*10^6/(217*71*105)=11.99]. The CER of 2.06 is actually just the $39.96M divided by the facility cost, or that is a GSE ratio of cost as compared to the facility cost (39.96/19.4=2.06).

Simply enough, the previous estimator had simply subtracted out the Shuttle payload dimensions to leave "space" factors in calculating for a new size payload. Surely, this broad assumption that the space that we required when we did this once is space we'll likely require again would lead to errors in the future using such a relationship far from the Shuttle payload dimensions? No problem - in this case, the Space Station facility question, it is Shuttle payloads, exactly, so the estimator proceeds.

The CofF and GSE simply is the "same" as a VPF, except that escalation for inflation is required.

CofF (SSPF) =19.4*1.15=$22.3M
GSE (SSPF) =39.96*1.15=$45.96M

The escalation factor of 1.15 for taking 1987 dollars to 1990 dollars is taken from NASA inflation indexes.

The estimator knows one other factor to consider in the calculation before declaring an answer. The SSPF is planned to process payloads horizontally, not vertically. Perhaps an adjustment is required in the calculation? In either case, what would be the difference and how would it be known? There are 22 minutes left before the hour is gone. The estimator turns the equation on its side.

The equation would have been:
CofF (Vertical)=11.99*(202+15)*(56+15)*(45+60)/10^6*Esc = $19.4M

It is now (horizontally), with the same escalation:

CofF(SSPF Horiz.) =11.99*(202+60)*(56+15)*(45+15)/10^6*1.15 = $15.4M

And GSE is:

GSE(SSPF Horiz) =15.4*2.06=$31.7M

The estimator reports back (on time) the following:

An SSPF processing a single Shuttle payload at a time, horizontally, assuming it will be roughly 18,602 sq-ft (a product of 262 ft and 71 ft, L and W from above) will cost, in $FY 1990 dollars:

CofF (SSPF Horizontal) =$15.4M
GSE (SSPF Horizontal) =$31.7M

Upon further questioning of the estimate the estimator further adds that the number is an "as built" cost, such as what a major contract would come to, not including the costs on the government side of oversight or activation. The VPF historical data was for what was easily accountable and published after all, not the overhead and in-direct costs that would be more debatable and less traceable.

Some weeks pass, and the estimator must now refine his estimate for processing a "few" shuttle size payloads at a time. It begins to appear the facility will be quite larger than 18,602 sq-ft!

Now, being an expert estimator, and since, after 1 month of the estimate being passed to Washington, the White House and the Office of Management and Budget someone realized the facility was the wrong size, the estimator undertakes the complex task of an "adjustment".

How large will the SSPF facility be? The estimator receives guidance only that up to 3 payloads may be in flow at a time. Being an expert estimator, and this time having a whole week to document the new analysis, the estimator multiplies the previous estimate by 3 and increases his documentation to 60 pages of tables, graphs and explanation.

The cost is now, for duplicating the previous capacity facility, at 55,806 sq-ft:

CofF (SSPF Horizontal) =3*$15.4M=$46.2M
GSE (SSPF Horizontal) =3*$31.7M=$95.1M

And some months pass…

As some more months pass, the estimator sees his initial numbers come and go in discussion, reports, briefings, and general misunderstanding. Teams are formed to derive a better estimate, 60 pages of documentation from the cost estimator being deemed insufficient, as well as that contracts will soon be floated that require actual definition of the what the SSPF will be.

It is documented the SSPF facility will likely be in the range of "465,000 sq-ft and 3 stories high". This would be a volume of about 155,000 sq-ft X 45 ft = 6,975,000 cubic-ft.

The estimator realizes this is finally useful information as the CER was volume based!

Easily enough, using Equation 1 again:

CofF = 11.99*(202+L)*(56+W)*(45+H)/10^6*Esc

Replace the L, W and H with the expected "box" volume and, (with Esc=escalation to year 1990, a factor of 1.15)…

CofF = 11.99*(6,975,000)/10^6*1.15
CofF = $96.2M

And GSE can be taken, using Equation 2 again:

GSE = 96.2 * 2.06 = $198M

The estimator happily reports back that the SSPF facility project is a "roughly $300M project to bring about". He increases his documentation to 173 pages, with 172 pages of boilerplate referencing or copying other useless program documents (as required of the reviewers of his work, and to establish credibility) and 1 page for the previous calculation.

Not believing the result, a very high-up manager forms a "red team" to "hammer out the real numbers, in detail, from the bottoms up, without using these models and stuff no one believes…".

And what actually happened…

In December of 1992 a case study Cost Engineering Report was published of the SSPF C-100 government estimate.

> *"This report is an important cost engineering tool for construction, activation, and GSE design, estimating, fabrication, installation, testing, termination, and verification of this over $380,000,000 (including GSE and activation) project."*

A bottoms up government cost estimate placed the SSPF CofF at ~$57M. This is shown below (estimate #2 on the list).

BID OPENING: SPACE STATION PROCESSING FACILITY 1/23/91

IFB 10-0055-0 PCN 93268 ADVERTISE DATE: 8/1/90

CONTRACTOR	TASK I-V	TASK VI Add 2500-Ton Chiller	TASK VII Power Feeder	TOTAL BID	DIF FM GOV CE
1. Metric Const Tampa, FL	$54,780,000	$1,150,000	$285,000	$56,215,000	- 1.2%
2. Govt Est, DF-FED Jacobs/Hahn/MDAC	$54,508,886	$1,735,898	$617,199	$56,861,983	0
3. W&J Const Cocoa, FL	$55,955,000	$1,300,000	$330,000	$57,585,000	+ 1.3%
4. Blount Bros Const Montgomery, AL	$56,998,000	$1,400,000	$400,000	$58,798,000	+ 3.4%
5. Centex-Rooney Ft Lauderdale, FL	$57,627,000	$1,216,000	$327,000	$59,170,000	+ 4.1%
6. Sovran Const Winter Park, FL	$58,341,058	$1,283,228	$331,290	$59,955,576	+ 5.4%
7. Caddell/Hardway Montgomery, AL	$60,498,000	$1,295,000	$315,000	$62,108,000	+ 9.2%
8. Walsh Const Trumbly, CT	$60,500,000	$1,395,200	$347,600	$62,242,800	+ 9.5%
9. Morrison-Knudsen Ft Lauderdale, FL	$68,967,000	$1,400,000	$385,000	$70,761,000	+24.4%

We are also aware from the same document of total costs for the SSPF, with GSE, including activation at ~$380M.

How well did our estimator do?

For comparison the estimator generated the following values for the SSPF query, based solely on knowing it was Shuttle, and it was horizontal:

Estimate 1:

An SSPF processing a single Shuttle payload at a time, horizontally, assuming it will be roughly 18,602 sq-ft (a product of 262 ft and 71 ft, L and W from above) will cost, in $FY 1990 dollars:

CofF (SSPF Horizontal, Single Capacity) =$15.4M
GSE (SSPF Horizontal, Single Capacity) =$31.7M

Later, a simple multiplier for quantity was used, 3 payloads at a time:

Estimate 2:

*CofF (SSPF Horizontal, 3 Payloads at a time) =3*$15.4M=$46.2M*
*GSE (SSPF Horizontal, 3 Payloads at a time) =3*$31.7M=$95.1M*

Lastly, as the building had actual dimensions attached, the estimator fudged a new result, based on the building (not the vehicle / payload dependency as a driver):

Estimate 3:

CofF (SSPF Horizontal, knowing only building volume)= $96.2M
GSE (SSPF Horizontal, knowing only building volume)= $198M

Estimate 1 and 2, for the caveat attached, can be compared against the eventual numbers reported.

- $46.2M deviates from the $56.9M by an under-estimate of $10.7M, or ~19%.
- The total of Estimate 2 (46.2+95.1=$141.3M) can not be compared to the known total of $380M, as Estimate 2 did not include activation and this quantity is unknown.
- At a rough level, estimate 3, if building information is available even sketchily, shows how a knapkin and a good estimator can within minutes provide a major program factor of roughly a size that can give a “heads up” on where money will (or may) go. 96.2+198=$294M is a sizable factor to consider as “usable” even in the most conceptual of program phases. Later estimates and refinement using orders of magnitude more resources may only change such as value by *less than 25%.*

In closing…on the usefulness of early rough conceptual level cost estimating…

- Estimates can be incorrect but still useful.
- Moderate enhancement of an incorrect estimate can make it roughly correct for an infinitesimally small amount of effort as compared to sub-sequent efforts to refine an estimate using bottoms-up approaches.
- A high level estimate can still be incorrect, as it’s easy to miss a detail when only a few details exist.
- Find a good, honest estimator who’s done it before.

FF. ACKNOWLEDGEMENTS

The material for this handbook was drawn from many different sources, including Center cost estimating procedures, NASA Procedural Requirement (NPRs), and industry best practices. To gather the most up-to-date information for this handbook, subject matter experts from NASA Centers including cost estimators, resource analysts and project managers were interviewed and we gratefully acknowledge their contribution to this document. Each Center was visited and interviews were conducted with numerous participants. The following is a complete list of interview and workshop participants in the 2004 NASA CEH. Our thanks go to all participants and we acknowledge your important contribution to this 2004 edition of the NASA CEH.

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About the Covers

NASA was but three years old when, on May 25, 1961, before a joint session of Congress, President John F Kennedy challenged America to put a man on the Moon by the end of the decade. Eight years and 60 days later, Michael Collins, Command Module Pilot, and Neil Armstrong and Buzz Aldrin, the first men to set foot on the Moon (July 20, 1969), splashed down safely in the Pacific Ocean, successfully meeting that challenge. This year we celebrate the 35th anniversary of that first Moon landing.

As we look back on the history of manned space flight, we first pay tribute those 17 Astronauts flying under the flag of the United States who gave their lives in pursuit of the lofty goal of human space exploration: the crews of Apollo 1 (Note 1), Challenger (Note 2), and Columbia (Note 3). Second, we acknowledge the Astronauts of Apollo 11, 12, 14, 15, 16, and 17 who conducted the Moon landing flights (Note 4). And third, we recognize all the space flights that led to the successful landings on the Moon.

In preparation for lunar landings there were photo missions with Ranger, Lunar Orbiter and Explorer. There were the five exploratory Surveyor Moon landings. There were the five Apollo flights to check out hardware, techniques, crews and trajectories, including Apollo 8 that brought us the serenity of Christmas eve scripture readings as the flight emerged from the dark side of the moon, and Apollo 13 that brought days of suspense as the crippled flight was brought safely home.

In honor of these voyages of lunar manned exploration, the front cover displays the official Apollo mission patches. The back cover depicts of all the spacecraft lunar landing sights of the precursor missions to Apollo.

At the same time that we acknowledge the accomplishments of the Apollo astronauts, we recognize that they are but the most visible of the tens of thousands of hard working men and women of NASA (civil servants and industry) who made it possible for all these American astronauts to complete their successful missions in space and to explore the surface of the moon. There were earlier heroes, such as Ham the first American living being to be launched into space, and later heroes such as Sally Ride, the first US woman in space. While we focus on the manned lunar explorations, we applaud all who have proudly served in the NASA community.

On the 35th anniversary of the first man on the moon, we look back with admiration and appreciation for all that the people of NASA have given, tangible and intangible, directly and indirectly, as a result of the lunar manned space flight effort. We have seen developments ranging from massive and more powerful rockets, to microminiature and more powerful electronics. We've seen unimaginable advances in aeronautics, science, medicine, and astrophysics, all as a direct result of the manned space flight endeavor and the unmanned missions that helped make it possible.

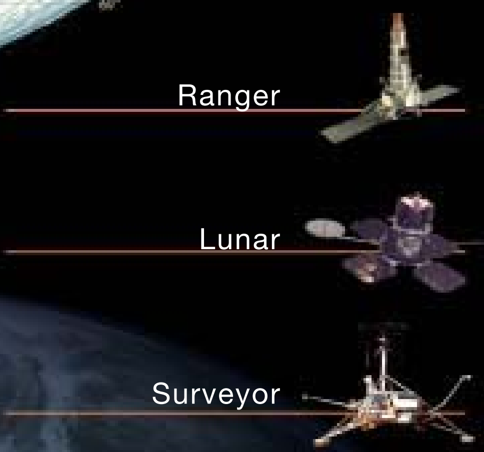
The achievements coming in this new century are limited only by our imagination. We may well return to the moon, and it's likely we'll set foot on Mars. There will be much to celebrate in the next thirty-five years as we head for the 70th anniversary of the first lunar manned landing. Our vision must be as boundless as space, and as we wish Godspeed to the men and women of the manned space flight community, as they plan and safely execute our continuing journey into the frontiers of space, we wish unbridled success to the entire NASA family in the ongoing quest of advancement in aeronautics and space exploration.

Note 1: Apollo 1 launch pad fire: Virgil "Gus" Grissom, Ed White, and Roger Chaffee

Note 2: Challenger launch failure: Francis R. (Dick) Scobee, Commander; Michael J. Smith, Pilot; Judith A. Resnik, Mission Specialist; Ronald E. McNair, Mission Specialist; Ellison S. Onizuka, Mission Specialist; Gregory B. Jarvis, Payload Specialist; Sharon Christa McAuliffe, the first teacher to fly in space

Note 3: Columbia re-entry failure: Rick D. Husband, Commander; William C. McCool, Pilot; Michael P. Anderson, Payload Commander; David M. Brown, Mission Specialist; Kalpana Chawla, Mission Specialist; Laurel Blair Salton Clark, Mission Specialist; Ilan Ramon (Israel), Payload Specialist

Note 4: By the end of the Apollo program, December 1972, a dozen men had walked on the surface of the moon: Neil Armstrong; Buzz Aldrin; Charles Conrad, Jr.; Alan L. Bean; Edgar D. Mitchell; James J. Irwin; David R. Scott; Charles M. Duke, Jr.; John W. Young; Eugene A. Cernan; Harrison H. "Jack" Schmitt; and Alan Shepard



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