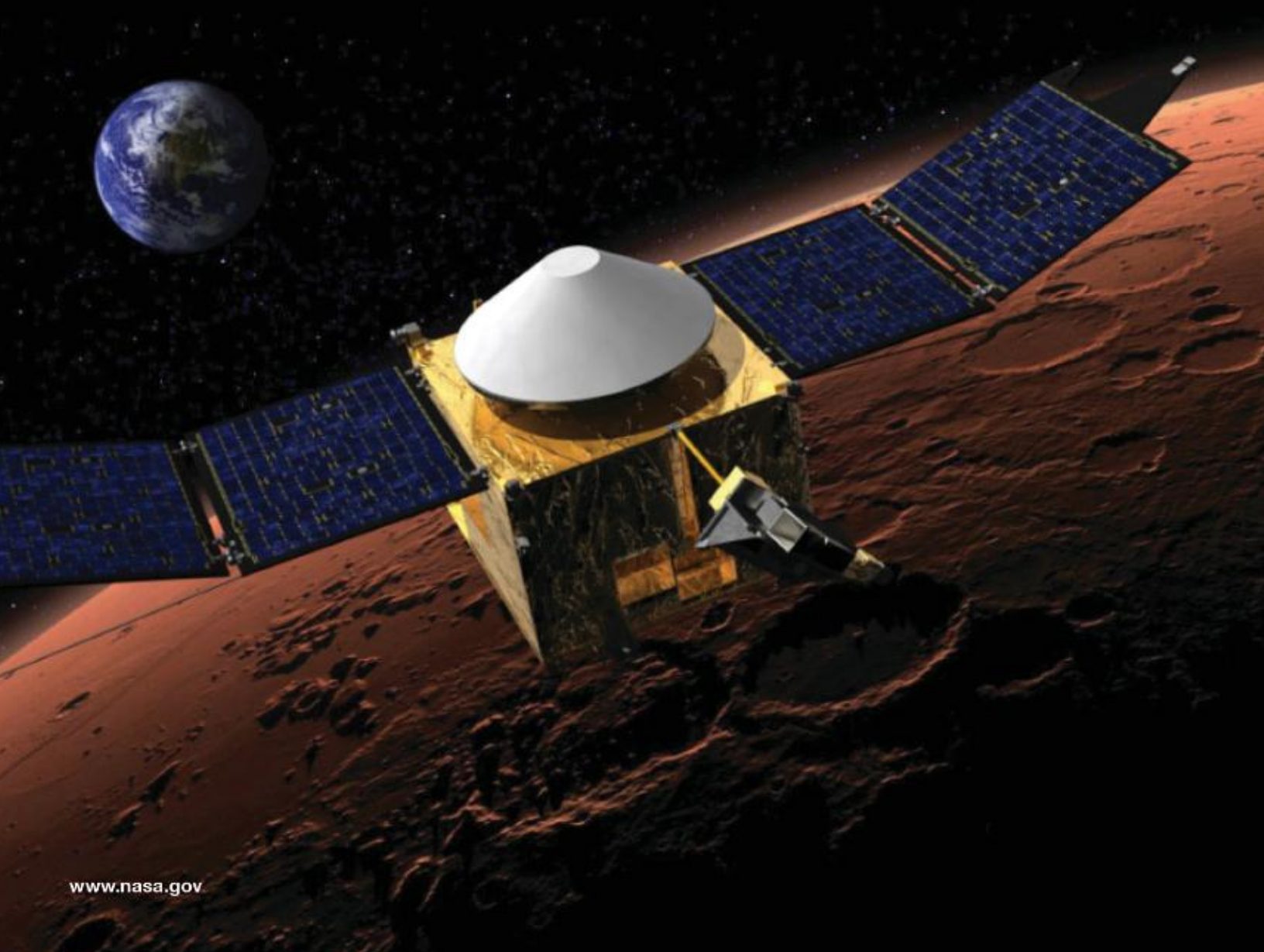
National Aeronautics and Space Administration

NASA Cost Estimating Handbook

Version 4.0



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The image on the cover is the MAVEN spacecraft in orbit around Mars, looking back at Earth. MAVEN launched on November 18, 2013, and, following a roughly 10-month trip of over 442 million miles, reached Mars on September 21, 2014. The MAVEN project successfully implemented the principles in this handbook to produce their JCL analysis. MAVEN was launched on schedule and delivered under its budget commitment.

Acknowledgments

Many people contributed to the development of the Version 4.0 edition of the Cost Estimating Handbook (CEH). The members of the NASA Executive Cost Analysis Steering Group (ECASG) are the foundation of NASA's cost estimating expertise and provided valuable discussion and materials from their personal wealth of NASA experience. They also spent many hours reviewing and commenting on the handbook. The information from these sources helped identify topics that needed to be enhanced, updated, or created in order to preserve the CEH's usefulness for NASA estimators, contractors, and customers.

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Our thanks go to all contributors as we acknowledge their important inputs to this edition of the NASA CEH and the cost estimating community.

Welcome to the NASA Cost Estimating Handbook, Version 4.0

This is the fourth edition of the National Aeronautics and Space Administration (NASA) Cost Estimating Handbook (CEH), updating the 2008 edition. The purpose of this handbook is to serve as a guide for cost

estimating at NASA. The intended audience covers the non-estimating professional and the new cost estimator, as well as experienced analysts. The intent of this revision is to provide an update reflecting significant policy changes since the 2008 edition.

Revision Highlights

This revision includes the addition of an Appendix J addressing Joint Cost and Schedule Confidence Level (JCL) analysis and is intended to be a reference for cost estimating best practices at NASA. Other new topics have been added, and the document layout has been updated. This revision has been developed with the input and participation of the members of the Executive Cost Analysis Steering Group (ECASG), a multi-Center group that coordinates the internal NASA cost estimating and analysis community; ensures that appropriate policy is adopted; and promotes best practices are being developed, communicated, and used across the Agency.

This update to the CEH provides current information on NASA cost estimating policy, including requirements for probabilistic estimating at Key Decision Points (KDPs) in the project[1] life cycle. The information on how to develop probabilistic cost and schedule ranges for KDP-B (approval to start preliminary design) is provided in Appendix C and a JCL calculation in support of KDP-C (approval to start final design) is provided in Appendix J. For probabilistic estimating, the NASA cost community has found it necessary to incorporate active consideration of risk, schedules, and performance and to develop methods of incorporating these factors into cost estimates.

[1] The term “project” is used throughout this handbook for ease of reading, but it may be interpreted as “program” or “project” in accordance with NPR 7120.5E.

Using the Handbook

Version 4.0 of this handbook is designed to be an electronic resource, but every effort has been made to provide a layout that enables the user to print out a hard copy.

The main body provides a standalone summary of the process for developing cost estimates; individual appendices cover a variety of additional subjects in more detail.

This CEH belongs to a community of NASA handbooks that include the following:

- EVM Implementation Handbook, Integrated Baseline Review (IBR) Handbook, and Work Breakdown Structure (WBS) Handbook (which are all available at *http://evm.nasa.gov/handbooks.html);*
- Schedule Management Handbook (*http://www.nasa.gov/pdf/420297main_NASA-SP-2010-3403.pdf*);
- NASA Risk-Informed Decision Making Handbook *(http://www.hq.nasa.gov/office/codeq/doctree/NASA_SP2010576.pdf);*
- Systems Engineering Handbook (*http://www.acq.osd.mil/se/docs/NASA-SP-2007-6105-Rev-1-Final-31Dec2007.pdf*);
- Project Management Handbook *(http://www.nasa.gov/offices/oce/documents/NPR7120-5_pm_handbook.html)*; and
- Risk Management Handbook *(http://www.hq.nasa.gov/office/codeq/doctree/NHBK_2011_3422.pdf).*

Updating the Handbook

Please send feedback or suggested improvements via the form located on the CEH website at *http://www.nasa.gov/office/ooe/CAD/CEH_Input.pdf*. CAD intends to make periodic updates to the CEH and/or individual appendices as needed (will review annually), and will rely on feedback and input from the community of CEH users as an important source for identifying areas for improvement or addition.

For any general information requests, please submit them to *hq-cad@mail.nasa.gov*.

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1. Introduction

The needs of the cost estimating community are as varied as the projects being undertaken at NASA. NASA has a wide range of mission requirements and a variety of expectations and tools that are used to plan and execute those requirements. Cost estimators and cost analysts may be asked to support activities ranging from the development of estimates for competitive proposals to the development of independent estimates. These estimates can be used either for the selection of proposals or the approval to proceed to the next life-cycle phase. NASA requires cost estimating for major acquisition programs. Resources are increasingly scarce, and space systems are increasingly expensive. Informed decisions are critical.

1.1. The Need for Cost Estimating and Cost Analyses

NASA and many external organizations are consumers of cost estimates and analyses. The Agency needs estimates for Project Office formulation and implementation phases, nonadvocate cost estimates, source selections, what-if exercises, affordability studies, economic analyses, and Analysis of Alternatives (AoA), as well as to support numerous types of decisions related to projects. System cost must be a design variable to help focus on major cost drivers during design and to challenge estimates that deviate strongly from history. The cost estimating process defined in this handbook will provide the decision maker with a clear understanding of the cost risk inherent in the project, cost of alternatives within the project, and information to make resource allocation decisions. Once the decision is made to proceed with the project, cost estimates provide management with critical cost-risk information to improve the control of resources in the present and the future as well as provide insight into the impact of project changes on the program budget. The cost estimating process must therefore be adaptable and flexible while holding firm to the principles, objectives, and practices of cost estimating. The following groups are informed by cost estimates:

- Projects, programs, Centers, Mission Directorates, and the Agency as a whole
- External stakeholders (e.g., Congress and the Office of Management and Budget [OMB])
- Auditors (e.g., the Government Accountability Office [GAO] and the NASA Office of Inspector General [OIG])
- Taxpayers

1.2. The NASA Acquisition and Management Processes

The acquisition process helps projects meet programmatic, institutional, technical, cost, schedule, and performance commitments. NASA's acquisition policy for funding space missions, NASA Policy Directive (NPD) 1000.5 (*http://nodis3.gsfc.nasa.gov/lib_docs.cfm?range=1*), outlines the policy and process expectations for the acquisition process. The acquisition policy is supported by NASA Procedural Requirement (NPR) documents, such as NPR 7120.5E (*http://nodis3.gsfc.nasa.gov/displayDir.cfm?t=NPR&c=7120&s=5E*), which describes how space flight programs and projects are to be managed throughout their life cycles. All NASA cost estimators should be familiar with both NPD 1000.5 and NPR 7120.5E. While the focus of the CEH is on cost estimates for flight projects, the same guiding principles apply to other types of programs or projects, such as information technology (IT), technology development, and Construction of Facilities (COF).[2]

[2] For additional guidance, visit the NASA Online Directives Information System (NODIS) at *http://nodis3.gsfc.nasa.gov/main_lib.html*. See Appendix L of this document for more information on Construction of Facilities.

The Project Life Cycle Milestone Chart, Figure 1, defines the roadmap for identifying points in the project life cycle where cost estimates may be needed to support the justification, formulation, approval, and implementation of the project. For a project to progress through its project life-cycle phases successfully, it must provide cost estimates at each review leading up to the next Key Decision Point. The policy document NASA Systems Engineering Processes and Requirements, 7123.1B (*http://nodis3.gsfc.nasa.gov/displayDir.cfm?t=NPR&c=7123&s=1*), details the complete entrance and exit criteria for each review. This process defines the activities to which the cost estimator's product contributes. In most cases, a project's schedule and cost uncertainties decrease over the project's life cycle as the project matures. It is important for the estimator to understand and communicate not only cost and schedule estimates but also uncertainties associated with these estimates. This is covered in more detail in section 2.

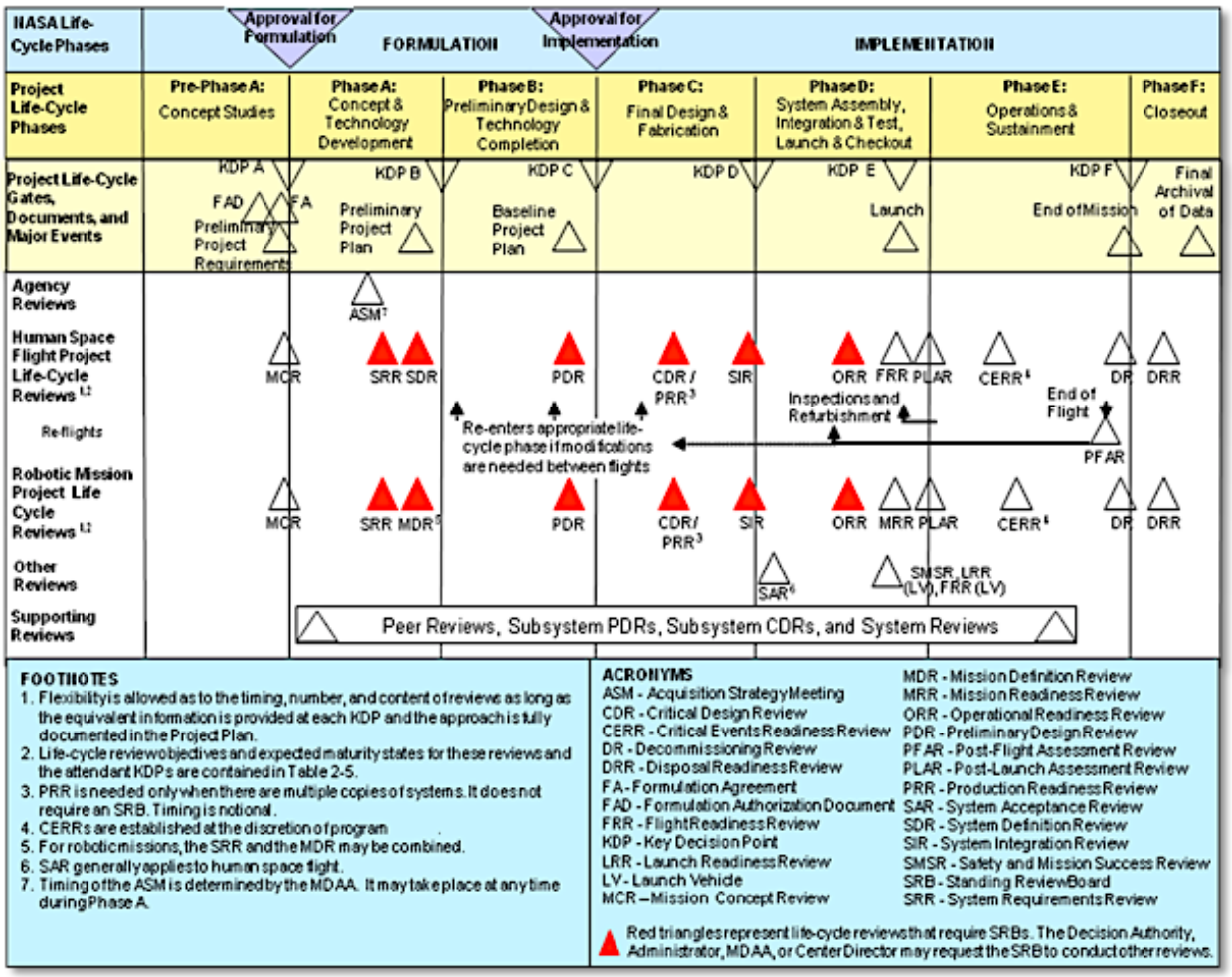


Figure 1. Project Life Cycle Milestone Chart[3]

[3] Figure 1 is taken from NASA Procedural Requirement 7120.5E (*http://nodis3.gsfc.nasa.gov/displayDir.cfm?t=NPR&c=7120&s=5E).*

2. The Cost Estimating Process

This section presents the how-to, start-to-finish details of the cost estimating process. As shown in Figure 2, there are three main parts to the NASA 12-step cost estimating process: Part 1—Project Definition, Part 2—Cost Methodology, and Part 3—Cost Estimate. This process is consistent with the cost estimating processes in NASA's 2002, 2004, and 2008 Cost Estimating Handbooks, and it is substantively consistent with the GAO's process[4] but tailored to fit NASA's needs.

Cost Estimating Process as Applied

The Cost Estimating Process described in Figure 2 is shown as a series of successive steps for instructional convenience. However, in practice it is often an iterative process that is rarely linear. Steps are performed as opportunity, data, and need arise.

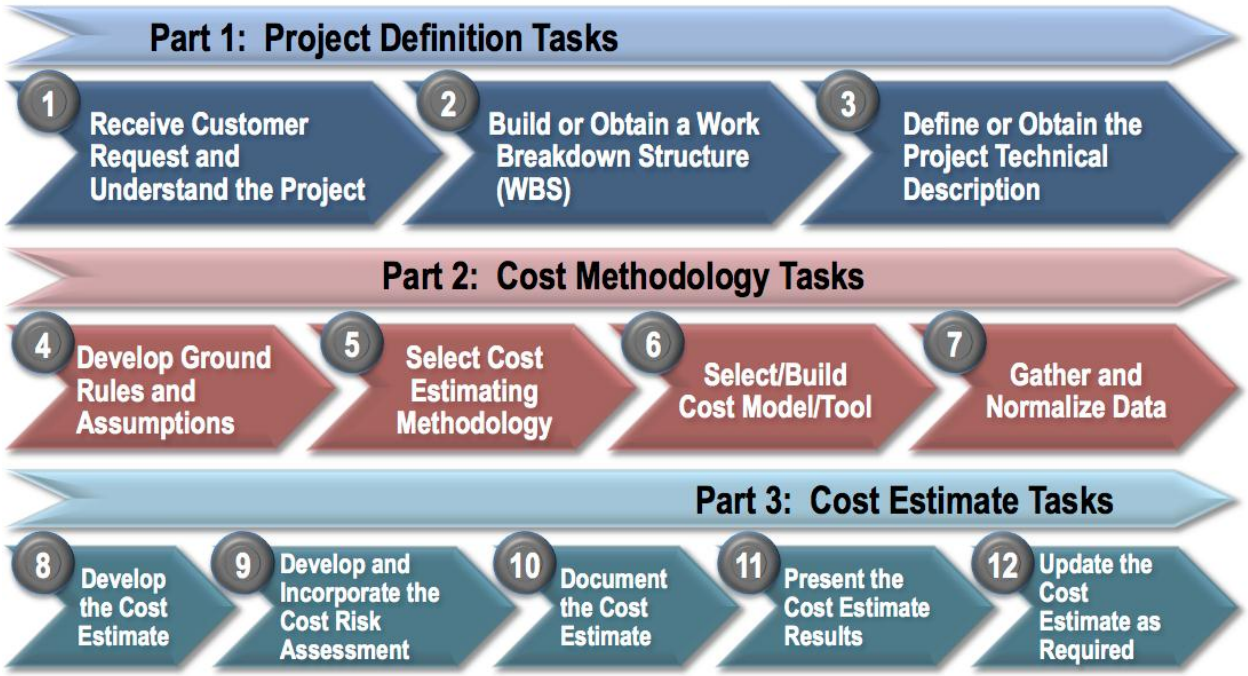


Figure 2. The NASA Cost Estimating Process

The first part of the NASA cost estimating process is called the *Project Definition*. During this part, the estimator clarifies the reason for the estimate, defines expectations, and begins to understand the project that will be estimated. As the estimate is being defined and data are gathered, a Work Breakdown Structure and technical description are obtained. These items help define the project and form the foundation for the estimate. As the estimator continues through the estimating process, these steps may be revisited as new information is obtained.

[4] See box on following page, and more information at http://www.gao.gov/products/GAO-09-3SP.

Part 2 of the cost estimating process, the *Cost Methodology*, includes four tasks that create the approach and framework for the estimate. Developing the ground rules and assumptions will be the most revisited task in this part of the process. As methodologies are selected and the data are gathered, the ground rules and assumptions, methodologies, and even the cost model may be refined, as appropriate.

Part 3 of the cost estimating process, the *Cost Estimate*, has five tasks that include the actual conduct, presentation, and maintenance of the cost estimate. All of these tasks are important in their own right, and together, they become critical for a defensible and complete estimate.

As noted above, the cost estimating process, described in detail below, is shown as a series of successive steps. It is in practice often an iterative process that is rarely linear. For example, the initial estimating results may be revised one or more times because of changes to the technical and programmatic baselines, questions about the sensitivity of results, changes in ground rules and assumptions, or indications that the estimate is not complete. The revised results and findings are then documented and, along with the estimating models and data, made available for subsequent estimating and analyses.

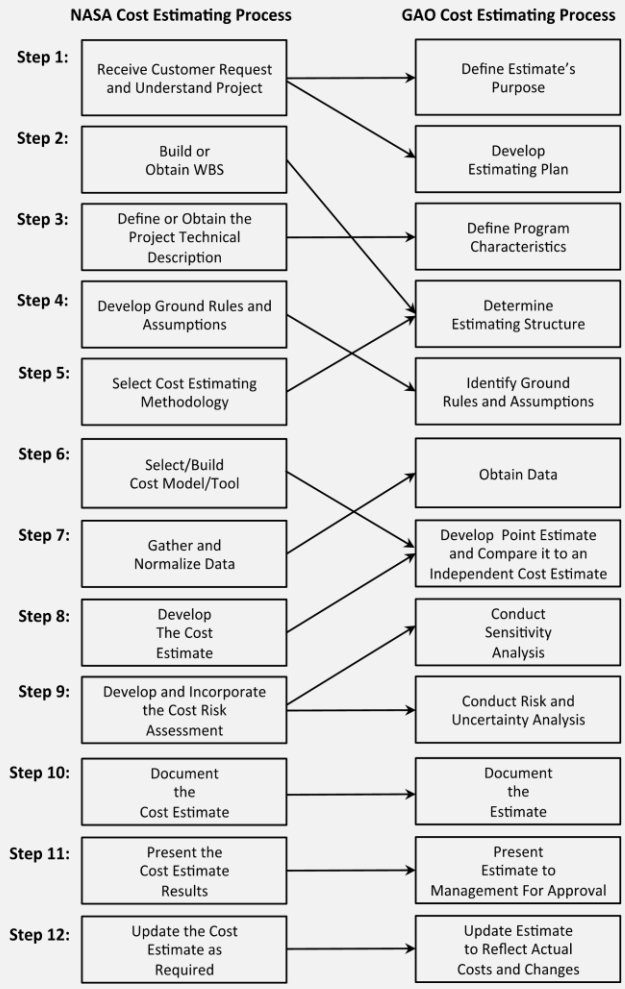
2.1. Part 1: Project Definition Tasks

To properly estimate the cost of a project, it is vital that the project be thoroughly defined and understood by the estimators. Therefore, the initial stage of the cost estimating process is dedicated to:

- Receive the customer's request and understand the project;
- Build or obtain a WBS; and
- Obtain/participate in the development of the project's technical description.

Consistency of the NASA Cost Estimating Process with the GAO Cost Estimating Process

NASA's cost estimating process is consistent with the estimating process recommended within GAO's Cost Estimating and Assessment Guide (*http://www.gao.gov/products/GAO-09-3SP*). This mapping of the processes is depicted below:



To take a deeper look into this mapping schema, it is recommended to first read sections 2.1 through 2.3 of this handbook, which provide a detailed description of each step of the NASA cost estimating process. After reading these sections, use the illustrated map as a guide to compare task descriptions in this handbook to "Associated Tasks" in Table 2 of the 2009 GAO Cost Estimating and Assessment Guide.

NASA has retained the structure of its general cost estimating process flow for consistency and tailoring purposes, rather than exactly duplicate the GAO process.

2.1.1. Task 1: Receive Customer Request and Understand the Project

The goal of this task is to communicate sufficiently with the customer to gather enough project information to generate a quality estimate.

There are three major activities associated with understanding the project:

1. Identify the customer(s) and stakeholder(s) who will use the results of the estimate.

2. Document expectations for program/project by (a) identifying the purpose of the estimate; (b) specifying mission needs, objectives, and goals; and (c) assessing the operating environment and life-cycle phase.

3. Gather and review all relevant project data for evaluation (e.g., an existing technical baseline or Cost Analysis Data Requirement [CADRe], previous estimates, lessons learned and customer feedback, budget data, and programmatic data such as schedules). Discuss schedule, data, expectations, and resource requirements with the requesting customer.

    a) When a request for a cost estimate is received, the supervisor of the cost group must ascertain if there are adequate resources to accept the assignment based on the understanding of the expectations of the estimate.

    b) 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 and assign an estimator (or estimators) to the task. If the supervisor has issues with the request, it will be negotiated with the requestor.

NASA's Cost Analysis Data Requirement (CADRe)

The CADRe is a three-part document that captures detailed programmatic, technical, and cost data in a single document for NASA-funded space missions. The document is prepared six times during the life cycle of a project at major milestones: SRR, CSR or Project PMSR; PDR; CDR; SIR; Launch and EOM.

The CADRe initiative began in 2005 as a way to systematically collect and archive programmatic, technical, and cost information. The CADRe program satisfies a basic cost estimating need to provide historical cost data that are vital to performing estimates for future systems. In performing this task, data across all major flight projects at NASA are captured, including major instruments that fly on foreign international partner spacecraft.

The CADRe program has captured dozens of key historical missions looking back approximately 10 years where the data are available. As the number of CADRes on current and completed missions grows, a better understanding of key programmatic changes and their associated cost and schedule impacts is attained, resulting in more advanced costing practices and tools. Completed CADRes are available on the One NASA Cost Engineering (ONCE) database. Incorporating CADRe into the ONCE database, in turn, facilitates fast searches and easy retrieval to support cost engineering development.

For more information on CADRe, refer to Appendix A.

As illustrated in Figure 3, 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 developed. These four elements are resources, data, schedule, and expectations.

Data

- What data do you need?
- Are the data readily available?
- If the data are not readily available, what are your alternatives?
- Are the organizations you need to collect the data from cooperative & accessible?
- Are non-disclosure agreements required?

Expectations

- What is your expectation of the estimate?
- What is the expected outcome or usage of the estimate? (based on estimate type)
- What is the customer's expectation of the estimate?
- What is the team expectation of the estimate?
- What is the Agency-wide expectations of the estimate outcome and usage?

Resources

- How many people are required to conduct the estimate?
- How many people are available to conduct the estimate?
- What is the budget required to conduct the estimate?
- What is the available budget to conduct the estimate?

Schedule

- How long have you been given to complete the estimate?
- How long do you need to complete the estimate, given the available resources and data?
- Do you have the resources needed to conduct the estimate with the allotted schedule?
- Do you have the time to collect the required data and analyze the data?

Figure 3. Four Critical Elements Related To Conducting Cost Estimates

In early life-cycle phases of a project 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) and to address issues such as personnel, schedule, technologies, and cost drivers that can have a major impact on risk. Data gathering is no less important in later phases of a project, when more is known and overlooking any element could affect the estimate's outcome.

2.1.2. Task 2: Build 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 that the cost estimate will cover.

As confirmed by NPR 7120.5E, the WBS is a key element of project management. The purpose of a WBS is to divide the project into manageable pieces of work to facilitate planning and control of cost, schedule, and technical content. A WBS ensures that all work to be performed on the project is organized and aligned in accordance with the total scope of a program, using a hierarchical structure. Each element in the cost estimate represents the cost to do that work. This structure becomes the cost estimator's framework for ensuring full coverage (without double counting) of the project's objectives, including the following:

- Project and technical planning and scheduling;
- Cost estimation and budget formulation (in particular, costs collected in a product-oriented WBS can be compared to historical data collected for the same products);
- Definition of 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 Estimate at Completion [EAC]); and

- Creation of plans such as the Systems Engineering Management Plan (SEMP) and other documentation products such as specifications and drawings.

The WBS is also used as a communication tool to present the project's scope in an understandable form that can be easily communicated to the project team and other stakeholders.

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

1. Begin with the NASA standard flight project WBS (only to Level 2);[5]
2. Define the WBS elements to the lowest level appropriate to the level of project maturity for the estimate;
3. For a WBS structure below Level 2, refer to the CADRe standard[6] as a reference for suggested lower level breakouts;
4. Create a dictionary to define the WBS elements; and
5. Ensure that the cost estimating WBS is consistent with other project functions including scheduling (the cost estimator is responsible for preparing the cost WBS and mapping it back to the standard WBS). A mapping example is provided in Appendix E.

The type of estimating product varies by program life-cycle phase. In Pre–Phase A, the cost estimator will either obtain a high-level project WBS from the project staff or work with them to develop one. A project WBS is the comprehensive WBS comprising all life-cycle phases, recurring and nonrecurring costs, and components including the hardware for the product; as well as other items such as mission assurance, Systems Engineering and Integration (SE&I), Integration and Test (I&T), mission operations, data analysis, outreach, science team, and project management. At a higher-level WBS (e.g., WBS Levels 1 and 2), it is important to standardize the WBS to not only facilitate data (and data analysis), but also to enable apples-to-apples comparisons to heritage programs.

Figure 4 shows the NASA Level 2 Standard Space Flight WBS that is required for all NASA space flight projects. **For a more detailed recommended WBS, see the box at the end of this section describing the standard CADRe WBS**.

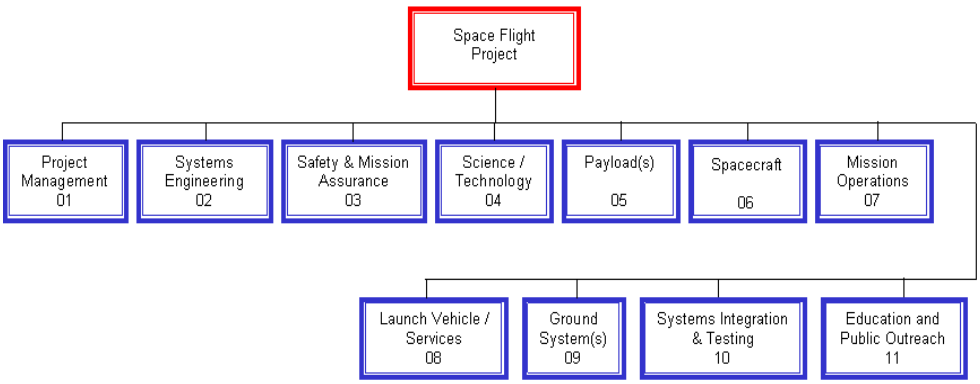


Figure 4. Standard Flight Project Level 2 Work Breakdown Structure[7]

NASA's standard WBS helps ensure that similar projects within each NASA organization have standard and consistent labels, definitions (i.e., content), and data across different cost disciplines (e.g., CADRe reporting, cost estimating, EVM, cost databases). This consistency will enable improved cost estimation,

[5] For more information, please see the NASA Work Breakdown Structure Handbook, NASA SP-2010-3404, January 2010 (*http://evm.nasa.gov/handbooks.html*).
[6] The CADRe standard WBS is shown in the box at the end of this section and is available on the CAD website at http://www.nasa.gov/offices/ooe/CAD.html, and on the ONCE Portal at *http://www.oncedata.com*.
[7] For more information, see the NASA Work Breakdown Structure Handbook (*http://evm.nasa.gov/handbooks.html*).

performance measurement, and project management. Note that a WBS created from NASA Level 2 Standard Space Flight might not necessarily map to the estimating structures found in commercial tools used in the estimating community. Know the tool planned for use before beginning and be prepared to provide a map of the WBS back to the project WBS if there are differences.

The WBS Level 3 goes into greater detail (e.g., individual instruments, spacecraft subsystems) and is typically the level used for estimating the hardware and software elements.

There are many good WBS references including:

- The NASA Systems Engineering Handbook sets forth policies and processes for preparing a WBS (Section 6.1.2.1)[8]
- The NASA Work Breakdown Structure Handbook[9]
- MIL HDBK 881C, "Department of Defense Handbook, Work Breakdown Structures for Defense Materiel Items"[10]
- NASA Space Flight Program and Project Management Requirements (NPR 7120.5E)[11]

A consistent WBS structure across multiple projects/programs is important for data collection, analysis, and communications throughout NASA. This promotes a defendable estimate for the project. More WBS information is provided in Appendix B.

[8] *http://nodis3.gsfc.nasa.gov/displayDir.cfm?t=NPR&c=7123&s=1*
[9] *http://evm.nasa.gov/handbooks.html*
[10] *https://acc.dau.mil/adl/en-US/482538/file/61223/MIL-STD%20881C%203%20Oct%2011.pdf*
[11] *http://nodis3.gsfc.nasa.gov/displayDir.cfm?t=NPR&c=7120&s=5E*

CADRe WBS

The NASA Standard WBS required by NPR 7120.5E only proceeds to level 2. This increases the degrees of freedom for the Program/Project Manager to construct a WBS that best facilitates project accomplishment. However, the cost estimator and project lead must be aware that there are managerial data demands that must map from the project's WBS. Construction of a WBS that considers these requirements may alleviate significant PM level of effort at stages of the project beyond initial WBS formulation.

For each Agency project, the WBS established by the project must use the NSM numbering scheme and also must correlate exactly through level seven to the corresponding financial accounting structure utilized for each project within the NASA Core Financial System.

In addition to the NASA Core Financial System requirements, projects must submit data into the CADRe system under the CADRe WBS format, shown at right. This data is used by the Agency for reference in future cost estimates. Construction of a project WBS that mirrors or easily maps to the CADRe structure will achieve savings in future level of effort and is considered a 'best practice'.

More information on CADRe is available in Appendix A, and the CADRe standard WBS is available on the ONCE Portal at *http://www.oncedate.com.*

NASA WBS Elements

- System Name
  - Project Management
  - Systems Engineering
  - Safety and Mission Assurance
  - Science/Technology
  - Payload(s)
    - Payload Management
    - System Engineering
    - Payload Product Assurance
    - Instrument *n*
      - Instrument *n* Management
      - Instrument *n* Systems Engineering
      - Instrument *n* Assurance
      - Antenna
      - Optics
      - Sensors/Detectors
      - Structures & Mechanisms
      - Thermal Control
      - Electronics
      - Power
      - Pointing Subsystem
      - Harness & Cabling
      - C&DH
      - Ground Support Equip
    - Integration, Assembly Test & Check
  - Flight System \ Spacecraft
    - Flight System Project Management
    - Flight System Systems Engineering
    - Flight System Product Assurance
    - Spacecraft
      - Spacecraft Management
      - Spacecraft Systems Engineering
      - Spacecraft Product Assurance
      - Spacecraft Structures & Mechanis
      - Spacecraft Thermal Control
      - Spacecraft Electrical Power &
      - Spacecraft GN&C
      - Spacecraft Propulsion
      - Spacecraft Communications
      - Spacecraft C&DH
      - Spacecraft Software
        - CSCI Name 1
        - CSCI Name 2
        - Software Subsystem I&T
      - Spacecraft I&T
    - Entry/Decent/Lander
    - Rover
    - Spacecraft Retirement & Disposal
  - Launch Vehicle/Services
  - Mission Operations System (MOS)
    - MOS Management
    - MOS Systems Engineering
    - Mission Operations Center
    - Science/Data Operations Center
    - Data Distribution & Archival
    - Communications/Network Infrastruct
    - Training
  - Ground Data System (GDS)
    - GDS Management
    - GDS Systems Engineering
    - Mission Operations Center
    - Science/Data Operations Center
    - Data Distribution & Archival
    - Ground Stations
    - Communications/Network Infrastruct
    - GDS Integration & Test
  - System Integration, Assembly, Test &
  - Education & Public Outreach

Reserves

CM&O
G&A

2.1.3. Task 3: Define or Obtain the Project Technical Description

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

The project technical baseline defines and provides quantitative and qualitative descriptions of the project characteristics from which cost estimates will be derived. As such, the project technical baseline 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 objective of this step is to ensure that the estimating team understands and can obtain the documents that thoroughly describe the project to be estimated. The project technical baseline 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. If a CADRe has already been created for the system being estimated, it can be used to understand the technical baseline for the estimate. 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., key performance parameters [KPPs]) and actual costs at the end-of-contract are ported into the One NASA Cost Engineering database (ONCE) at *http://www.oncedata.com*. See Section 4 and/or Appendix A for more information about CADRe and ONCE.

There are several activities associated with understanding the complete program characteristics, including:

1. Gather and review all relevant project data (e.g., existing technical baseline or CADRe, previous estimates, lessons learned and customer feedback, and budget data as well as other programmatic data such as schedules);
2. Collect system characteristics, configuration, quality factors, security, operational concept, and the risks associated with the system; and
3. Obtain the system's (or the project's) milestones, schedule, management strategy, implementation/deployment plan, including launch, test strategy, security considerations, and acquisition strategy.

The estimating team should work closely with the NASA organization sponsoring the cost estimate for access to pertinent documentation describing the system being estimated.

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 following:

- The time available to conduct the estimate;
- The size of the project;
- The technical information available, including the requirements' thresholds and goals (objectives); and
- The phase of the life cycle in which the project 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 Rough Order Magnitude (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 estimates developed separately by the Project Offices and the independent review organizations are based on a common definition of the system and project. The project technical

description 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. Actual costs at the end-of-contract are ported into the ONCE database.

2.2. Part 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.

2.2.1. Task 4: Develop Ground Rules and Assumptions

The Ground Rules and Assumptions (GR&A) are intended to communicate the scope, context, and environment within which the estimate is being developed.

Below are four 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 costs are excluded);
2. Coordinate and gain agreement/approval from the NASA Program/project Manager (P/pM) (or other cost estimate point of contact);
3. Achieve consensus on the GR&A with stakeholders, vendors, end users, etc., to ensure their applicability and to avoid problems leading to inaccurate or misleading estimates; and
4. Document the GR&A as they evolve during the entire estimate process.

The cost estimator works with the NASA P/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 involved 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 ones conducted by independent agencies. GR&A provide cost estimators with the means to bound the estimate, focus attention on the most important elements, and provide temporary resolution of undefined technical and programmatic questions.

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, what is and is not included in the cost estimate, and total quantities. Element-specific GR&A are developed as each WBS element is being estimated and are found in the detail section for each WBS element. Element-specific 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 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, personnel, maintenance, support, and logistics policies are generally included in the GR&A. Global and element-specific GR&A can also be found in the CADRe and should be in sync with the estimate.

GR&A commonly address, but are not limited to, the following topics:

a) **Scope.** The scope identifies the content that is covered by the cost estimate, including activities, hardware elements, and quantities. The GR&A clarify the scope in relation to acquisition milestones, especially specific items or content excluded from the cost estimate. A typical project includes the costs of designing and fabricating or specifying and purchasing components, integrating and testing assemblies, transporting project articles to the operating environment, and conducting operations and maintenance, as well as other life-cycle cost (LCC) elements such as the launch vehicle.

a. **WBS.** As part of the Scope, the WBS organizes the activities and products of a project in a hierarchical structure that matches or maps estimating methods against the elements of the project WBS to ensure that all costs are accounted for without double-counting and/or missing elements.

b) **Make vs. buy decisions.** Identifies and accounts for costs of either manufactured or purchased items. Manufactured items typically require nonrecurring engineering and design effort, tooling, and production setup prior to production. Purchased items may require effort to ensure their proper integration and testing. GR&A about manufacturers, prices, and availability of procured items will help to simplify the estimating effort. (There is further discussion on make/buy in Section 3.0 and Appendix C.)

c) **Government Furnished Equipment (GFE)/Government Furnished Information (GFI).** Describes each Government-provided item and its technical capabilities as well as what portion of its costs should be included or excluded from the estimate results. GR&A prescribe when the GFE/GFI will be available and highlight potential risks associated with their availability and performance. Examples of GFE include such items as launch vehicles, communications networks, and spacecraft hardware components. Examples of GFI are software libraries and routines that can be reused with minimal or no modification. Though GFE/GFI can facilitate projects and reduce overall costs, there are usually costs associated with their proper integration and testing.

d) **Development philosophy.** Plans for how the system will be developed (e.g., prototype or protoflight) as well as the testing philosophy.

e) **Contractors, subcontractors, and their roles.** Determines cost depending on efficiency, labor rates, and fee of subcontractors that may be used to perform specified activities and deliver specified items for a variety of reasons.

f) **Amount of test hardware and key system tests.** Varies by project; needs to be known so that an accurate estimate is obtained.

g) **Budget profile.** Predicts the effect that the budget has on the project's overall cost. In many cases, the availability of fiscal resources in a given period of time may constrain activities and purchases, forcing project delays if the activities and purchases are on the program's/project's critical path. In some cases, the ready availability of funds can enable project efficiencies and discount prices.

a. Often, the cost estimator provides an initial budget profile. When this occurs, the cost estimator needs to document how this is performed within the GR&A section of the estimate.

h) **Schedule and key milestones.** Affect the level of activities and purchases as well as the distribution of estimated costs across time periods. Also affect the project's overall estimated cost and risk. Insofar as point estimating methods are based on historical patterns of expenditures, schedule information permits estimators to assess the applicability of specific analogies or phasing methods to the current project. Includes development and production start and stop dates, Phase B Authorization to Proceed (ATP), Phase C/D ATP, first flight, and Initial Operating Capability (IOC) timeframe for LCC computations, etc.

i) **Labor resources and rates.** Availability of project-specific information enables the estimator to use nongeneric assumptions about the availability of labor and any associated labor costs. Labor resources are typically characterized as the number of full-time-equivalents (FTEs) needed by specialty or skillset. Assumptions that influence FTEs include if (and when) the specific skill mix is available and the number of persons working full time versus part time. Direct labor rates can be as specific as an hourly rate for a person's given specialty and level of experience. Alternatively, direct

labor rates can be as top level as an overall average for all FTEs within a given specialty. It is also important to include GR&A on the added impact of overhead to labor rates (i.e., overhead rate).

j) **Risks and associated risk reduction or mitigation activities.** Describes risks and likely reduction or mitigation activities to be used by estimators to properly size the project effort. Risk can affect cost in two ways. Realization of a technical, programmatic, or cost estimating risk may increase overall project cost. Such risks, which can have significant effect on cost uncertainty, should be described as a part of the baseline cost estimate. In addition, activities and purchases designed to reduce the probability of a risk or mitigate its effect on a program will increase the project's baseline effort and should be incorporated into the baseline cost estimate. Phasing or spreading the estimate over time should also incorporate risk evaluations.

k) **Profit/Fee.** Identifies the profit or fee charged by prime contractors and their subcontractors as well as what items and activities are subject to those rates. This can represent a significant portion of overall project cost.

l) **Design heritage/technology.** Almost all new NASA projects will have some degree of design commonality with a previously flown system—this is also known as "design heritage." The GR&A section should take new technology and design heritage into account when estimating the cost of system design, development, and testing. The GR&A should indicate the systems with which commonality is assumed and how this is reflected in the estimate. Documenting what parts of the baseline cost estimate leverage design heritage helps improve the Basis of Estimate (BoE). For more information about technology cost estimating, see Appendix D.

m) **Management and acquisition approach.** Considerations such as whether cost reductions are taken for change in management culture, new ways of doing business, in-house versus contract, etc. Includes percentages (or approach) used for computing program level wraps (i.e., unallocated future expense, program support, other direct charges, Headquarters taxes, Level II Program Office, etc.).

n) **Production unit quantities.** Includes assumptions regarding spares, long lead items, make or buy decisions, as well as the quantity of development units, prototype, or protoflight units.

o) **Description of Dollars and Inflation**. Specifies the types of year dollars that are presented in cost estimating analyses and results. Costs can be presented in Base Year dollars (synonymous with Constant Year dollars) and/or Real Year dollars (synonymous with Then Year dollars). Reference the inflation indices source(s) used to convert cost data (e.g., from Constant FY15 dollars to Real Year dollars).

p) **LCC considerations.** Includes the mission lifetimes; the hardware replacement assumptions; the hardware and software heritage; the launch rates; the number of flights per year and any cost sharing or joint funding arrangements with other government agencies, if any (e.g., partnerships); and the make/buy decisions, outsourcing, or commercialization approach.

q) **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.

r) **Facilities.** Use of existing facilities, modifications to existing facilities, and new facility requirements. Refer to Appendix L for more information on cost estimation of facilities.

s) **Operations Concept.** Includes a description of any systems or efforts that contribute to the overall operation of the system from launch through end-of-mission. This includes, for example, a description of the launch vehicle used; the location of the Mission Control Center (MCC); and the use of the Tracking and Data Relay Satellite System (TDRSS), Deep Space Network (DSN), or other communication systems, etc. It is also important to provide the Operations and Support (O&S) period, the maintenance concept(s), and, if required, the training strategy.

The customer may provide cost estimators with some GR&A. More likely, GR&A are identified during the review of baseline artifacts and during data collection. Because GR&A can have a significant influence on the overall cost estimate, a joint review of GR&A with the customer early in the estimating process can help to eliminate surprises when initial results are presented. All GR&A should be documented, whether they are obtained from the customer or generated by the estimator. GR&A may also be an important consideration in conducting sensitivity analyses as outlined in Task 9.

2.2.2. Task 5: Select Cost Estimating Methodology

The goal of this task is to select the most appropriate cost estimating methodology (or combination of methodologies) for the data available to develop a high-quality cost estimate (Figure 5).

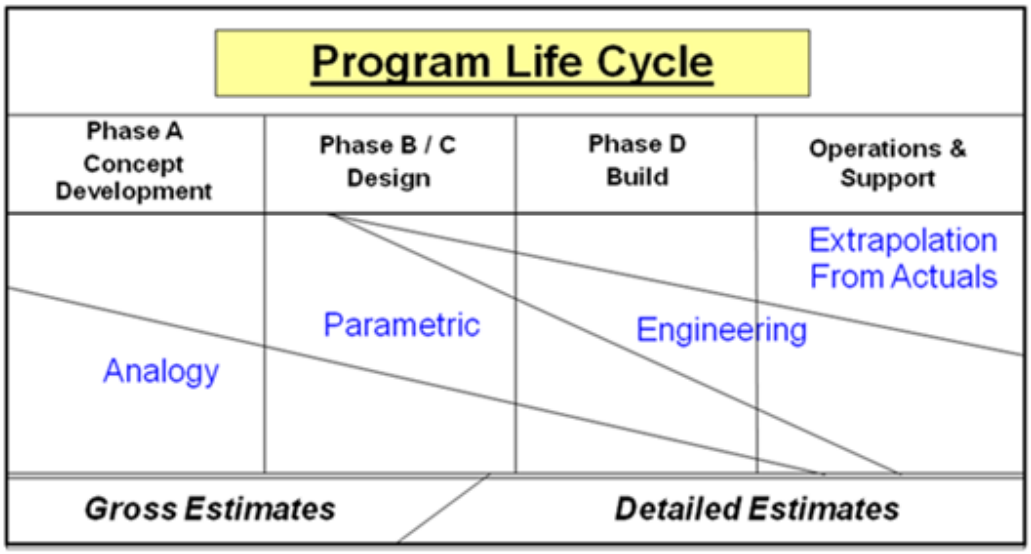


Figure 5. Use of Cost Estimating Methodologies by Phase[12]

Figure 5 shows the three basic cost estimating methods that can be used during a NASA project's life cycle: analogy, parametric, and engineering build-up (also called "grassroots"), as well as extrapolation from actuals using Earned Value Management (EVM).[13] Figure 5 indicates that the prevalent cost estimating methodology changes over the project life cycle. A primary reason for this is that the amount of data available to conduct the project estimate typically changes over time.

[12] Defense Acquisition University, "Integrated Defense Acquisition, Technology, and Logistics Life Cycle Management Framework chart (v5.2)," 2008, as reproduced in the International Cost Estimating and Analysis Association's "Cost Estimating Body of Knowledge Module 2."

[13] More information on the use of EVM at NASA can be found at *http://evm.nasa.gov*.

A basic explanation of each cost estimating methodology is provided here. Appendix C provides a detailed explanation of each cost methodology.

Analogy Cost Estimating Methodology

The analogy method uses the cost of a similar system, adjusts for differences, and estimates the cost of the new system. This technique identifies a currently fielded system (comparable system) similar in design and/or operation to the proposed system.

Analogy estimates are based on a comparison and extrapolation to similar 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 more or less complex than the analogous program. Clearly, subjective adjustments compromise the validity and defensibility of the estimate and should be avoided, while historical data and analysis are considered more credible and defendable.

This estimating approach is typically used when an adequate amount of program and technical definition is available to allow for the proper selection, and adjustment, of comparable program costs. 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. Table 1 provides a list of the strengths and weaknesses of using an analogous system method to develop a cost estimate.

Table 1. Strengths, Weaknesses, and Applications of Analogy Cost Estimating Methodology

Strengths	Weaknesses	Applications
Based on actual historical data	In some cases, relies on single historical data point	• Early in the design process • When less data are available • In rough order-of-magnitude estimate • Cross-checking • Architectural studies • Long-range planning
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"	

For more information on the analogy method, refer to Appendix C (Cost Estimating Methodologies).

Parametric Cost Estimating

Parametric cost estimates are a result of a cost estimating methodology using statistical relationships between historical costs and other program variables such as system physical or performance characteristics, contractor output measures, or personnel loading. 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 in 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 (see Appendix M for more on software). The data that relate to these estimates 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 be easily replicated. Figure 6 shows the steps associated with parametric cost estimating.

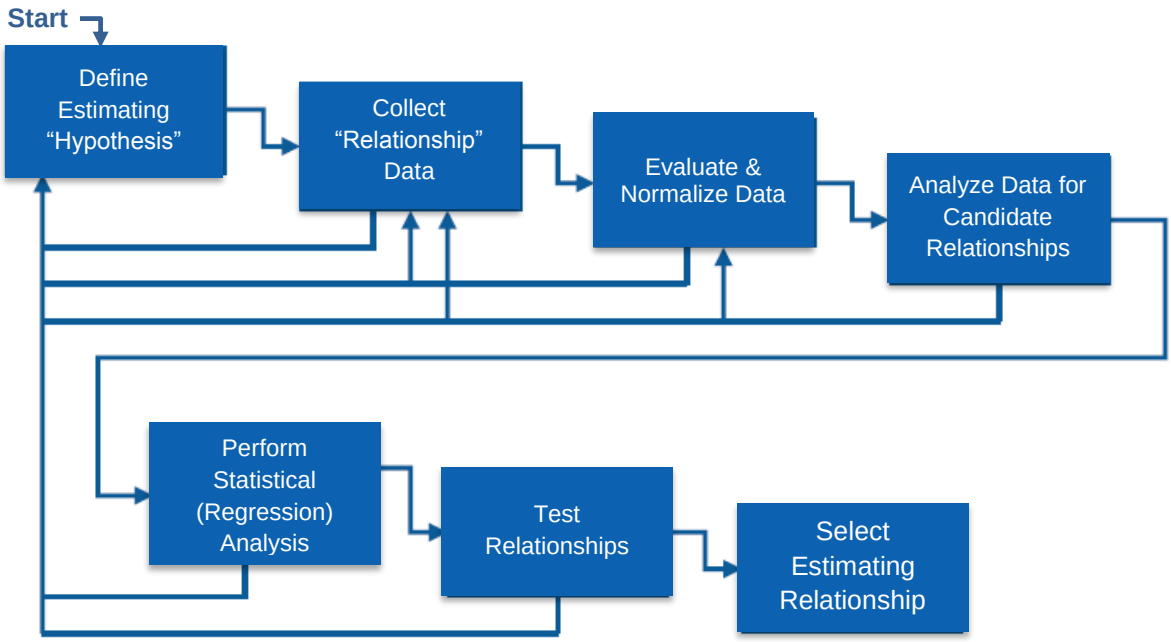


Figure 6. Parametric Cost Modeling Process

As part of these seven top-level steps, an estimator performs a regression analysis to develop one or more cost estimating relationships (CERs). The main objective of regression analysis is to generate a CER in the form of an equation that represents a relationship between a "dependent" variable to one or more "independent" variables. The dependent variable is called that because it responds to changes in the independent variable where:

- The value of the dependent variable, designated by the symbol Y, is calculated;
- The value(s) of the independent variable(s), designated by the symbol X, is known; and
- The resulting relationship between Y and X can be described mathematically.

When working with CERs, the dependent Y variable typically represents cost, while the independent X variable(s) represents the parameter(s) of the system or effort being estimated. Independent variables or "cost drivers" should be chosen because there is a strong correlation between these variables and cost (Y) and because there are sound principles for the relationship being investigated.

For example, the assumption may be made that the weight of a component drives its total cost. Figure 7 provides an example of how this may be portrayed as a standard Cartesian coordinate graph. The dependent variable is the Y axis (Cost) and the independent variable is the X axis (Weight). By using historical data that compare cost to an independent variable and plotting, we can establish whether there is a relationship between the variables. From these data points, a "line of best fit" can also be plotted (depicted as the blue line in Figure 7). The line of best fit to the data can be tested and used for a CER. Methodology for developing a CER by resolving a line of best fit is covered in more detail in Appendix C.

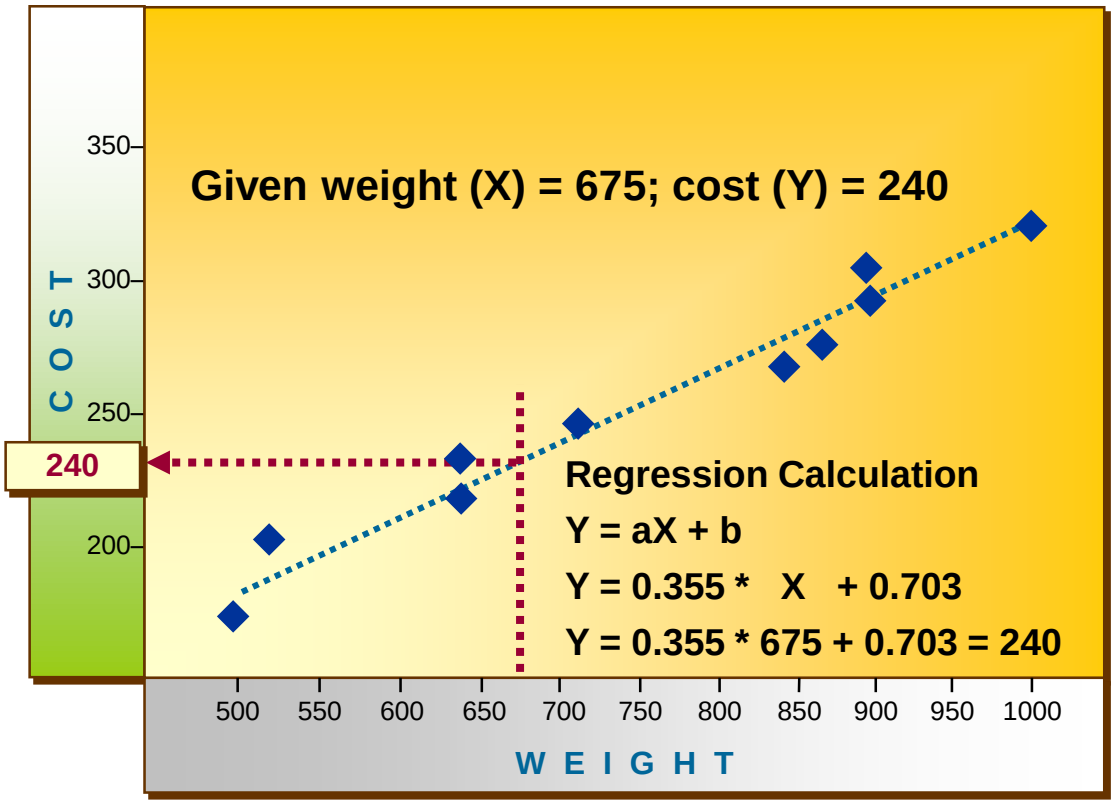


Figure 7. Scatterplot and Regression Line of Cost (Y) Versus Weight (X)

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. Microsoft Excel or other commercially available modeling tools are most often used for these calculations. Table 2 lists some strengths and weaknesses of using parametric cost estimating methodology to develop a cost estimate.

Table 2. Strengths, Weaknesses, and Applications of Parametric Cost Estimating Methodology

Strengths	Weaknesses	Applications
Once developed, CERs are an excellent tool to answer many "what if" questions rapidly	Often difficult for others to understand the statistics associated with the CERs	• Design-to-cost trade studies • Cross-checking • Architectural studies • Long-range planning • Sensitivity analysis • Data-driven risk analysis • Software development
Statistically sound predictors that provide information about the estimator's confidence of their predictive ability	Must fully describe and document the 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	

For more information on the parametric cost estimating method, refer to Appendix C (Cost Estimating Methodologies).

Engineering Build-Up Methodology

Sometimes referred to as "grassroots" or "bottom-up" estimating, the engineering build-up methodology produces a detailed project cost estimate that is computed by estimating the cost of every activity in a Work Breakdown Structure, summing these estimates, and adding appropriate overheads. 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. This is often referred to as the Cost Breakdown Structure (CBS) or the Cost Estimating Structure (CES). In most cases, 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 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 project GR&A. It is also the cost estimator's responsibility to test, understand, and validate the knowledge base and data used to derive estimates.

Figure 8 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 detailed activities such as documenting the Basis of Estimates and schedules and applying wage and overhead rates.

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 provide latitude in predicting costs for the estimator. This method of engineering judgment and expert opinion is known as the Delphi method.

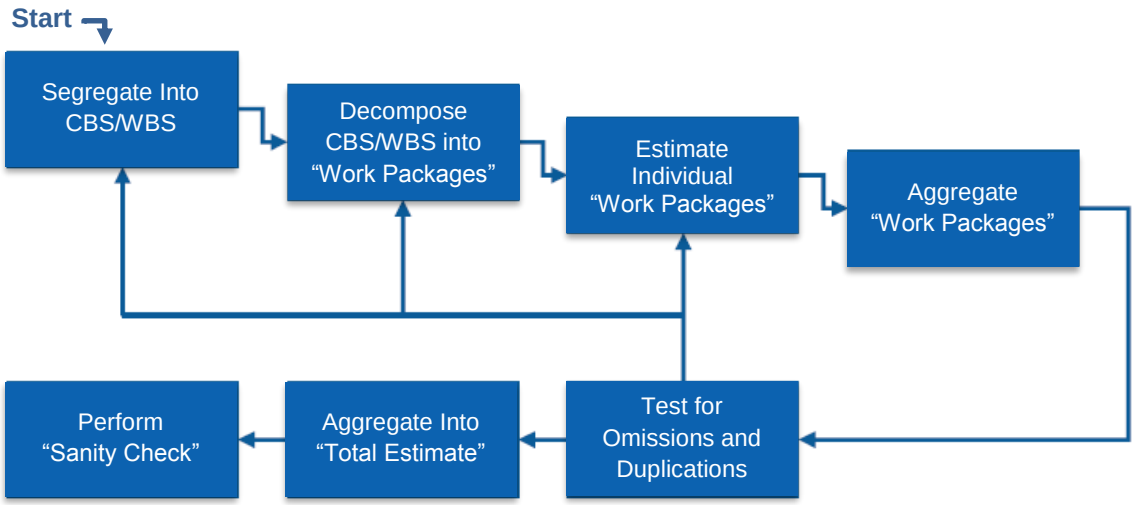


Figure 8. Method for Developing Engineering Build-Up Estimate

The cost estimator's interview skills 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. During this process, individuals are generally not identified to the outside and, in some experiments, not identified to each other. More information is available in Appendix C.

Table 3 provides a list of the strengths, weaknesses, and applications of using the engineering build-up method to develop a cost estimate.

Table 3. Strengths, Weaknesses, and Applications of Engineering Build-Up Methodology

Strengths	Weaknesses	Applications
Intuitive	Costly; significant effort (time and money) required to create a build-up estimate Susceptible to errors of omission/double counting	• Production estimating • Negotiations • Mature projects • Resource allocation
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 by itself provide "statistical" confidence level	
Provides excellent insight into major cost contributors (e.g., high-dollar items).	Does not provide good insight into cost drivers (i.e., parameters that, when increased, cause significant increases in cost)	
Reusable; easily transferable for use and insight into individual project budgets and performer schedules	Relationships/links among cost elements must be "programmed" by the analyst	

2.2.3. Task 6: Select/Build Cost Model/Tool

The objective of this task is to select the most appropriate model/tool 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 a variety of estimating tools and models available for NASA cost and schedule analysts to use in developing an estimate, including tools that NASA has sponsored and other commercially available tools for which NASA provides licenses. These models and tools are summarized in Table 4, indicating which estimating methodology they may be applicable for, as well as whether they are available on the ONCE Model Portal. Refer to Appendix E for additional information on these primary tools.

Table 4. Cost Models and Tools Utilization Guide

Tool Type		ONCE Portal[14]	Estimating Methodology Applicability: Parametric	Analogy	Build Up
NASA-Sponsored Models and Tools					
Project Cost Estimating Capability (PCEC)			✓		
NASA Air Force Cost Model (NAFCOM)	*(Transitioning users to PCEC)*		✓		
NASA Instrument Cost Model (NICM)		x	✓	✓	
Technology Cost and Schedule Estimation (TCASE) Tool		x		✓	
Schedule Management and Relationship Tool (SMART)		*soon*	✓	✓	
Phasing Model		x	✓		
Schedule Estimating Relationship Risk Analysis (SERRA)			✓	✓	✓
Quantitative Techniques Incorporating Phasing and Schedule (QTIPS)			✓	✓	✓
QuickCost			✓		
One NASA Cost Engineering (ONCE) Database		x	✓	✓	✓
REDSTAR Database			✓	✓	✓
Models and Tools with NASA-Provided Licenses					
Polaris[4] *(JCL Analysis)*	x		✓	✓	✓
Argo (Monte Carlo simulation)		x	✓	✓	✓
Automated Cost Estimating Integrated Tools (ACEIT)		x	✓	✓	✓
CO$TAT (statistical analysis package)		x	✓	✓	✓
Joint Analysis of Cost and Schedule (JACS)	*(JCL Analysis)*	x	✓	✓	✓
SEER for Hardware, Electronics, & Systems (SEER-H)		*soon*	✓		
SEER for Software (SEER-SEM)		*soon*	✓		
PRICE® TruePlanning™			✓		
PRICE® Estimation Suite (PES)			✓		

As shown in Table 4, many cost estimating models exist, and, as is the case with the estimating methodologies, no single cost model can be used for all purposes. Estimating models can vary significantly in terms of data availability and automation. Some models require the user to create datasets and develop CERs, while other models already include datasets 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.

[14] Current ONCE Model Portal availability as of February 2015. More tools and models will be made available via the ONCE Model Portal at *http://www.oncedata.com* over time.

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

- Review available choices and make a selection. If no suitable alternatives exist, explore the option of creating a model.
- Ensure that the model is validated.
- Be prepared to defend the choice.

For each methodology described in the previous section, the cost estimator can select from a multitude of both commercially available and Government developed or owned models, as summarized in Table 4. Generally speaking, one of these models or tools should help the cost estimator work more efficiently and effectively. In addition, many cost estimators use commercially available spreadsheet software to create their own models when estimating needs cannot be met by commercially available models. Information about many modeling products, including NASA licenses available and recommended for use to the cost estimator, can be found in Appendix E. Included in Table 4 are some tools specific to software estimation, which is addressed in additional detail in Appendix M.

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. For best results, these models should be calibrated to historical data that is comparable to the system being estimated to ensure that the estimate takes into account factors such as the project environment (e.g., Earth orbiting, planetary, etc.).

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 collected and new CERs developed. While planning the development, it is important to document the model GR&A.

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 have been incorporated, it is ready to generate estimates. If the model is going to be distributed to the NASA cost community, user documentation and training should be prepared.

Three Cost Model Best Practices

1. Before and after running the model, it is important to check and recheck data entry and formulas to ensure accuracy and to document each input and formula for the detailed Basis of Estimate (BOE).
2. 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.
3. 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 to support major investment and budget decisions.

2.2.4. 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 the most accurate and defendable cost estimate can be developed.

Data collection and data normalization are two cost estimating activities that are critical to the development of a credible and defendable cost estimate. Sufficient time and resources should be planned in advance for these efforts.

Data Collection

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, once collected, may need to be normalized to support a particular cost model or estimating method.

Because uncertainty is the underlying driver in a cost-risk analysis, it is 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 may assist in identifying risks early and potentially save time by reducing data collection during the cost-risk assessment later in the process. Therefore, it is imperative that the cost estimator meet with experts early and often about uncertainty in technology, design, requirements, etc.

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 (e.g., budget data, contract cost data, labor rates, workforce estimates, etc.).

One NASA Cost Engineering (ONCE) Database

The ONCE database is a secure, Web-based application that contains all completed CADRes for easy retrieval and analysis. The database provides advanced search functions to quickly access CADRe data across multiple projects and milestone events. Since CADRes represent snapshots of a project at successive key milestones, the ONCE database captures all of the changes that occurred on a project with the associated cost and schedule impacts.

The ONCE database provides enhanced insight into historical cost and technical data, and provides added capability to manage and organize these data. Such a capability helps advance costing practices and analysis across the Agency. The database is a Web-based ASP.Net application utilizing a Structured Query Language (SQL) server database on the back end. The ONCE server resides behind the Marshall Space Flight Center (MSFC) firewall and complies with all NASA security requirements.

Individuals who needs access to the ONCE database can go to the ONCE Web site (*http://www.oncedata.com*) and click on the "request access" link on that page. The requestor must have an account in NASA's Identity Management and Account Exchange (IdMAX) system in order to gain insight.

For more information on ONCE, see Appendix A.

Based upon the resources, the schedule, and the expectations, the estimator should use the most appropriate data collection mechanisms as can be supported. The cost estimator will work with the NASA P/pM and members of the technical team to obtain the technical and programmatic data required to complete the cost estimate. Typically, system requirements are contained in a document or set of documents such as a technical baseline, CADRe, and/or the One NASA Cost Engineering (ONCE) Database.

A well-documented set of project requirements ensures that the cost estimators are estimating the same product 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. Often, the cost analyst is estimating conceptual designs, so a requirements document does not exist. However, there is often conceptual design data such as master equipment lists, functional block diagrams, etc. Collecting programmatic data, such as schedules, is also key to data collection efforts. For more information on schedule analysis, see Appendix K.

Table 5 provides a list of typical data types and sources that cost estimators use to collect the data needed to develop an estimate.

Table 5. Data Types and Sources

Three Principal Types of Data		
Data Category	**Data Type**	**Data Source**
Cost Data	• Historical Costs • Labor Costs • Existing Agency CERs	• Basic Accounting Records • Cost Reports • Historical Databases and Libraries • Contracts (Secondary) • Cost Proposals (Secondary) • CADRes • ONCE
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 • Master Equipment Lists
Project Data	• Development and Production Schedules • Quantities Produced • Production Rates • Equivalent Units • Breaks in Production • Significant Design Changes • Anomalies (e.g., strikes, natural disasters, etc.)	• Project Database • Functional Organizations • Project Management Plan • Major Subcontractors

As a final note, 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 provided. 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 the Headquarters Cost Analysis Division.

Normalize Data

Normalizing data for cost includes adjusting for inflation, which makes the raw data set consistent and fit for use in CERs, models, or estimates. 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 Base Year (BY), Constant Year (CY), or Real Year (RY) dollars. Table 6 defines some common terms used for inflation and escalation.

Table 6. Inflation and Escalation Terms

Term	Definition
Base Year (BY) Dollars	A point-of-reference year whose prices form the basis for adjusting costs or prices from other years.
Constant Year (CY) Dollars (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 FY13 dollars).
Current Year (CY) Dollars (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.)
Then Year (TY) Dollars	Total Obligation Authority (TOA) that includes a slice of inflation to cover escalation of expenditures over a multiyear period.
Real Year (RY) Dollars	Money expressed as spent dollars. Sometimes this is referred to as Then Year Dollars.
Inflation Rate	The percentage 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 is 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 subappropriations.

The Cost Analysis Division (CAD) in the Office of Evaluation at NASA Headquarters provides an annual update of the NASA New Start Inflation Index (*http://www.nasa.gov/offices/ooe/cad/publications/*) to be used to prepare cost estimates for new projects. The NASA New Start Inflation Index has been created to estimate new efforts and to normalize historical cost from prior missions. The factors contained in this index should not be used to estimate NASA civil servant personnel costs or determine if a contract is currently in place. Defense Contract Audit Agency (DCAA)-approved forward pricing indices should be used for all efforts that are already under contract.

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 the price of a product or service over time. Escalation factor (or weighted inflation) is the "multiplier" that accounts for inflation plus

the normal occurrence of allocating money in 1 year and incorporates outlay rates over a number of years. For more information on inflation adjustments, refer to the DOD Inflation Handbook at *https://www.ncca.navy.mil/tools/OSD_Inflation_handbook.pdf*.

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. Production rate (units produced over a time period) may also have an effect 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 personnel that affect the data. At NASA, there are few projects that involve production rate factors; however, NASA estimates should take into account production considerations for data collected from other sources. Adjustments that may need to be made in order to normalize data include the following:

- Scope consistency between the historical data of a product and the product being estimated;
- Unusual events or anomalies in a project's life, such as extra testing, failures, or labor anomalies;
- Technology improvements and advancements, where the data may need to be adjusted by engineering judgment;
- Raw data from reporting system anomalies or changes, such as a change in rates, factors, or hours for standard reporting; and
- Reporting system differences that may require mapping accounting classifications or categories of data to WBS elements.

Normalized data should be reviewed and validated by the estimator to ensure that a consistent data collection methodology, 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 the traceability of adjustments made to the data are also critical. These documented factors assist the estimator with the validation of the data, lead to data reliability, and ultimately contribute to estimate credibility.

If an estimator takes each of these elements 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.

2.3. Part 3: Cost Estimate Tasks

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

2.3.1. Task 8: Develop the Cost Estimate

The goal of this task is to create an initial LCC point estimate.

There are eight activities associated with developing a cost estimate:

- Verify the GR&A;
- Populate the model with the normalized data;
- Ensure that the estimate is full cost compliant;
- Run the model to calculate cost;
- Time-phase the estimate;
- Adjust the estimate for inflation;
- Conduct any cross-check estimate or estimate reconciliation; and
- Develop or update the cost track to previous or independent estimate.

Once the model has been selected or constructed and the data have been gathered, the next step is to populate the model with data according to the GR&A. The model is run and a point estimate is calculated. Generating a point estimate is an important step, but it is just the beginning of the cost-risk process.

It is important to understand that when project costs are being estimated, the costs are uncertain and the point estimate is not definitive and not the only possible estimate.

Time-Phasing the Estimate

Next, the cost estimator must properly time-phase the data according to the planned development schedule. This can be done using many techniques, including Beta Curves 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.

Baseline cost estimates that are generated in CY dollars can be phased by fiscal year prior to being converted into annual real-year dollars (also known as then-year dollars). Once baseline estimates are adjusted for inflation over the project life cycle, these RY dollars can be used as inputs for the annual NASA budget for the project. There are two main methods to accomplish this, and these are briefly discussed below and addressed in more detail in Appendix F.

The phasing of the cost estimate (which reflects when funds will be expended) needs to be further adjusted to reflect the budget authority, if being used for developing budgets by taking into account when budget authority is needed relative to when those funds will be expended.

Develop Probabilistic Cost Estimate

The NASA cost community started implementing probabilistic analysis in the early 2000s. NASA embraces probabilistic cost and schedule analysis as a means of improving its delivery of projects and programs on time and within budget. NASA leadership believes that all projects should submit budgets that are based upon a quantification of the risks that could cause the project to take longer or cost more than initially anticipated. Identification and estimation of risk and accommodation of uncertainty, for both cost and schedule, are keys to improving NASA's cost and schedule performance, thereby helping to establish a more credible cost and schedule baseline. By making use of probabilistic techniques, NASA is able to more effectively communicate the impact of changes to planned or requested resources by providing quantified effects on the probability of meeting planned cost and schedule baselines.

The estimation and analysis community has, as a group, moved to the adoption of probabilistic cost estimates rather than deterministic cost estimates. NASA has been a supporter, proponent, and creator of probabilistic cost estimates for more than 10 years. Probabilistic cost estimates attempt to quantify risk and uncertainty. A probabilistic cost estimate provides management with significant insight into the key cost and schedule drivers of the program, allowing them to actively manage and develop mitigation strategies to reduce cost. In addition to providing insight, probabilistic cost estimates are useful for reporting and analysis purposes, providing valuable information to stakeholders, management, and partners.

The development of a probabilistic estimate can often originate with a point estimate (deterministic estimate), but enhances it by including risk and uncertainty through a variety of techniques. These methods (typically described as inputs based, outputs based, and scenario based) may rely on Monte Carlo simulation or be analytical in nature.

Why do Probabilistic Analysis?

NASA does probabilistic analysis to enable more informed management decisions based on an understanding of risk and uncertainty. NASA deals with complex, one-of-a-kind systems that have a lot of risk and uncertainty associated with them. A probabilistic analysis process helps NASA management understand the risk involved, *informing decisions* on the appropriate amount of risk that the Agency is willing to accept.

In most cases, adding up the most likely point estimates produces an understatement of the total cost because the sum of most-likely estimates does not equal the most likely total.[15] Refer to Appendix C for further explanation.

Conducting a probabilistic analysis involves the identification and quantification of risk and uncertainty. As mentioned above, the method being used to develop the probabilistic analysis may differ, but the fundamental goal and outcomes are the same. Completing a probabilistic analysis as a part of the estimating process ensures that decision makers can view and assess the risk of a project. The successful completion of a probabilistic analysis will produce a range of probable answers for cost, schedule, or both.

Estimators and analysts may choose to develop a Technical Baseline Estimate (TBE) or "point estimate" first before conducting a probabilistic risk analysis. However, this is not a hard requirement. Many estimators and analysts will not perform the activities in serial, but instead will perform them in parallel during the estimating process. Iteration may also be required during the estimating process as data, models, and methodologies are refined.

2.3.2. Task 9: Develop and Incorporate the Cost Risk Assessment

The objective of this task is to produce a credible project cost cumulative distribution function (CDF, or "S-curve") for the range of costs of the project.

Cost-Risk Assessment

There are six activities associated with developing a cost-risk assessment in order to understand the current confidence level of the project and estimate the amount of unallocated future expense (UFE) necessary to achieve a desired confidence level:

1. Determine the project's cost drivers and risks with input from the NASA P/pM and staff;
2. Develop probability distributions for the technical and schedule cost drivers;
3. Develop probability distributions for the cost model uncertainty;
4. Run the risk model;
5. Identify the probability that the actual cost is less than or equal to the point estimate; and
6. Recommend sufficient UFE to achieve the desired percent 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. Cost-risk analysis is an analytical process that captures estimating error (or uncertainty); uncertainty in the technical design, requirements, and technology; and project risks to determine a probabilistic range of outcomes. This task also allows the cost estimator to document risks in a manner that accommodates proactive management of project costs. Details about methodologies and how to conduct cost-risk assessments are provided in Appendix G.

Cost Risk Assessment

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 unallocated future expense (UFE) to achieve a desired confidence level. The objective of a cost-risk analysis is to produce a credible project cost S-curve (cumulative distribution function) for the cost of the project.

[15] Garvey, Paul R., *Probability Methods for Cost Uncertainty Analysis*, New York, Marcel Dekker, 2000

Cost-risk analysis quantifies the necessary budgeted UFE necessary to reach an acceptable level of confidence. Risk dollars should be phased in the estimate where they will most likely be needed. Most often, the risk dollars are needed when problems occur between PDR and CDR and then again during Integration and Test.

Sensitivity Analysis

It is recommended that a sensitivity analysis be performed to identify the major cost drivers (i.e., those design parameters whose changes create the greatest changes in cost). Sensitivity analysis helps to determine how sensitive the estimate is to changes in assumptions, technology, or system design. By relating model inputs back to such changes, sensitivity analysis provides the decision maker with added insight into how program decisions can change estimates that cost models produce. For these 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 may 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 and then begin to "back off" that solution in the interest 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.

More details on sensitivity analysis can be found in Section 4.1 and Appendix G.

Choosing the Level of Unallocated Future Expense

The level of UFE or UFE percentage should be selected based upon achieving a particular level of confidence from the cost or joint cost and schedule risk analysis. The appropriate level of confidence is chosen by the appropriate NASA management council after the analysis, and the resulting UFE 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 UFE so as to hold the level of confidence constant across all alternatives and report the resulting cost. Or the cost analyst may add UFE so as to hold the cost constant and report the resulting level of confidence.

2.3.3. Task 10: Document the Cost Estimate

The objective of this task is to capture, concurrently, from project initiation through completion, the LCC results of the cost estimating process, and all of its byproducts (confidence levels, Basis of Estimate (BOE), risk, UFE, etc.).

The purpose of the cost documentation is to provide a written justification for the program cost estimate. This documentation is typically referred to as a BOE. The BOE documents the ground rules, assumptions, and drivers used in developing the cost and schedule estimates, including applicable model inputs, rationale or justification for analogies, and details supporting cost and schedule estimates. Given the size and importance of programs, the documentation should be viewed as a substantive 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—Agencywide—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 the estimates for each element supporting the point estimate, the inputs used to develop the cost-risk estimate, and a description/analysis of the cost-risk estimation results.

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.

In addition to providing a brief description of the system or project being estimated, cost documentation provides:

- The 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, including:
  - Inflation and other supporting assumptions;
  - Data sources;
  - BOE (e.g., equations applied, quantities used, labor rates and workforce estimates, schedules);
  - New facilities, initial spares, and other start-up investment costs; and
  - Operations costs with specific operational scenarios.
- The means by which each part of an estimate and the databases used can be fully explained;
- A brief description of the acquisition strategy as it impacts/influences the LCC;
- The cost S-curve and unallocated future expense (UFE) sufficiency analysis;
- The sensitivity analyses; and
- A comparison track to identify and explain any deviations between the current estimate and any prior estimate.

A well-documented estimate provides an understanding of the cost elements so that decision makers can make informed decisions. Other reasons why proper documentation is important in a cost estimate include:

- Experience from formal cost reviews, such as Non-Advocate Reviews (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 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 effort 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 an updated PCC.

Documentation should include a reasonable description of each line item, along with risk confidence levels for many, if not all, cost elements. The level of detail varies with the estimate, but the minimum amount of detail should be enough for another estimator to reconstruct the estimate. Supporting data too complex for inclusion in the main documentation should be included in an appendix. It is important for the documentation to be accessible beyond the actual cost model. Whenever sufficient details and data sources are available, consider developing a separate document (e.g., BOE) to sufficiently describe these available data. There should be an accompanying 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 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 it should be completed in full once the estimate is complete and documented.

Cross Checks

To verify the reasonableness and credibility of the estimate, estimators are encouraged to generate secondary estimates based on the same set of normalized data and inputs, but using different models and techniques. For example, an estimator may compare the results of a parametric model with costs from an analogous program. Another cross-check is to compare the results from one parametric model with those from a different model, or different estimators can run the same model independently and then compare results. The availability of cross-checks, historical data, estimates for similar projects, and expert judgment enables estimators to assess the credibility, reasonableness, and validity of the estimates as a whole and at the detailed level. When issues are identified that lead to questions about the cost estimates, the estimators can apply a cross-check using different methods and tools. They can also conduct sensitivity analyses by identifying key inputs and then varying their values to understand the estimate drivers. The assessment process typically involves a collaboration of estimators and subject matter or technical experts. Many estimators find that a peer review is useful in cross-checking their estimates.

Furthermore, the cost analyst must ensure that the cost estimate meets certain quality standards, including such attributes as traceability, defensibility, and repeatability.

Cost Documentation Best Practices

- Begin documentation efforts early and continue throughout the cost estimating process. Document sources in the actual models and include these details in the estimate write-up and in the estimate presentations. Provide the data or rationale to support qualitative or subjective inputs, like percent new design or manufacturing complexity.
- 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 (see Appendix C). This information is necessary to adequately assess the applicability of a CER.
- Where subjective judgments are used to adjust estimates made by analogy with other systems or components of systems, the sources of those judgments must be identified (e.g., cost analysts, engineers) and full citations for the source(s) of the costs of each element in an engineering or grassroots estimate must also be cited.

- Present detailed examples of methodologies used to estimate first and second levels of the cost elements normally included in life-cycle cost estimates (LCCEs) for 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.) must be documented.
- 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.
- The approach, GR&A, inputs, sources, etc., for the cost-risk analysis must be fully documented.
- Tracking through a comparison or a cost trace is required when an estimate changes. Documentation must include the specific reasons for the change.

See Appendix H for more discussion on documenting the estimate.

2.3.4. Task 11: Present the Cost Estimate 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, the objective of this task is to successfully create and communicate a quality cost estimate to decision makers and stakeholders.

There are three activities associated with presenting/briefing results:

- Create briefing materials and supporting documentation for internal and external presentations, as appropriate.
- Present and defend the estimate.
- Gather and provide feedback to capture improvements for the next estimate.

Consistency in presenting cost estimates across Centers facilitates understanding during the management review process and promotes completeness and quality of the cost estimating and analysis documentation.

The cost estimator should prepare briefing material and supporting documentation for internal and external presentations, as appropriate. It is again recommended that each Center internally maintain as much data formatting consistency as possible, as that will facilitate understanding during the management review process and promote completeness and quality. 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.

2.3.5. Task 12: Update the Cost Estimate as Required

The purpose of updating the cost estimate is to improve the estimate as better information becomes available. Doing so can help the estimator defend the estimate over time, reduce updated estimate turnaround time, and give decision makers a clearer picture for major decisions or "what if" drills.

There are two activities associated with updating the cost estimate:

- Assess and utilize customer feedback along with lessons learned and incorporate this feedback into the next version of the estimate.

- Update the estimate when project content changes and as the project moves through its life-cycle phases and conducts milestone reviews.

It is important to maintain a good project cost baseline as a forward indicator for cost overruns. 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.

One of the best ways a project team can update its schedule and cost estimates is to adjust these according to its own performance, as discussed in Appendix I. Earned Value Management is recognized as a best practice for making such cost and schedule adjustments (e.g., on a monthly or quarterly basis).[16]

[16] EVM information available at *http://evm.nasa.gov/* .

3. Joint Cost and Schedule Confidence Level Analysis

Joint Cost and Schedule Confidence Level (JCL) is an integrated analysis of cost, schedule, risk, and uncertainty. The result of a JCL indicates the probability that a project's cost will be equal to or less than the targeted cost *and* that the schedule will be equal to or less than the targeted finish.

The development of a probabilistic cost-loaded schedule (PCLS) is the primary methodology for developing a JCL. This method requires the project and the review entity to focus on the project's plan, which in turn improves project planning by systematically integrating cost, schedule, and risk products and processes. It also facilitates transparency with stakeholders on expectations and probabilities of meeting those expectations. Lastly, it provides a cohesive and holistic picture of the project's ability to achieve cost and schedule goals and helps the determination of reserves (or UFE) for cost and schedule to achieve the desired confidence level.

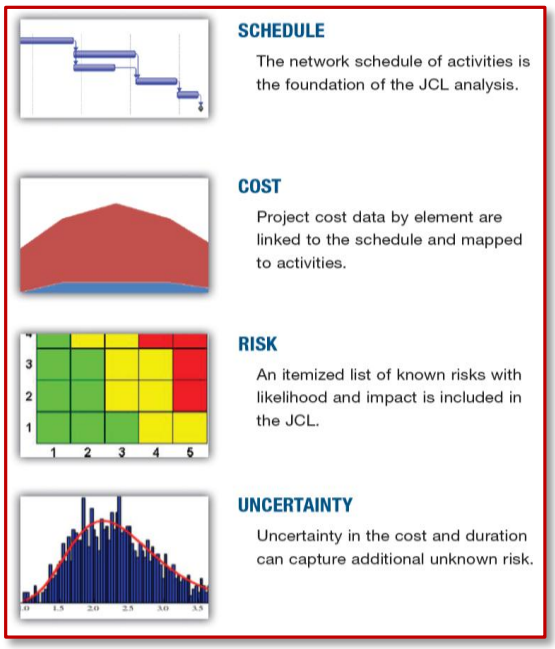
This section presents an overview of the JCL process, outputs, and usage. Appendix J provides more in-depth information and should be referenced by those developing a JCL.

3.1. JCL Process Flow

This section gives a broad overview of the JCL process.

In general, there are five fundamental steps in building a JCL and one prerequisite (step 0):

0. Identify goals of the JCL analysis.
1. Develop a summary analysis schedule.
2. Load cost onto the schedule activities.
3. Incorporate the risk list.
4. Conduct an uncertainty analysis.
5. Calculate and view the results.



The following sections will walk the reader through a simple illustrative example, describing each of the key steps in the JCL analysis process.

3.1.1. Step Zero: Identify Goals of the JCL Analysis

As stated previously, JCL is a policy requirement, but it can also be a very valuable management tool. There are certain quality standards that must be met to satisfy policy. However, depending on the goals and expectations of the JCL analysis, the cost estimator may want to set up the JCL analysis to assist and be synergistic with other products and processes. When setting up the JCL process, especially the schedule, it is important to think about what questions the JCL should answer, who the primary users and beneficiaries will be, and what fundamental insight the JCL should provide.

3.1.2. Step One: Develop a Summary Analysis Schedule

The backbone of the entire JCL analysis is the schedule that includes well-defined activities and logic networking. For more information on developing a schedule, please refer to Appendix K and/or the NASA Schedule Management Handbook (*http://www.nasa.gov/pdf/420297main_NASA-SP-2010-3403.pdf*). For the purposes of this illustrative example, it is assumed that a project has set up a very simple schedule.[17] Figure 9 shows a simple schedule with two parallel activity streams, one with three tasks and one with two tasks, converging on a single integration task. Once that integration task is complete, the project is complete.

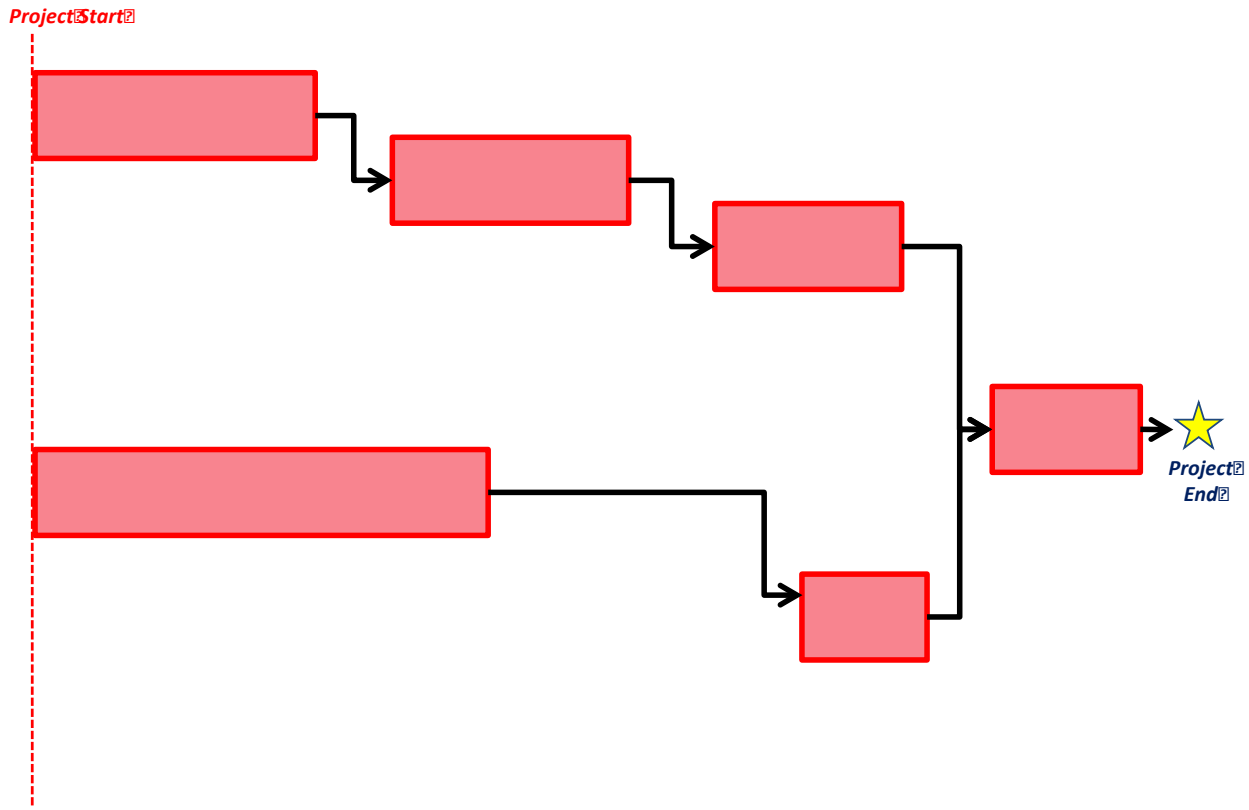


Figure 9. Summary Schedule

As you will notice, the schedule is logically linked, meaning that you can see the predecessors and successors for every task. You may also notice that the project's milestone—in this case, Project End—is linked in the schedule network, too. Such milestones will automatically adjust as you populate the JCL schedule.

3.1.3. Step Two: Load Cost onto the Schedule Activities

Once a robust schedule that accurately portrays project work flow is established, the next step is to cost load the schedule. Cost loading is accomplished by mapping cost to schedule. Cost data can be summarized by a Work Breakdown Structure to aid with mapping.

To do this, distinguish cost into two characteristics: Time Dependent (TD) and Time Independent (TI) costs.

[17] Note that this example analysis schedule is extremely simplified—a high-level schedule of a typical spacecraft system will have much more detail than this.

TD costs are defined as those costs tied directly to the duration of a task. TD costs increase as duration increases and decrease as duration decreases. Costs may be time-dependent because they are overhead, such as project management, or they represent resources that remain fixed over the duration of a task. An example of the latter would be the minimum staff and facilities required to support a test activity.

TI costs represent activities whose costs are not affected by changes in overall duration. TI costs are not affected by schedule slips or compressions.

Figure 10 shows that time-dependent costs can spread over separate tasks. This example shows two sets of TD costs. One set expands across the entire project. This implies that there is a "standing army" of personnel that will follow the project regardless of where it is in the life cycle (i.e., project management). Another observation is that there are two tasks that do not have TI costs. This is not to imply that there are no costs associated with these tasks—in fact, there are TD costs; it does, however, show that these tasks are level of effort (LOE) tasks that are executed only by the TD resources or costs.

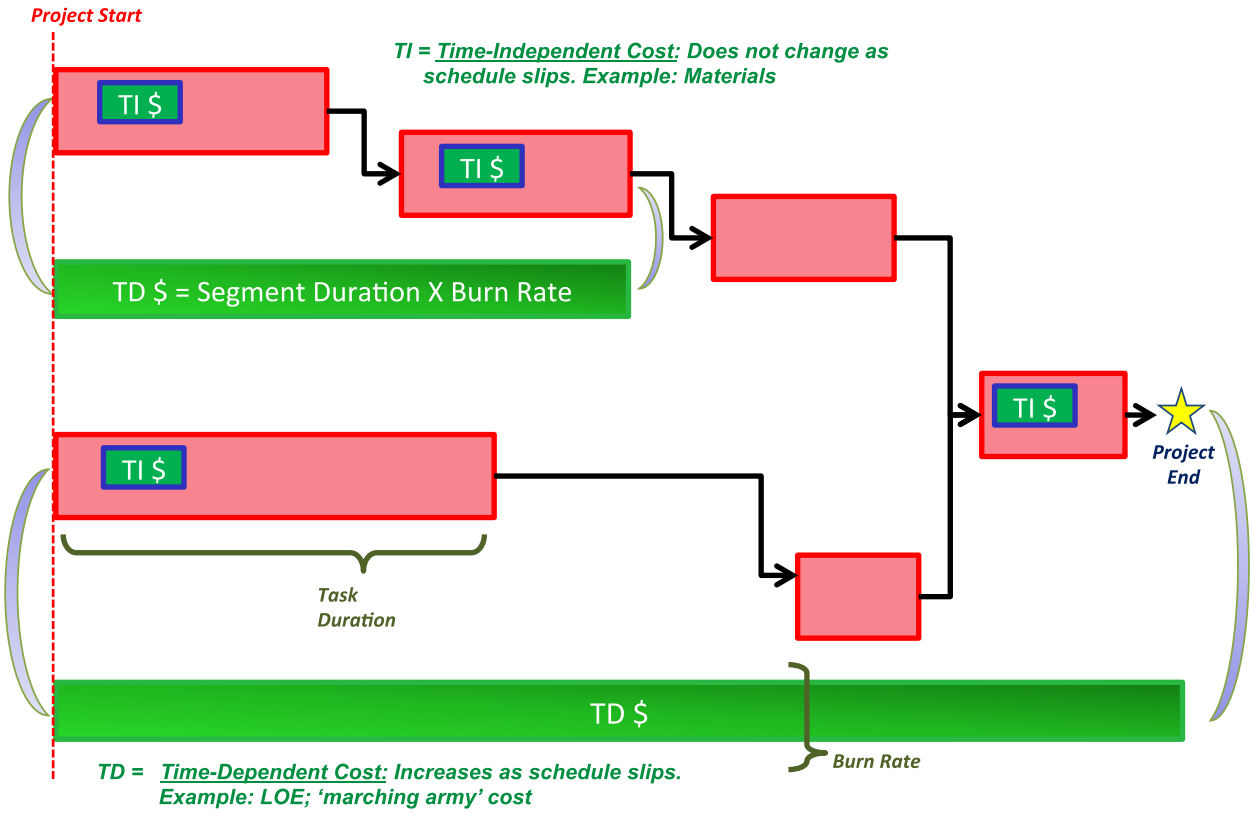


Figure 10. Cost-Loaded Schedule

3.1.4. Step Three: Incorporate the Risk List

So far, the schedule represents the baseline plan for the project (cost and schedule). All durations and cost assumptions may have risk mitigation (for costs and schedule) embedded in the plan, but risk

realization from the risk management system has not been incorporated. Traditionally, NASA programs will utilize their risk management system to help populate these risk tasks; however, a JCL analysis does not have to be limited by what is currently being managed in the risk management system. For example, there may be a programmatic risk that does not "make it" into the risk management system but still is of concern to the Project Manager. The JCL analysis allows the project to model the programmatic consequences and expected value of these risks. Figure 11 demonstrates how to incorporate discrete risks into the system. Refer to Appendix G for an in-depth explanation of incorporating risk.

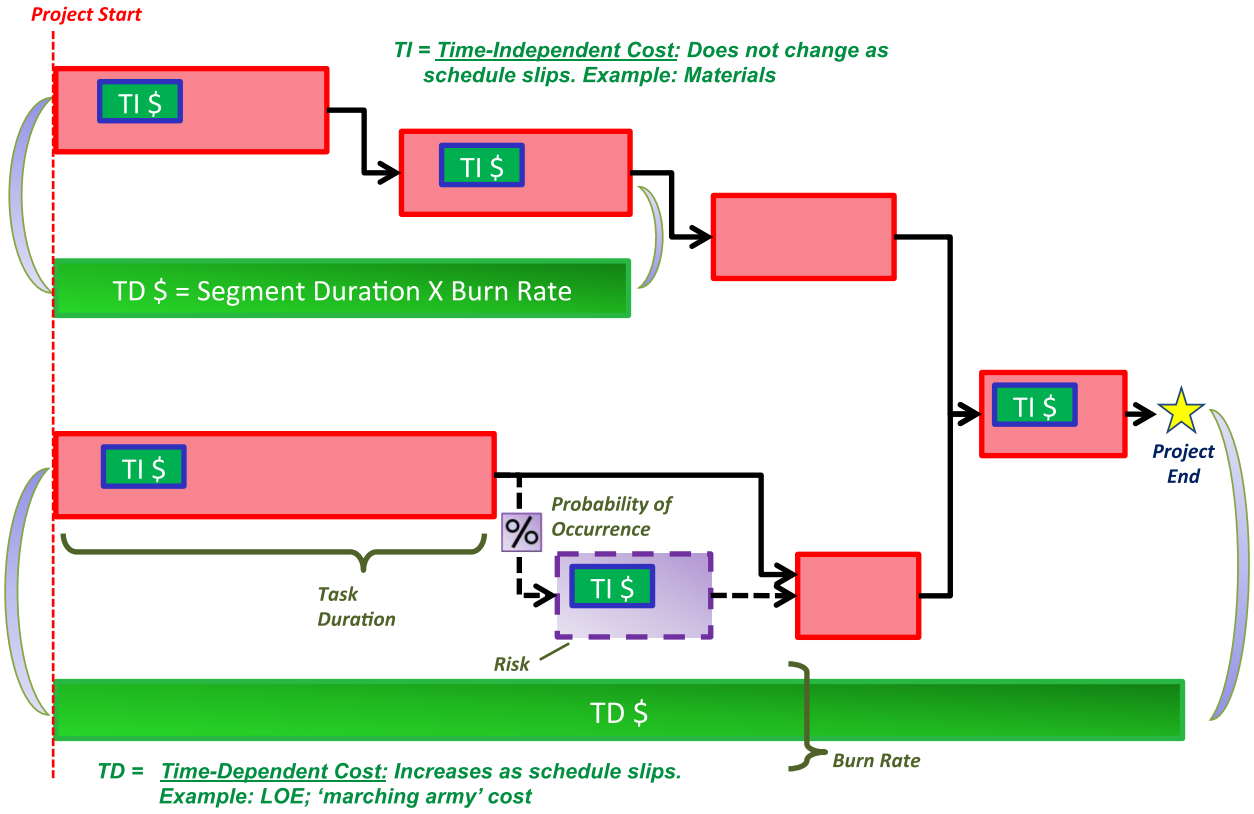


Figure 11. Schedule with a Discrete Risk

3.1.5. Step Four: Conduct Uncertainty Analysis

Step 4 in performing a JCL is identifying and implementing the uncertainty. To this point in the JCL process, the primary driver of the JCL results is the quantitative risk assessment and the effect it has on the cost-loaded schedule.

While the risk assessment provides a snapshot in time of potential future events that may cause the project to overrun, it does not account for two key facets that have the ability to drive cost and schedule:

- Incomplete Risk Register: Although NASA's Continuous Risk Management (CRM) process aims to create as comprehensive a risk register as possible, it is unrealistic to predict all events that may increase cost or schedule.

- Uncertainty in the Baseline Estimate: Disregarding risks altogether, it is impossible to predict the time or budget required to complete various segments of space-vehicle research, development, and production.

Tip:
History and experience have shown that the variance in a typical JCL model is driven significantly more by the uncertainty inputs than the discrete risks. With this said, it is essential to consider uncertainty when conducting a JCL analysis.

In recognition of these two facets, the cost estimator and/or JCL analysts must account for uncertainty in baseline cost and schedule plans. For the purposes of the JCL, it is important to further distinguish between risk and uncertainty, as they are distinct inputs to the JCL model. For JCL analysis, risk and uncertainty are defined as the following:

- *Risk* is an event not in the project's baseline plan that is an undesirable[18] outcome (discrete risk). This definition is similar to what appears in a risk matrix. The event is characterized by a probability of occurring and an expected impact if the event did occur.

- Uncertainty is the indefiniteness about a project's baseline plan. It represents our fundamental inability to perfectly predict the outcome of a future event.

For a seasoned cost or schedule risk analyst, it is clear that there is an overlap between these two terms. The indefiniteness of a project's baseline plan is partially caused by risks to the project. In the JCL, the analysis risks from the project's risk register are modeled alongside uncertainties applied to the baseline plan. This is done to increase the usefulness of the JCL analysis to a Project Manager; being able to discern the effect each risk has on a project's cost and schedule allows for the development of risk-mitigation plans.

To avoid double-counting, special care must be taken to segregate uncertainty caused by risks already being modeled in the JCL simulation from the underlying uncertainty of the project's plan once these risks have been discounted. Although it is surely the case that this segregation can never account for all aspects of double counting, the benefit of Project Managers seeing the risks outweighs the potential for slight errors in the analysis.

Typically, uncertainty is modeled using a triangular distribution. The low value represents the low extreme of uncertainty, the middle value represents the "most likely" value of the cost or duration, and the high value represents the high extreme of uncertainty. Please note that the baseline plan may not be any of these numbers (low, middle, high) but should fall within the range of low and high. Please refer to Figure 12 for a visual representation.

[18] Risks can also be opportunities if the outcome of the event is a positive outcome.

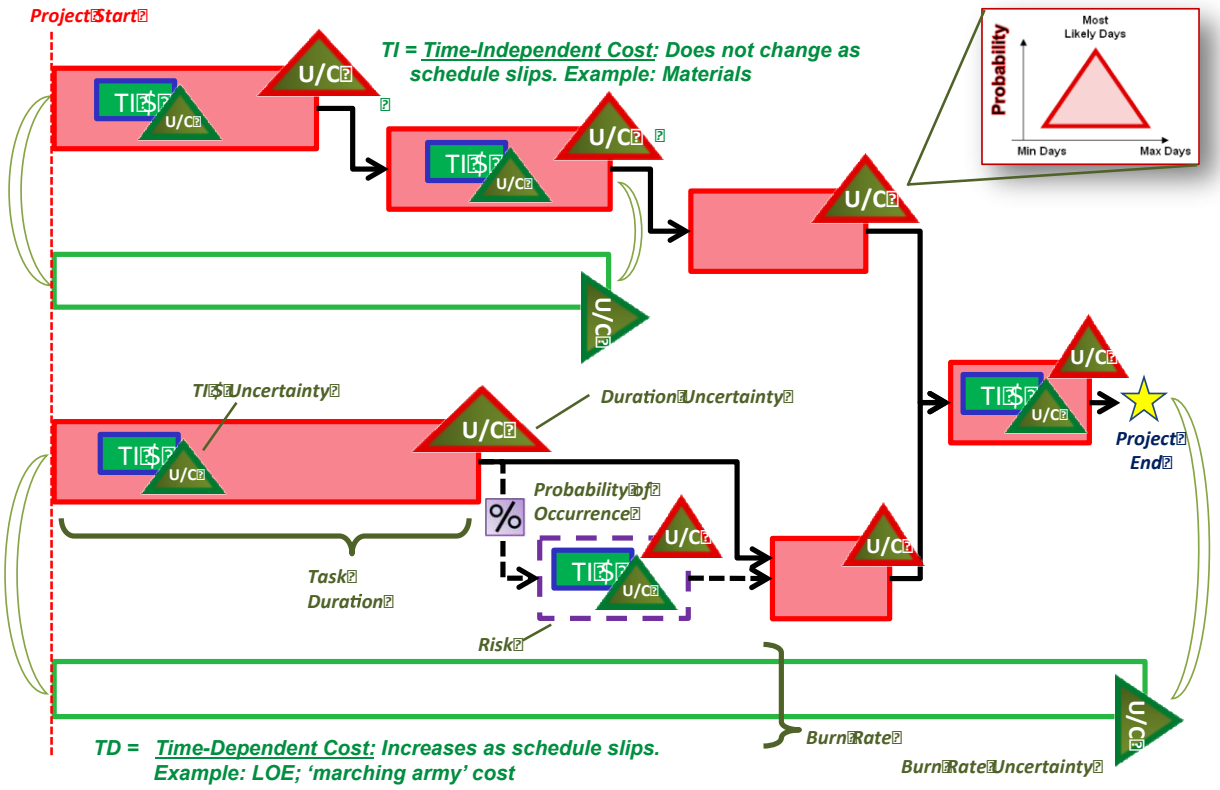


Figure 12. Schedule with Uncertainty

3.1.6. Step Five: Calculate and View Results

The process shown above should be considered iterative in that analysts need to ensure that durations and logic make sense and that milestones are achievable. At any point in the JCL iteration process, the final and key step is interpreting the results of the analysis. The JCL model can produce a variety of reports to help an analyst finalize the JCL inputs. This exhaustive list of possible reports is not shown for brevity purposes. With that said, it is important to explain briefly the most commonly used JCL chart: the scatterplot.

The JCL scatterplot in Figure 13 is a standard XY chart with the schedule on the X axis and cost on the Y axis. Each point is the result of the simulation calculation representing a cost and schedule pair.

Establishing a cost and schedule target (where the blue lines intersect in Figure 13) divides the scatterplot into four quadrants. One quadrant contains results that are at or beneath the target (shown in green). Another quadrant contains results that exceed the target (shown in red). The white points represent results that exceed either cost or schedule, but not both. Adding up points in a given quadrant provides an overall confidence level (CL) with respect to the cost and schedule target. For example, the number of data points in the lower left quadrant divided by the total number of points in the scatterplot equals 14.4 percent. In other words, there is a 14.4 percent joint cost and schedule confidence level (JCL)—the probability that the project will end up at or below its cost and schedule target. (In this example, the cost is $3.5 million and the finish date is July 1, 2013.)

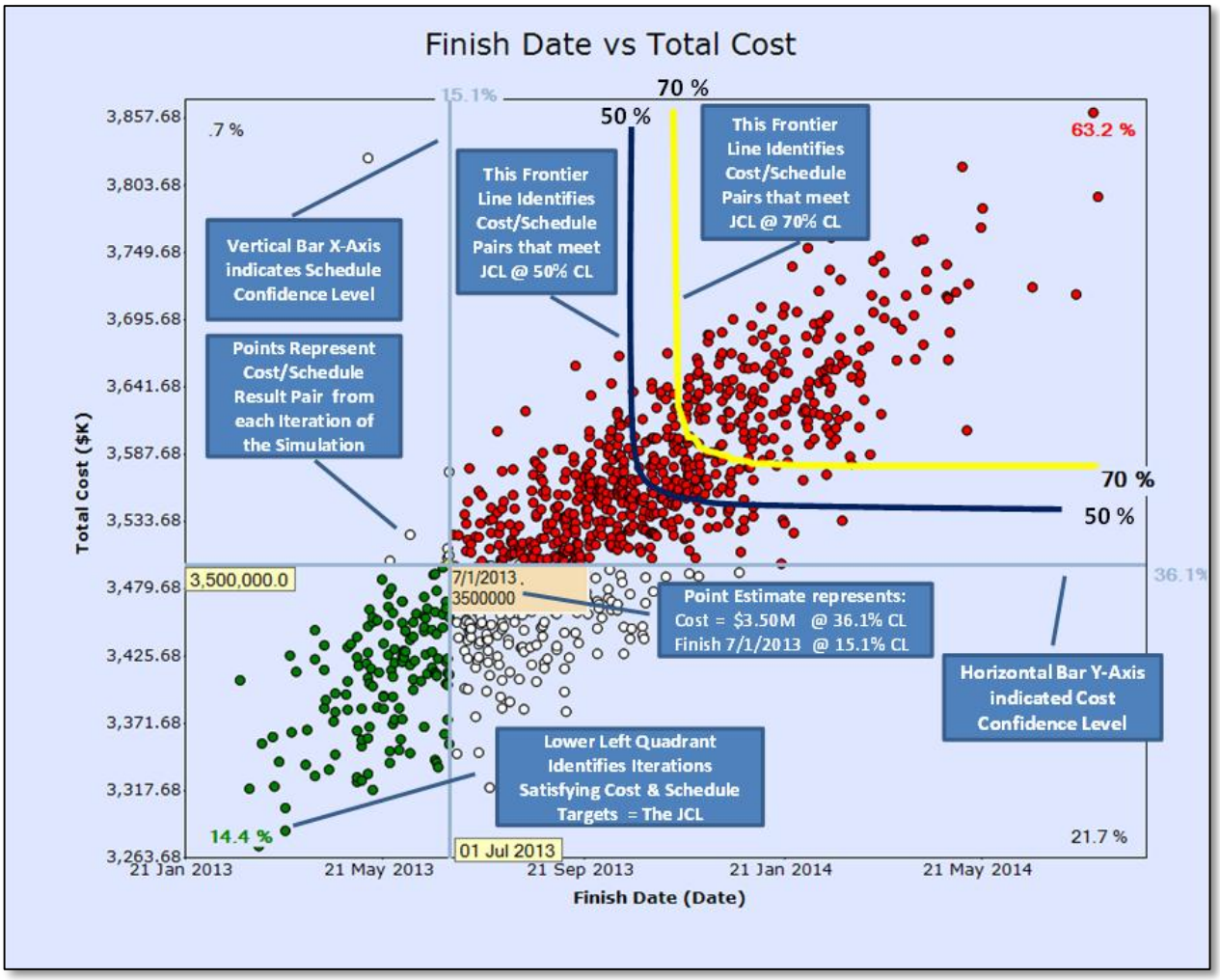


Figure 13. JCL Scatterplot

In addition to the quadrants are frontier lines. Each frontier line represents a separation between all the results from the simulation that meet a desired JCL from those that do not. As seen in Figure 13, the JCL for each frontier line differs from the JCL of the cost and schedule target, where the black frontier line has a chosen JCL of 50 percent and the yellow frontier line has a chosen JCL of 70 percent. Multiple points from the simulation may meet the JCL. In-depth analysis of a JCL scatterplot is provided in Appendix J.

One significant note on the scatterplot: it is *only* valid for the current plan and should be considered a snapshot in time. If the project changes its baseline plan, due to factors such as a funding or schedule increase or technical challenge, this will fundamentally change the project's risk posture and the project team will need to rerun the analysis to generate the current JCL. The scatterplot only illustrates scenarios at specified confidence levels (e.g., at 70 percent JCL to provide sufficient project UFE)—it does not prove guidance and should only be used as a starting point to trade off cost against schedule.

The JCL process yields more useful products than just the JCL scatterplot. Sensitivity analysis from the JCL provides decision makers with awareness of what may affect a project or program as adjustments are made, and the process also allows the analyst to produce Annual Cost Uncertainty results since the cost, and probabilistic risk results will be phased over the project schedule. As an example in Figure 14,

the time-phased probabilistic results of the integrated cost-schedule risk analysis are displayed from the 5th to 95th percentile for the years 2012 through 2020. The years 2015, 2016, 2017, and 2018 are annotated to highlight the likelihood of reserve utilization. In these years, the available annual resources, denoted by the orange line, are significantly less than the mean statistical result from the analysis, denoted by the blue line. Appendix J provides an in-depth analysis of JCL implementation, including advanced products from the analysis.

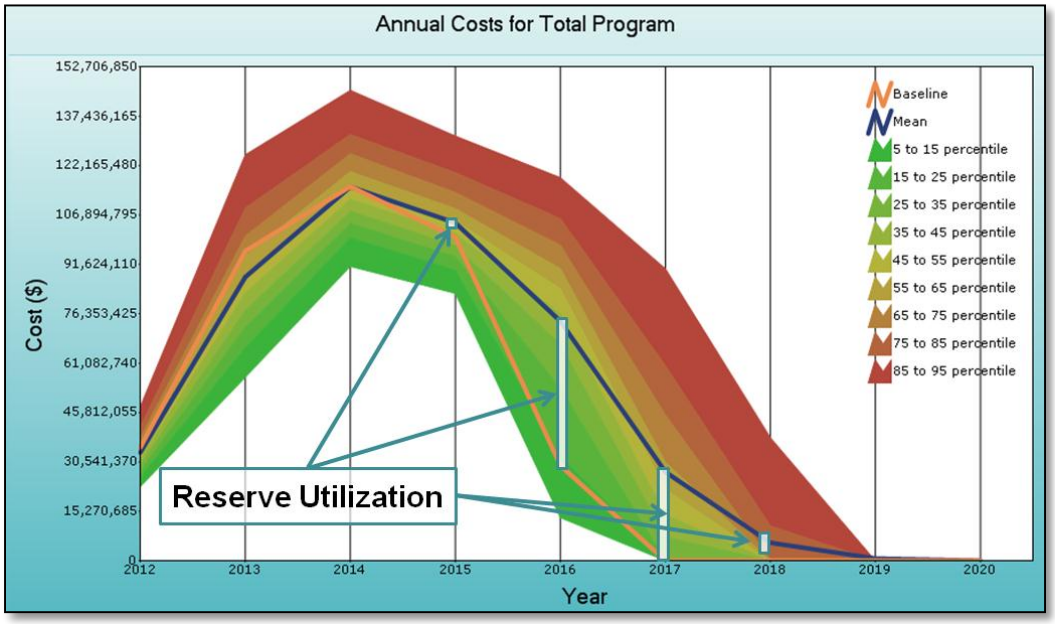


Figure 14. Annual Cost Uncertainty Example Displays Cost Risk Statistics Over Time in Comparison to Available Annual Resources

3.2. JCL Policy and Usage

NASA directs projects to generate a probabilistic cost-loaded schedule and to produce a JCL for KDP-I/C[19] for each project to be executable within the available annual resources.[20] This JCL analysis will be evaluated by a non-advocacy body (i.e., the Standing Review Board).[21] The Decision Authority will determine the appropriate JCL (probability) for the associated development and life-cycle cost at which the Agency commits to deliver the program/project. It is policy[22] that the JCL value be at 70 percent for the Agency Baseline Commitment (ABC), with a Management Agreement (MA) value of at least 50 percent (the decision authority may deviate from these values with documented rationale).

In conclusion, by combining its cost, schedule, and risk into a single model, a project's cost estimator can generate a probabilistic assessment of the level of confidence of achieving a specific cost-schedule goal. The rationale for conducting the JCL in support of KDP-C is to help ensure that:

1) The project's plan is well defined and risks are understood, and

[19] Key Decision Point I or Key Decision Point C. Use KDP-I for programs. Use KDP-C for projects.
[20] See NPR 7120.5E
[21] The NASA Standing Review board handbook is at *http://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20140008530.pdf*.
[22] See NPR 7120.5E.

2) The risk posture is acceptable for the timeframe and cost to which NASA is committing to external stakeholders.

The Agency uses this assessment when considering its external commitment (KDP-C) as one means of ensuring that the project has a robust plan with costs linked to schedule, where both are informed by risks.

4. Analyses for Decision Support

In addition to developing cost estimates, NASA cost estimators are key contributors to providing decision support. Over the life of a project, there are many choices that project personnel must make. Whether these decisions take the form of an LCC analysis, an engineering trade, an architecture selection, or an affordability assessment, decision makers look to the cost estimating community to help inform these choices with data.

This section provides an overview of analytical methods that are commonly used to guide decision makers. These methods are organized into the following five categories:

1. Sensitivity Analysis;
2. Trade Studies;
3. Affordability Analysis;
4. Cost As an Independent Variable (CAIV); and
5. Economic Analysis.

Additional details on how to conduct these analyses with supporting references are supplied in Appendix N.

4.1. Sensitivity Analysis

Sensitivity analysis is a technique used to address variations in project requirements. It is used to evaluate the effects of changes in system parameters on the system cost. It is also used to examine variations in the ground rules and assumptions.

4.1.1. Steps To Perform Sensitivity Analysis

There are five steps in a sensitivity analysis:

1. *Compute the point estimate.* The point estimate is a deterministic cost estimate where inputs are fixed values. It is developed using the most-likely inputs from our experts. The point estimate sets the baseline for measuring change.
2. *Select the elements for analysis.* System parameters and requirements, the values of which are likely to change, are usually selected. They are not usually the values we insert into our cost estimating equations, but they impact the values we need. Other things to consider are ground rules or assumptions used for the estimate (e.g., inflation, discount rates for economic analyses, buy quantity, and expected mission life). The focus here is on getting the right requirement. For example, the current requirement for the new office complex is that it must hold at least 500 employees. The question here is will the capacity requirement change over time in either direction? As the capacity changes, the square footage of the building and the associated cost changes.
3. *Determine the range of values for each element selected for analysis.*
4. *Determine the cost impact.* Recompute the estimate using, first, the high, then, the low values of the element in question. In sensitivity analyses, each change is applied one at a time; all other elements remain constant at their baseline values. This procedure is repeated for each element of interest.

5. *Graph or table results.* Once the analyst completes the analysis, graphs or tables can be used to communicate this information.

To demonstrate how to apply these five steps, see the example provided in Appendix N.

4.1.2. The Pros and Cons of Sensitivity Analysis

Sensitivity analysis focuses on individual items that cause large or imbalanced changes in cost. Requirements and parameters that cause large changes in cost are considered to be sensitive. Requirements and parameters that can vary without significantly affecting cost are insensitive. Imbalanced changes are seen in cases where the percentage change in cost is different depending on which direction you move the requirement.

Sensitivity analysis allows managers and decision makers to focus scarce resources by (1) concentrating on the sensitive elements, (2) understanding when to fight against (or push for) change, and (3) identifying events that might change which alternative is the least expensive. One of the cons of this method is that a sensitivity analysis cannot describe the exact likelihood of any value occurring—a particular outcome might be more likely than another, but its exact probability would be unknown. Another drawback of this analysis is that the impact of dependencies, or lack thereof, among elements of the estimate cannot be quantified.

4.2. Trade Studies

This section includes information about trade-study analysis, make-versus-buy analysis, and lease-versus-buy analysis.

4.2.1. Trade-Study Analysis

Cost-performance trade studies are systematic, interdisciplinary examinations of the factors affecting system costs. These studies analyze numerous system concepts to find acceptable ways to attain necessary performance and system requirements that meet an acceptable cost and schedule. The objective of a cost-performance trade study is not necessarily to minimize the cost of the system, but to achieve an optimal balance of performance and cost. Conducting cost-performance trade studies is one of the most effective means used, especially in the early life-cycle phases. These studies help to define a system and help narrow the universe of potential technologies, processes, and/or operational concepts to aid in the definition of the optimal solution.

Trade studies are at the heart of the affordability process, and their solutions are often represented in a multidimensional trade space bounded by a cost element and by one or more performance parameters. Figure 15 illustrates a simplified two-dimensional trade space with a plot connecting candidate design alternatives. At one point on Figure 15, a big gain is made in performance for a small gain in cost. A multidimensional trade space may be substituted to show the interaction of multiple cost drivers, including performance, schedule, and risk. Solutions (data points) at the far left of the trade space may show alternatives that look attractive from a cost perspective but may not satisfy even the threshold (minimal) performance requirements. Similarly, data points at the far right may be alternatives that exceed the threshold cost boundary only to provide performance beyond the requirement, which may not be justified.

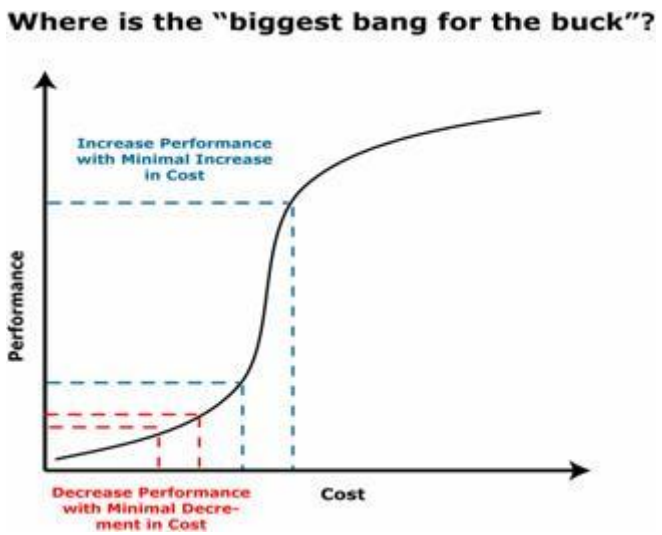


Figure 15. Cost As an Independent Variable

The steps for performing trade studies are presented in Appendix N.

4.2.2. Make-Versus-Buy Analysis

The make-or-buy decision is a strategic choice between producing an item internally (in-house) or buying it from an outside supplier (outsourcing). Make-or-buy decisions may arise when the Agency has the ability to develop or produce a product or part but is having trouble with its workforce and/or current suppliers, has diminishing capacity, and/or has changing demand. Strategic factors such as the desire to maintain quality control, workforce proficiency, or the need to protect proprietary technology may make this decision easy by requiring an in-house build. Aside from these details, operational and cost factors must be considered. Additional make-or-buy guidance and reference information with an example can be found in Appendix N

4.2.3. Lease-Versus-Buy Analysis

A lease-vs.-buy analysis can be performed once the decision is made to acquire an asset. This analysis is commonly used in business cases and applies most often to facilities and information technology projects. While the process of analyzing the economics of buying an asset has been discussed, the analysis behind the lease-versus-buy decision is slightly different. For a lease-versus-buy analysis, various tradeoffs need to be examined.

When analyzing the financial considerations under the lease-versus-buy decision process, the cost analyst needs to consider the LCC of either leasing or buying as well as the O&S cost. 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. Guidance on conducting these analyses is provided in OMB Circular A-94,[23] and additional information on the methodology is contained in Appendix N.

Note that in some cases, the sponsor has the capability to make the asset as well. If so, this possibility would have to be assessed along with the other lease-and-buy options. (For more information, see make-versus-buy previously described in Section 4.2.2 and Appendix N.)

[23] OMB Circular No. A-94, "Guidelines and Discount Rates for Benefit-Cost Analysis of Federal Programs," October 29, 1992 (available at *http://www.whitehouse.gov/omb/circulars_a094/*).

4.3. Affordability Analysis

Often used in a trade-study analysis, an affordability analysis ensures that the final system, program, project, product, or service can be delivered (or owned, operated, developed, and produced) at a cost that meets previously established funding (or best value) constraints while still meeting all approved requirements (or standards, needs, and specifications). Affordability is a continuous, overarching process applied throughout the program/project life cycle that ensures a program/project is doing the following:

- Optimizing system performance for the total LCC while satisfying scheduling requirements and managing risks;
- Acquiring and operating affordable systems by setting aggressive yet achievable cost objectives and managing those objectives throughout the full program/project life cycle;
- Balancing between cost objectives and mission needs with projected out-year resources, taking into account anticipated product and process improvements;
- Maintaining cost as a principal input variable in the program/project structure and in the design, development, production, operation, and support of a system; and
- Emphasizing cost as more of a constraint, and less of a variable, in the process of developing and supporting affordable systems once system performance and cost targets are determined.

Affordability should be incorporated into all programmatic decisions, as sound affordability practices have proven to be highly beneficial when developed and implemented as part of complex programs and projects.

Much of the LCC associated with NASA's human space systems can occur during program/project O&S. For robotic NASA missions, most of the mission cost is typically incurred during Phases C and D. Therefore, careful attention to affordability, particularly by establishing an affordability process and methodology in the early program/project phases, will help NASA maximize cost savings; define best value solutions to the top-level requirements set; and reduce future program/project operations and sustainment costs.

4.4. Cost As an Independent Variable

The purpose of a CAIV study is to ensure that an affordable design solution meets threshold performance requirements. CAIV can be used to evaluate requirements and to assist in performing trade studies. A key tenet of CAIV is that design can converge on cost rather than allowing cost to converge on design. In applying the CAIV process, NASA leadership will be able to demonstrate the following concepts:

- That performance is not sacred and certain performance requirements may be challenged if significant cost savings are possible.
- That the CAIV process continually challenges the requirements when affordability is at stake.

The U.S. Government embraced CAIV in the mid-1990s to counter large program acquisition and sustainment cost overruns. CAIV has been adopted by the aerospace industry including many NASA contractors. A similar process is applied in commercial practice, where it is typically identified as "target costing" or "target pricing." CAIV results can help the project office, working with its acquisition staff, to 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. Where cost is the independent variable, both performance and schedule requirements will be traded to achieve the cost objectives.

4.5. Economic Analysis

The primary basis of an economic analysis (EA) is to develop and compare discounted cash flows (in terms of costs and benefits) of competing alternatives. Generally, an EA considers several proposals having different current and future cost and benefit patterns.

EAs help provide the basis for initiating a project or task by evaluating all possible alternatives in an unbiased manner. EAs are based upon the logic that whenever resources such as money or effort are consumed, they should be in support of a specific organizational need. EAs assist decision makers in the comparison of alternative approaches, options, or projects and consider not only all LCC identified by a LCCE, but also other quantifiable and nonquantifiable benefits.

An EA can help establish the financial or economic justification for a specific program, project, or decision undertaken by NASA. It can provide the reasoning for why the proposed program or project should be undertaken and how that program or project will meet NASA's objectives.

Note that an EA does not make decisions. It *helps* the decision maker by identifying significant factors, clarifying differences and similarities, and quantifying and enumerating characteristics. The decision maker then brings experience, judgment, values, and leadership to bear upon those factors when needed. With an EA, the manager has a much better understanding of investment options, thus, enabling improved decisions.

4.5.1. What Is Economic Analysis?

An EA is commonly used within the Federal Government to guide or support decisions on the "worth" of pursuing any form of action that departs from the status quo or do-nothing scenario. For example, an EA can help determine if downstream benefits of startup research, a new acquisition, or a change in maintenance procedures outweigh the near-term costs of implementing the desired changes.

An EA is a technique to give decision makers a means to make more informed decisions. Although EA definitions vary within private, public and academic communities, the following definition captures the common theme of an EA:

> Economic analysis is a systematic approach to the problem of choosing the best method of allocating scarce resources to achieve a given objective. A sound economic analysis recognizes that there are alternative ways to meet a given objective and that each alternative requires certain resources and produces certain results. To achieve a systematic evaluation, the economic analysis process employs the following two principles:
>
> 1. Each feasible alternative for meeting an objective must be considered, and its life-cycle costs and benefits evaluated.
>
> 2. All costs and benefits are adjusted to "present value" by using discount factors to account for the time value of money. Both the size and the timing of costs and benefits are important.[24]

Note that there are three main elements that differentiate an economic analysis from its respective life-cycle cost estimate: an EA (a) applies the concept of discounting, (b) weighs costs against benefits, and (c) produces economic measures of merit (e.g., net present values and benefit-cost ratios).

[24] Enclosure (3) of Department of Defense Instruction 7041.3, November 7, 1995 (Subject: Economic Analysis for Decisionmaking).

4.5.2. OMB Economic Analysis Guidance

In October 1992, the Office of Management and Budget published "Guidelines and Discount Rates for Benefit-Cost Analysis of Federal Programs." Such guidance, commonly referred to as OMB Circular A-94, serves as the overall reference for all Federal programs. Included in this document are discount rates (similar to inflation rates) that OMB updates annually.[25]

4.5.3. The Concept of Discounting

One element that differentiates economic analyses from cost estimation is the concept of discounting. In order to understand what discounting is and the reasoning behind it, one must first understand the philosophy of time-value-of-money and how it translates into monetary terms: primarily, interest and interest rates. More details on the concept of discounting are provided in Appendix N.

4.5.3.1. Time-Value-of-Money

The phrase "money has time value" means that a dollar to be paid (received) today is worth more than a dollar to be paid (received) at any future time. Time value arises because of (a) the opportunity to earn interest on money in hand or (b) the cost of paying interest on borrowed capital.

In OMB Circular A-94, the explanation for the Government use of a discount rate was changed to, simply, the Government cost of borrowing money as represented in Treasury bill rates. This change in policy led to the Federal Government using discount rates that rarely exceeded 7 percent over the past 20 years.[26]

4.5.3.2. Interest Versus Inflation

It is important to differentiate between the concepts of inflation and the time-value-of-money. They are two different effects. Inflation accounts for the loss of the purchasing power of a dollar due to the general rise of prices in the economy. NASA produces a NASA New Start Inflation Index (NNSI) annually that cost analysts should use in their estimates.[27] The time-value-of-money accounts for the fact that a dollar today is worth more to us than a dollar received in the future, say, a year from now. For example, if you invest a dollar you get today in a fixed-interest account, you will have more than a dollar a year from now because you will have earned interest on the investment.

4.5.3.3. Interest and Interest Rate

As the previous paragraph illustrates, there are two terms used almost synonymously when discussing the future value of money: interest and interest rate. Interest, when expressed in dollars, represents the money paid or received over time. The interest rate is a percentage that expresses the fraction of cost or return on the principal over time. For most Federal EAs, the specific interest (discount) rate to use is directed by OMB directives. Interest (*i*) is:

- expressed as a percent (%) or decimal (0.00);
- assessed on the dollar balance (of money borrowed or invested);
- stated for a specified period of time (usually a year); and
- based on the project life and type of analysis (e.g., constant dollar or current dollar).

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[25] OMB Circular A-94, October 29, 1992, Appendix C: Discount Rates for Cost-Effectiveness, Lease-Purchase, and Related Analyses.

[26] http://www.whitehouse.gov/omb/circulars/a094/dischist-2007.pdf

[27] NNSI is available on the NASA ONCE portal at http://www.oncedata.com.

OMB Circular A-94, dated October 29, 1992, with annual memoranda updates, prescribes specific interest rates depending on the project term. Different rates are also used if the analysis is in base-year (without inflation) or then-year (with inflation) dollars—the difference being an assumed general inflation rate.

Interest rates can be depicted in one of two forms: the nominal rate or the real rate. The nominal rate is the rate of return that is used for payments that include inflation (i.e., cash flows measured in current- or then-year dollars). Nearly all loans and returns provided by financial institutions (e.g., mutual fund companies, banks, credit card companies, mortgage companies) are communicated to the customer as nominal rates. The real rate is the nominal rate adjusted to eliminate the effect of anticipated inflation/deflation, and it is used for payments that are in terms of stable purchasing power (cash flows measured in constant- or base-year dollars). Real rates are primarily used to perform EAs with cash flows depicted in constant (base-year) dollars.

Discount Rate

Note that the rate (i) associated with compound interest is synonymous with the rate associated with discounting future cash streams (discount rate).

Hence, for simplicity, the notation for the interest rate and the discount rate is left as i.

The discount rate is the interest rate used to determine the present value of a future cash stream.

The discount rate used represents the opportunity cost of making the investment. The opportunity cost is the rate of return that is given up by choosing one use of funds over another.

4.5.3.4. Future Value and Present Value

Compound interest occurs when the interest charged (or received) over one period is based upon the balance of principal and interest of the previous period. The Future Value (FV), representing the total amount received of repayment, is based on compound interest for a single payment or receipt in Present Value (PV). FV is calculated as $PV(1 + i)^n$ where i is the interest rate and n is the number of years from the date of initiation for the project. Another way to describe this calculation is that FV equals the product of PV and *compound interest factor*, $(1 + i)^n$.

The PV is an amount that, if invested today at the current interest (or discount) rate, would equal the value of the future cash flow. In essence, the time-value-of-money reflects the fact that money in hand today is likely to be more valuable than an identical amount of money received in the future and that benefits and costs have a greater value 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 PV.

Time-Value-of-Money Example

What if your bank promises you $11,000 a year from now if you deposit $10,000 today?

To determine if the "value" of waiting a year is worth the $1,000 in accumulated interest, you explore other investment options.

It would not be worth it, for example, if you believe a mutual fund will yield an 11% return over the next year (i.e., your $10,000 investment would grow to $11,100).

The time-value-of-money increment in this case would equal $1,100 instead of $1,000.

As demonstrated by FV, time-value-of-money can cause a dollar today to become more than a dollar in the future (commonly measured in terms of accrued compound interest). Such mechanics of time-value-of-money can also be applied in reverse. That is, one can compare the value of a dollar in the future (FV) to the value of a dollar held now (PV). This adjustment to a common point in time (traditionally a PV) is called *discounting***.**

The formula for determining FV of money can be adjusted to match the PV formula. This is accomplished algebraically by dividing both sides of the FV by the compound interest factor, $(1 + i)^n$. This adjustment of the compound interest formula calibrates the sum of capital at a future time to a present value (PV). The

PV is calculated as FV / $(1 + i)^n$, where i is the interest rate and n is the number of years from the date of initiation for the project. Another way to describe this calculation is that PV equals the product of FV and *discount factor*, 1 / $(1 + i)^n$.

Given that i and n depict an annual interest rate and year, respectively, 1 / $(1 + i)^n$ represents an "End-of-Year" discount factor. Consequently, this discount factor can only by applied to End-of-Year (EOY) cash flows. To discount future values, other conventions are used such as Middle-of-Year (MOY) and continuous discount factors. For more on these discounting conventions, refer to Appendix C.

4.6. The Economic Analysis Process

Based on OMB policy, costs and benefits must be viewed from the *perspective of the Federal Government* as a whole. EA cash flows are not limited to only the costs and benefits incurred by the organization for which the analysis is being done.

4.6.1. Steps for Performing an Economic Analysis

The basic steps for performing an EA are as follows:

1. Prepare the statement of objective;
2. List the assumptions and constraints;
3. Identify the alternatives;
4. Identify and estimate the benefits and costs;
5. Rank the alternatives using economic measures-of-merit;
6. Perform sensitivity and risk analyses; and
7. Prepare the results and recommendation (documentation).

It is important to note that economic analysis is a process to aid in making resource-allocation decisions. Therefore, an EA commonly goes from a step-by-step process to an iterative one (see Figure 16). There are many interrelationships among the steps in the process. Rather than performing each step in order to completion, the steps may be revisited during the analysis.

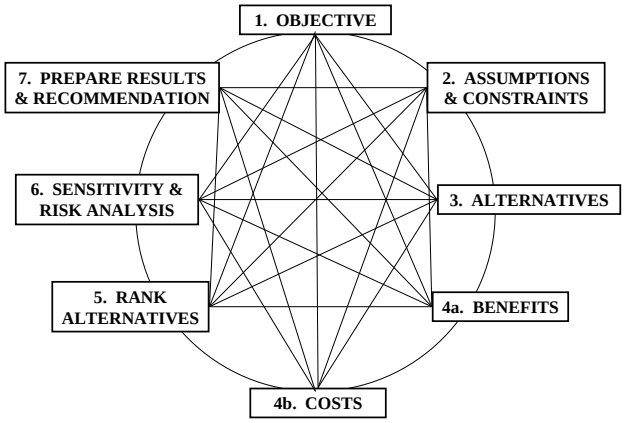

Figure 16. Steps for Performing an EA

An overview of each EA step is provided in the economic analysis section of Appendix N. Nevertheless, the remainder of this section provides some of the critical aspects that should be accounted for within an economic analysis.

4.6.2. The Challenge of Quantifying Benefits

Space science programs and projects generally do not have easily quantifiable benefits. The value of a science mission is difficult to quantify with any credibility. Therefore, the EA becomes a cost-effectiveness analysis that focuses on the quality and completeness of the LCCE and the quality of the expected science data returned. The qualitative benefits are usually determined by panels of experts in the particular field.

How an EA is structured depends upon the answers to two questions:

(1) Is the EA for a spaceflight program/project, or is it for an institutional project?

(2) Are the benefits quantifiable?

If the benefits are quantifiable, the EA can usually be depicted as a feasible set of alternatives, each having its own discounted cash flow (representing a summation of net benefits and net costs).

Quantifiable benefits are more often associated with institutional programs, though they can sometimes be calculated for launch systems or technology programs.

4.6.3. Use of Net Present Value to Rank Alternatives

Each discounted cash flow provides the basis for step 5 (rank alternatives), where economic measures-of-merit are calculated for each alternative. OMB Circular A-94[28] establishes Net Present Value (NPV) as the standard criterion for deciding whether a Government project's cost can be justified on economic principles. The criterion in this case is that the alternative with the "most positive" NPV would be most preferred.

In simple terms, NPV is the amount of dollars that would have to be invested during the base year at the assumed discount (interest) rate to cover the costs or match the revenues or savings at a specific point in the future. All costs and benefits are reduced to a single discounted net value. This allows for a simple comparison of alternatives on an equitable basis.

NPV is the algebraic combination of the PV of costs and benefits. It allows for the comparison of the costs of different alternatives because it reflects the total cost of an alternative over the given timeframe of analysis in terms of current or normalized[29] dollars. NPV is a way of making costs and benefits occurring in different years comparable. A common way to determine NPV of an alternative is to first calculate net benefits (or costs) from the costs and benefits in each year. Once this net cash flow is created, each individual cash flow is discounted to a present value and summed up to produce NPV. Benefits used in the NPV calculation should be quantified in cost/financial terms. All costs and benefits are adjusted to their PV by using discount factors to account for the time value of money. See Appendix N for additional detail.

Other measures-of-merit, such as Equivalent Uniform Annual Cost (EUAC) and Savings/Investment Ratio (SIR) are also covered in detail in Appendix N.

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[28] http://www.whitehouse.gov/omb/circulars_a094/

[29] The same year's dollars for all options.

4.6.4. Documentation and Review of an Economic Analysis

It is important to properly document the EA for review by peers, stakeholders, and management. A good documentation package captures all inputs, GR&A, descriptions of the alternatives, analysis approaches, risks and uncertainties, and evaluations of the results. Because an EA is often used to justify major NASA decisions, it is vital that the documentation package be comprehensive, complete, and clear. Major decisions are often subject to review by the NASA Inspector General and outside groups such as the Government Accountability Office (GAO). A well-documented analysis will assist the Agency in responding to these reviews.

For more details on the seven steps of the EA process, refer to Appendix N. For more information on guidance for performing a Government EA, refer to OMB Circular A-94.

The NASA Cost Analysis Division hopes you find the NASA Cost Estimating Handbook Version 4.0 useful. If you have any questions concerning the material presented in this handbook, suggestions for future editions, or general information requests, please contact us at *hq-cad@nasa.gov*. In addition, if you would like to make a contribution for possible inclusion in future editions, please send feedback or suggested corrections, additions, or improvements to us via the form at *http://www.nasa.gov/office/ooe/CAD/CEH_Input.pdf*.

On the back cover is NASA's Orion spacecraft, pictured as it awaits the U.S. Navy's USS Anchorage for a ride home. Orion launched into space on a two-orbit, 4.5-hour test flight at 7:05 a.m. ET on December 5, 2014, and splashed down safely in the Pacific Ocean, where a combined team from NASA, the Navy, and Orion prime contractor Lockheed Martin retrieved it. Orion is a part of NASA's plan to develop new technologies and capabilities to send astronauts farther than ever before—first to an asteroid, and onward to the Red Planet.