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Department of the Navy

Cost Estimating Guide

A Compendium of Best Practices for the Department of the Navy Cost Analysis Community

Preface

This Cost Estimating Guide (CEG) is a compendium of best practices that should generally underpin life-cycle cost estimates of weapon system and automated information system acquisition programs within the Department of the Navy (DON). The Guide strives to improve and standardize processes and procedures while recognizing the fluidity inherent in the field of defense cost analysis. Practices and procedures necessarily vary between cost analysis organizations, at least to some degree, according to mission requirements, workload, staffing, and special circumstances. The CEG, then, is not strictly prescriptive; that is, organizations are free, as exigencies dictate, to vary from its tenets.

Nevertheless, the CEG represents a consensus of best practices useful to cost analysis practitioners, their organizations, and to other stakeholders involved in producing and using our cost estimates. The order and the emphasis of material covered in the CEG attempt to follow state-of-the-art themes and concepts in the profession, such as the need to begin risk and uncertainty analysis early on, the need to question the accuracy of baseline parameters and to obtain buy in on the baseline from all stakeholders, and the need to independently verify and validate the cost estimate prior to its delivery. Further editions of the CEG will capture the fruits of our cost research efforts currently underway.

This CEG is a product of the entire DON cost analysis community. It is based on valuable inputs and insights obtained from the cost analysis organizations in the Systems Commands and from other stakeholders. The basic precepts and policies reflected in the CEG align with those found in guidebooks of the same genre while, at the same time, proffering many innovations recently instituted within the DON cost community.

Getting the costs "right" is essential as we strive to balance cost, capabilities, and risks in a constrained budget environment and to meet the challenges of Congressional and Secretarial acquisition reform initiatives. I hope that employment of the CEG will advance the development of accurate, reliable, and timely cost estimates within the DON and, ultimately, contribute to the delivery of the systems needed to support our warfighters.

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Introduction

Life-cycle cost estimates of defense acquisition programs are inherently uncertain. Estimates are sometimes required when little if any of a program's total cost is known. Years of system development and production, and decades of operating and support costs, need to be estimated. Estimates, in turn, are based on historical samples of data that are almost always messy, of limited size, and difficult and costly to obtain. Herculean efforts are commonly required to squeeze usable information from a limited, inconsistent set of data. And no matter what estimating tool or method is used, historical observations never perfectly fit a smooth line or surface, but instead fall above and below an estimated value. To complicate matters, the weapon system or automated information system under study is often of sketchy design. Only limited programmatic information may be available on such key parameters as schedule, quantity of units to be bought, performance, requirements, acquisition strategy, and future evolutionary increments. Further, key characteristics of the system may actually change as the system proceeds through development and even production. Increases in system weight, complexity, and lines of code are commonplace.

For all of these reasons, a life-cycle cost estimate, when expressed as a single number, is merely one outcome or observation in a probability distribution of costs. That is, the estimate is stochastic rather than deterministic, with uncertainty and risk determining the shape and variance of the distribution.

Given the difficult job of producing credible, cradle-to-grave cost estimates in a highly dynamic acquisition and estimating environment, this Standard helps ensure the employment of a set of scientifically sound processes and procedures in the naval cost-estimating community. The ultimate goal is to increase the quality of life-cycle cost estimates of DON acquisition programs.

This Standard builds upon previous work within the defense cost community and its precepts align with those found in other commonly-used guidebooks.[1]

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[1] These include NAVAIR's Cost Estimating Standard, NAVSEA's Cost Estimating Handbook, SPAWAR's Cost Estimating Instruction 7720.4D; GAO's Cost Estimating and Assessment Guide, DoD's Defense Acquisition Guidebook, NATO's Methods and Models for Life-Cycle Costing, and NASA's Cost Estimating Handbook.

Overview

Figure 1 outlines six major steps for preparing a scientifically-sound life-cycle cost estimate of a defense acquisition program.[2] The steps are shown in the context of other major technical activities in the naval cost analysis community.

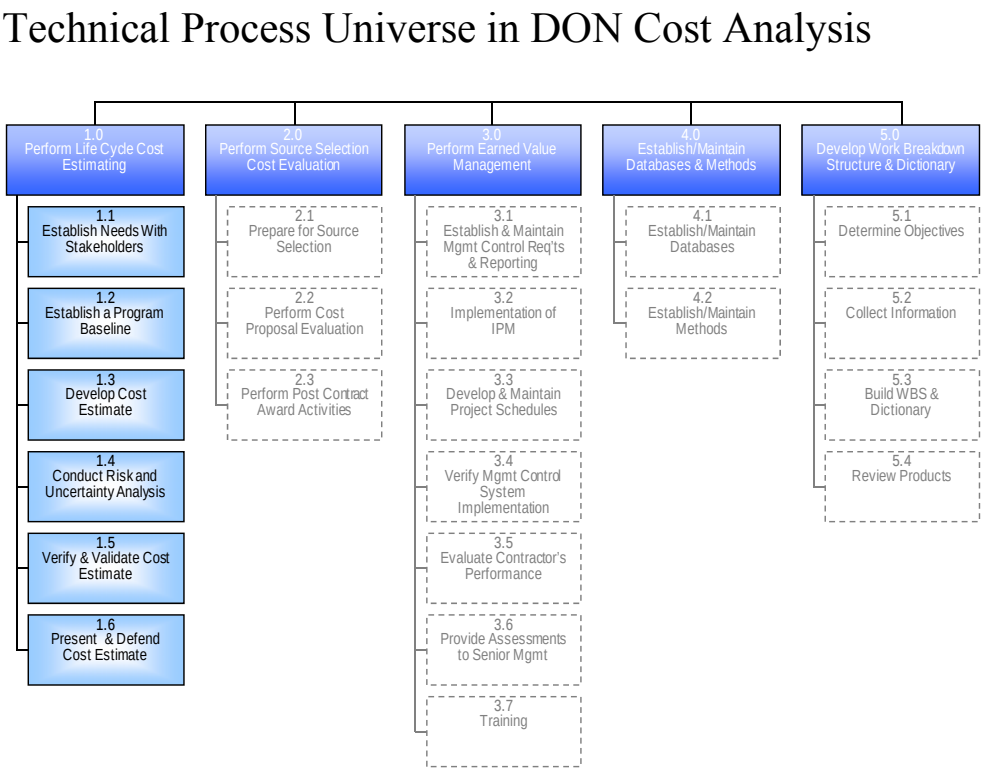

Figure 1- Technical Process Universe in DON Cost Analysis

1.1 Establish Needs With Stakeholders.

- Define and manage expectations among stakeholders on cost-analysis activities, events, and products throughout the life of the estimate.

1.2 Establish a Program Baseline.

- Define the program to include all technical and programmatic information required to generate the cost estimate.

1.3 Develop the Baseline Cost Estimate.

- Generate an estimate by collecting data, selecting methods, building models, and analyzing risks and uncertainties.

[2] Many additional sub-steps are specified throughout the Standard. Other references use similar steps but in varying degrees of aggregation.

1.4 Conduct Risk and Uncertainty Analysis.

- Use an acceptable statistical technique to develop a probability distribution for the estimate.

1.5 Verify and Validate the Cost Estimate.

- Assess critically the inputs, outputs, and methodology of the cost estimate using peer reviews and cross-checks.

1.6 Present and Defend the Estimate.

- Finish documenting the estimate to produce an audit trail of source data, methods, and results, and present the estimate to principal decision makers in a cogent, understandable, and informative fashion.

These major steps are currently employed in the naval cost-analysis community, with only slight organizational variation, according to the process flow of Figure 2. Since a "second set of eyes" is of paramount importance in the discipline of defense cost analysis, subject matter experts provide guidance and feedback at critical review points.

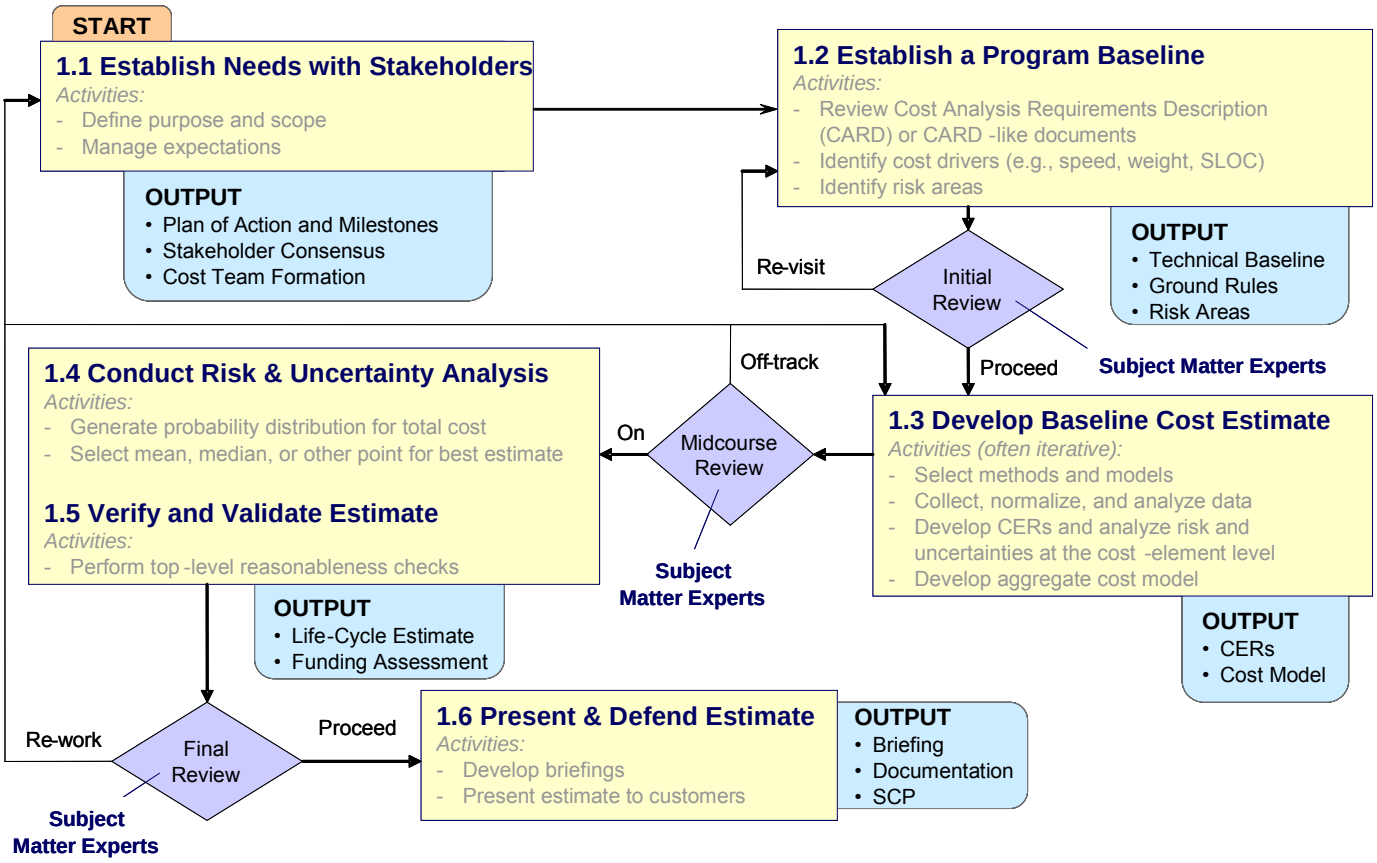

Figure 2- DON Cost Estimating Process Flow

1.1 Establish Needs with Stakeholders

Description.

Managing the preparation of a life-cycle cost estimate requires continual and complete coordination with all of the stakeholders or users of the product. Stakeholders may include the program office; financial, logistics, engineering, and personnel communities; and principal DON and OSD decision makers. In the context of Analyses of Alternatives, they may include representatives from "effectiveness" and "technology and alternatives" panels. Frequent in-progress reviews or meetings are usually a good practice.

A critical first step is establishing expectations on the deliverable. Stakeholder requests or requirements are researched to determine the content, fidelity, and limitations of the estimate; delivery schedule; work plan; and data required by the cost competency[3] to enable the production of a scientifically sound estimate. Results of consensus-building are documented in a study plan that includes a master list of tasks, responsibilities, due dates, and an initial set of groundrules and assumptions.

Purpose.

Requirements of the stakeholders guide the development and execution of the cost-estimating plan. If existing resources are inadequate to produce the required deliverable, determine if alternative resource options exist. Determine whether to accept or reject the request for analysis. If necessary, obtain guidance from higher authority in the chain-of-command.

[3] Cost competencies include the Naval Center for Cost Analysis (NCCA); the NAVAIR 4.2 Cost Department; the NAVSEA 05C Cost Engineering and Industrial Analysis Division; the Marine Corps Systems Command's Office of the Assistant Commander for Programs - Economic & Business Analysis Branch; and the SPAWAR 1.6 Cost Estimating and Analysis Division.

Inputs and Suppliers.

Inputs	Suppliers
• Requests or requirements for estimate or analysis	• Requests from program offices; Integrated Product Teams (IPTs); and SYSCOM, OPNAV, SECNAV, and OSD principals • Requirements of SECNAVINST 5000.2D, SECNAVINST 5223.2, and DoDI 5000.02
• OSD, SECNAV and SYSCOM resource databases	• ASN(RD&A) "Information System" • OSD CAPE databases • SYSCOM and NCCA databases
• Ad-hoc inquires from the cost competency to the acquisition community	• Program offices; DASNs; PEOs; OSD CAPE

Entry Criteria. This sub-process is initiated upon the emergence of a known requirement or the request for analysis from a stakeholder. Depending upon where in the defense acquisition management framework the program falls, requirements or requests may be driven by: (1) the Initial Capabilities Document or the Materiel Development Decision of the Joint Capabilities Integration and Development System; (2) a DoD milestone or DON gate review; and (3) a resource decision in the Planning, Programming, Budgeting, and Execution process.

Primary Sub-processes.

1.1.1 Identify Purpose

Identify the purpose and scope of the life-cycle cost estimate or analysis to determine resource requirements. Purposes include support of acquisition milestone reviews, gate reviews, program and budget formulation, analyses of alternatives, and special studies.

1.1.2 Define Scope/Work Content

Evaluate the request to determine the complexity, timeframe, and process steps that must be performed to develop the cost estimate. By defining the scope of the request, the cost analyst can determine the degree of effort involved to formulate a cost product that meets the needs of the stakeholders; e.g., content, accuracy, timeliness, usability.

Determine, based on stakeholder demand, which elements of total ownership cost will be included in the estimate. Total ownership costs, as shown in Figure 3, include not only R&D, procurement, and operating and support costs but also infrastructure or business process costs not necessarily attributed to the acquisition program in question. That is, they include pro-rated shares of the costs of all military department and defense agency activities that sustain the military force associated with the program of interest.

Similarly, determine which phases of an evolutionary or spiral development effort need to be estimated.

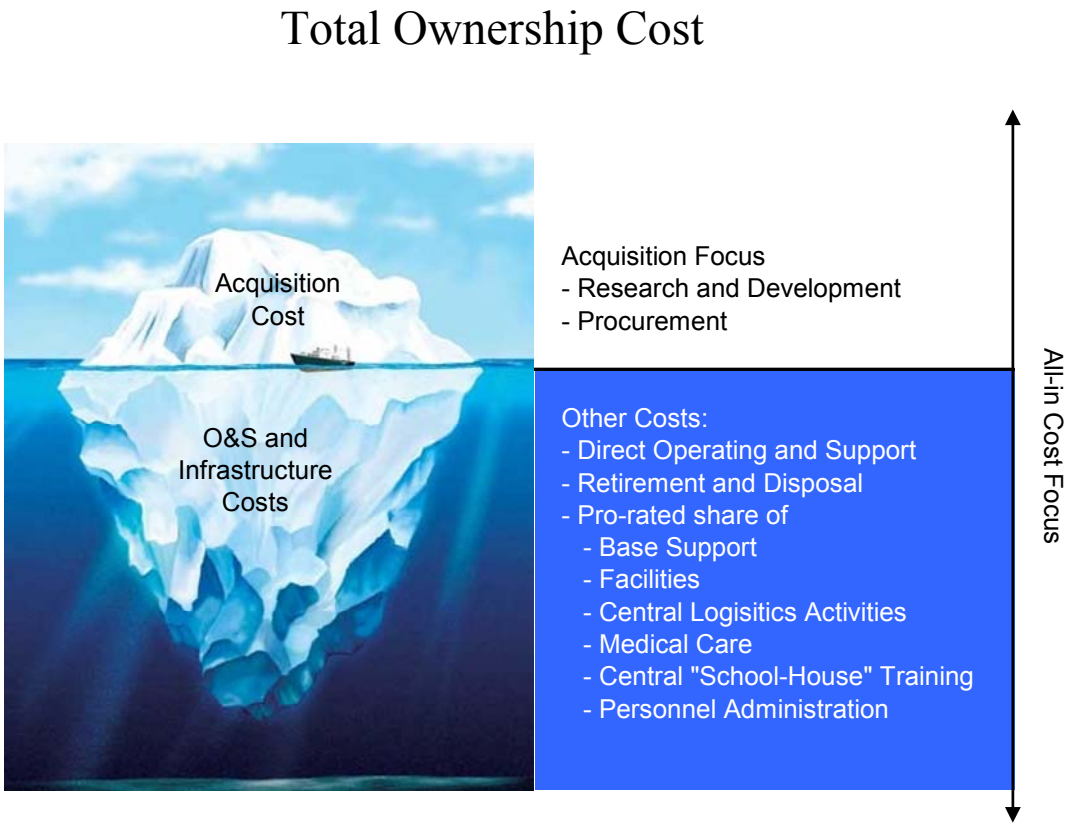

Figure 3- Total Ownership Cost

1.1.3 Determine Resource Requirements

Identify the manpower and funding resource requirements necessary to successfully complete the analysis. A good practice is to use historical data to facilitate this assessment.

1.1.4 Evaluate Availability of Resources

Evaluate the existing manpower and funding resources available to execute the stakeholder request or known requirement. This includes the analysis of resource planning commitments.

1.1.5 Identify/Resolve Issues

The cost competency works with the stakeholders to define the expectations and limitations of the cost estimate. Issues and conflicts may arise from requirements or requests that are outside of or in addition to established responsibilities and “handshake” agreements.

Compare existing manpower and funding resources with those required to

produce the desired product. Resource shortfalls, scheduling conflicts, and issues are identified. Outsourcing may be an alternative in some cases. Issue resolution includes the option of not being able to successfully meet stakeholder requests.

1.1.6 Generate Cost Estimating Development Plan

Develop a formal plan of action with tasks, milestones, and deliverables. Obtain approval from stakeholders. The product for weapon system cost estimates is similar to the Economic Analysis Development Plan currently used for Major Automated Information System (AIS) programs in the DoD.

Supporting Sub-processes. Perform Resource Management

Agents.

- Cost Competency
- Program office or IPT
- Financial, logistics, engineering, and personnel communities
- SYSCOM, OPNAV, SECNAV, and OSD principals
- OSD Cost Assessment and Program Evaluation (CAPE)
- Assistant Secretary of the Navy for Research, Development and Acquisition (ASN (RD&A)))
- Assistant Secretary of the Navy for Financial Management and Comptroller (ASN(FM&C))
- Assistant Secretary of the Navy for Manpower and Reserve Affairs (ASN(M&RA))
- Assistant Secretary of the Navy for Installations and Logistics (ASN(I&E))

Output and Stakeholders.

Output	Stakeholders
• Updates to resource databases	SYSCOM, OSD, SECNAV, & OPNAV business management offices
• Acceptance or rejection of request	All stakeholders
• Plan of action and milestones	All stakeholders

Exit Criteria.

This sub-process is complete when the request or requirement is accepted or rejected and, in the case of acceptance, a study plan is generated.

Tools.

- USD(AT&L)'s Defense Acquisition Guidebook

1.2 Establish a Program Baseline

Description.

A sound, robust life-cycle cost estimate is based on a well-defined program. Accuracy and completeness of the definition are critical in producing an estimate that *informs* rather than *confuses* decisions on the allocation of scare resources in the DON. The better the definition, all else equal, the higher will be the quality, flexibility, and usability of the cost estimate.

Defining the program, in other words, is an all-important initial step in the cost-estimating process. The degree of definitional content, completeness, and accuracy will influence the methods and models that can be employed by the cost analyst, and, ultimately, the results that can be achieved. An ambiguously defined program increases the use of assumptions, drives up estimation risk, and shifts the burden of uncertainty to senior decision makers.

A comprehensive baseline definition provides information on: system mission, technical and performance characteristics, work breakdown structure, legacy systems, acquisition strategy, quantities, test and evaluation plan, training plan, disposal plan, operational concept, logistics support, personnel requirements, and deltas from previous technical baselines, in addition to other data.

In the DON, a Cost Analysis Requirements Description (CARD) is generated whenever "… a program life-cycle cost estimate is required."[4] In theory, the CARD and associated references and attachments should contain all of the information needed by the cost analyst to generate a credible estimate. In practice, this is seldom the case, at least initially. Typically, the cost analyst needs to work with the program office and other stakeholders to define the program in sufficient detail to meet estimation requirements. Further, best practices and DON policy require that CARD parameters are assessed and approved by independent technical and oversight authorities.

Finally, defining the program is not a one-step-and-stop activity. It's common to refine the definition of the program throughout the estimation process.[5]

Purpose.

This step is critical to successful execution of the overall cost-estimating process in that it identifies and defines the technical and programmatic parameters that bound the estimate. The technical and programmatic baseline is the basis of the estimate and strongly influences the level at which the estimate will be developed, affecting its quality, accuracy, and flexibility.

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[4] A CARD is generated in the DON per SECNAVINST 5223.2, 16 Dec 2008.

[5] However, it's often necessary to temporarily "freeze" the program baseline to support completion of the life-cycle cost estimate according to schedule.

Input and Suppliers.

Inputs	Suppliers
• Cost Analysis Requirements Description	• Program Office
• Assessment of CARD parameters	• Engineering or technical community; other stakeholders
• Additional technical, requirements, and acquisition documents. These may include the System Design Specification (SDS), Integrated Master Schedule (IMS), Capability Development Document (CDD), and Concept of Operations (CONOPS)	• Program office; other stakeholders

Entry Criteria. This sub-process is initiated upon acceptance of the requirement or request for analysis by cost-competency leadership.

Primary Sub-processes.

1.2.1 Identify/Request Baseline Parameters

Almost invariably the cost competency and other stakeholders will need to work with the program office to develop an acceptable CARD. Therefore, this sub-process begins with a review of the RFEA and previous analyses to determine the appropriate definition of the system being estimated. A structure is developed to include all information necessary to perform the analysis. This information is then packaged for submittal to the program office and other agents responsible for the inputs. Figure 4 lists the major categories of information required to define the program.

Element of Information	
System description and characteristics	Time-phased system quantity requirements
System overview	
System performance parameters and characteristics	System manpower requirements
Technical and physical description	
Work breakdown structure	System activity rates (operating tempo)
Summary of maturity levels of critical technologies	
Software description and sizing information	Facilities requirements
Interfaces with other systems	
Subsystem descriptions, as appropriate	Summary of security or program protection features
System suitability factors	Summary of environment, safety, and occupational health considerations
Reliability/Maintainability/Availability	
PM's assessment of program risk & mitigation measures	System milestone schedule
System operational concept	Summary of acquisition plan or strategy
Organizational/unit structure	
Basing and deployment description (peacetime, contingency, and wartime)	Plans for system disposal
	Track to prior CARD
System sustainment concept	
System logistics concept	Approved or proposed CSDR plan
Maintenance concept	
Supply management concept	
Transportation concept	
Software maintenance concept	
System training concept	

Figure 4- Categories of Information Required for Program Definition

1.2.2 Collect & Evaluate Baseline Parameters

This sub-process is an extension of the previous sub-process where the cost analyst works closely with the technical agents to convert the request into a working CARD that is the foundation of the cost estimate. Technical and programmatic baseline inputs are evaluated to attain a thorough understanding of their basis and derivation. This should include crosschecks to ensure the baseline accurately defines the system/concept being estimated. Risk associated with baseline parameters should be identified and quantified to the extent possible.

1.2.3. Document Technical and Programmatic Baseline

This sub-process culminates with the development of a CARD and the collection of all other documentation that supports specifying the baseline parameters.

1.2.4 Conduct Technical and Programmatic Baseline Review Meeting

Per DON policy, the accuracy of baseline program parameters in the CARD is evaluated by "SYSCOM authorities,"[6] ideally independent of the program office, prior to submission to the cost competency. In addition, the accuracy and completeness of the CARD are evaluated by the cost team, subject matter experts in the cost competency, and other program stakeholders. Alternative values of parameters are specified, as needed, and become either part of a new program baseline or incorporated as elements of risk in the cost estimate.

Supporting Sub-processes.

1.2.5 Develop/Acquire & Approve Baseline Parameter Values (performed by technical and programmatic agents)

This sub-process is owned by the technical and programmatic communities and is performed in coordination with the cost competency. Its purpose is to define, develop, and acquire the technical and programmatic baseline parameters required to develop the cost estimate. The process requires extensive interfacing with each supplier to establish sound technical and programmatic baseline definitions for cost estimating purposes.

1.2.6 Develop Work Breakdown Structure (WBS)

A WBS should be developed to structure the cost and technical data identified in the development of the cost technical and programmatic baseline in process 1.2.1, *Identify/Request Baseline Parameters*. The WBS may be revised in process 1.2.2, *Collect & Evaluate Baseline Parameters*, after baseline parameters have been collected and analyzed.

Agents.

- One or more cost competencies
- Program Office
- Program stakeholders including engineering, logistics, and personnel communities; SECNAV, OPNAV, and OSD decision makers
- Industry

[6] SECNAVINST 5223.2, "Department of the Navy Cost Analysis," 16 Dec 2008.

Output and Stakeholders.

Output	Stakeholders
• Technical and programmatic baseline defined in the CARD and other related documents	One or more cost competencies and all other stakeholders
• Assessment of the accuracy of baseline CARD parameters	One or more cost competencies and all other stakeholders

Exit Criteria.

This sub-process is complete upon (1) adjudication of all stakeholder issues from the kick-off meeting; (2) approval by the stakeholders of a technical and programmatic baseline that accurately defines the program; and (3) attainment by the cost competency of a thorough understanding of the inherent risks associated with the technical and programmatic baseline.

Tools.

- Templates for capturing programmatic, performance, and technical information on the acquisition program
- Templates for use in generating CARDS

1.3 Develop the Baseline Cost Estimate

Description.

With a technical and programmatic baseline in hand, the next step in the cost-estimating process is to produce a baseline estimate. This entails following these steps which, while displayed linearly, are often executed iteratively:

- Develop an estimating approach,
- Collect, validate, normalize, and analyze data,
- Develop cost estimating relationships (CERs) and analyze risks and uncertainties,
- Develop the aggregate cost model, and
- Run the model.

Purpose.

These five tasks represent the essence of generating scientifically sound cost estimates that meet stakeholder needs. The first task, develop an estimating approach, often goes hand-in-hand with the second, data collection and analysis. Data, of course, is the raw material of cost estimating. Its importance is difficult to over-emphasize. As Dr. Thomas Pedersen of the Danish Defense Research Establishment has cogently noted,

> "Life cycle costing is a data driven process, as the amount, quality and other characteristics of the available data often define what methods and models can be applied, what analyses can be performed, and hence, the results that can be achieved." [7]

The better the data, all else equal, the higher will be the quality, flexibility, and usability of the cost estimate.

The third and fourth tasks entail the developing methods for estimating the cost of each WBS element, analyzing risks and uncertainties of each element, and aggregating costs into a usable model. The size and scope of the model are tailored to the needs of the stakeholders. The model can be anything from a simple spreadsheet with a half-dozen CERs to an elaborate workbook with hundreds of cost elements which, in turn, are sensitive to the values of a large group of input parameters reflected in the program baseline.

In the fifth task, the cost model is run based on a set of baseline input parameters. The output forms the basis of the end product, to be provided to the stakeholders. The formats of the cost estimates and reports are governed by the requirements of the

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[7] "Methods and Models for Life Cycle Costing," NATO Research and Technology Organisation technical report of task Group SAS-054, 2006.

stakeholders. Budget estimates, for example, need to follow certain guidelines from the DON Comptroller while Service Cost Positions on ACAT IC and ID programs need to meet additional requirements.

Input and Suppliers.

Inputs	Suppliers
• Requirements for the breadth and depth of the cost estimate, based on stakeholder consensus	• From Step 1.1
• The initial technical and programmatic baseline	• From Step 1.2
• References on work breakdown structures, such as MIL-HDBK-881A and the "Operating and Support Cost-Estimating Guide"	• Office of the Secretary of Defense (OSD)
• Previous cost analyses on the acquisition program or on similar programs	• DON cost-community libraries; OSD CAPE; industry
• Cost, technical, performance, and programmatic data on relevant acquisition programs	• DoD cost-analysis community including Service libraries, colleagues, defense research organizations, the Defense Cost and Resource Analysis Center; budgeting, programming and other stakeholder staffs; the program office; and the defense industry
• "Canned" cost models and cost-estimating relationships	• Defense cost-analysis community

Entry Criteria. This sub-process is initiated upon the development of an initial technical and programmatic baseline and its approval by the stakeholders.

Primary Sub-processes.

1.3.1 Develop Estimating Approach

Identify, evaluate, and select tentative estimating methodologies for each item in the Cost Element Structure (CES).[8]

1.3.1.1 Determine Estimating Level

The CES should be tailored for each program for the purpose of capturing all of the distinct characteristics or idiosyncrasies of that particular acquisition. Cost elements may differ slightly from program to program, even for the same platform type, and will differ significantly by phase. The level of detail of the cost estimate will ultimately be determined by stakeholder' needs and data availability.

The CES should capture all elements of the commonly-defined life cycle:

- Research and development costs associated with the Materiel Solution Analysis phase, the Technology Development phase, and the Engineering and Manufacturing Development phase;
- Investment costs associated with the production and deployment phases;
- Operating and support costs associated with the sustainment phase; and
- Disposal costs occurring after initiation of system phase-out or retirement, possibly including demilitarization, detoxification, and long-term waste storage.

Include any additional elements of total ownership cost required by stakeholders.

MIL-HDBK-881A, "Work Breakdown Structures for Defense Materiel Items," and the OSD CAPE's "Operating and Support Cost-Estimating Guide" are excellent starting points for guiding the development of the CES for acquisition and in-service support phases, respectively.

A critical step in the development of the CES is not only *identifying* cost elements but *defining* them, as well. A CES *dictionary* helps clarify issues of completeness or overlaps in coverage, and is particularly useful in the

[8] The term "Cost Element Structure," or CES, is sometimes used interchangeably with the term "Work Breakdown Structure," or WBS. Strictly speaking, however, they're different but related concepts. A "program WBS" is a hierarchy of product-oriented elements, such as hardware, software, data, and services that collectively comprise the system. A "contract WBS" relates the elements of the program to the elements of a contract statement of work. A CES, on the other hand, defines and groups all of the costs of an acquisition program in a disciplined hierarchy whose structure is largely determined by its suitability for cost estimation, i.e., by the availability of data. Typically, the CES is based on selected WBS elements (e.g., airframe) broken down into functional categories (e.g., engineering and manufacturing labor; overhead). Finally, in a NATO cost-estimating environment, the CES is usually called a "Cost Breakdown Structure," or CBS.

reconciliation process when differences in definition are often discovered.

As the cost estimate evolves, so does the CES. Flexibility and continual stakeholder involvement are required to generate a product that satisfies user demand.

1.3.1.2 Identify Alternative Estimating Approaches

For each cost element, identify two or more estimating approaches. These may include parametric, analogy, and engineering build-up, or any variation thereof. Approaches can be identified based on analogous studies, stakeholder knowledge, and peer reviews. Depending on where the program is in the acquisition process, actual cost data might be at least partly available.

1.3.1.3 Evaluate Alternatives

Evaluate alternative methodologies with respect to availability of data, cost of collection, schedule constraints, and prior performance with a particular estimation technique.

1.3.1.4 Determine Primary & Secondary Approaches

Select primary and secondary methodologies based on the outcome of the preceding evaluation. The primary approach is that which, all else equal, is expected to yield best results in terms of accuracy, completeness, and supportability of the estimate. Second or even third alternatives are useful as crosschecks and as fall-back positions in the event of non-availability of data or disappointing statistical results.

1.3.1.5 Develop a Template of Methodologies

It's good practice to record methodologies, element by element, in a formal document or template. Such a template serves as a useful roadmap throughout the estimation process as well as a reference for future work.

The template should identify possible areas of uncertainty or risk for each cost element.

1.3.1.6 Document Approach

The methodology template is a useful source in documenting the cost estimate.

1.3.1.7 Conduct Review Meeting

Peer reviews, such as the Technical Review Boards used in NCCA, provide additional insights into prospective estimating techniques.

1.3.2 Collect, Validate, Normalize, and Analyze Data

Data is broadly defined as any type of information used in a life cycle cost analysis. Included are technical, performance, and programmatic information related not only to the acquisition program in question but to comparable systems of potential use as analogies or as sample observations in CER development.

Because the quality and value of life-cycle cost analyses are highly dependent on the quality and quantity of available data, good information represents *real value* for an analysis of a defense materiel program.

1.3.2.1 Collect Data

Robust life-cycle cost analysis requires collecting a wide range of data from myriad sources. A distinction can be made between primary and secondary data, with the former generally of higher pedigree than the latter since it comes directly from the source, such as the accounting system of a defense contractor. Secondary data are derived, and possibly altered, from primary data.

Based on a thorough understanding of cost-estimating objectives, establish and execute a data collection plan for prospective methodologies. The plan should accomplish the following:

- Identify the actions required to capture cost, technical, and programmatic data;
- Ensure that every cost element is covered;
- Include a projected timeline to keep the estimating effort on track; and
- Recognize that the types and quantity of data available evolve as a system progresses through its life cycle. For example, little more than the specification of required capabilities may be known about a prospective end system during the Materiel Solution Analysis phase. By contrast, far more data are available when a system is in service.

Paradoxically, the value and need for accurate and robust data are probably greatest at precisely the point in the acquisition process when uncertainty and risks are most acute – early on. Technical and programmatic data at an early program stage, such as pre-Milestone A, tend to be soft and aggregated because hard numbers and detailed system specifications are not yet available. Nevertheless, sound cost analysis is essential here to support selection of the best materiel solution for the joint warfighter and to establish proper levels of funding. Extra effort, then, should be allocated for data collection early on.

Finally, future data requirements need to be anticipated throughout the life

of the program.

1.3.2.2 Validate Data

Assess the validity of data as they are gathered, along these dimensions:

- Currency. Generally speaking, recent, up-to-date data on analogous programs are generally preferred to older data on systems that use different technologies. For example, much better analogies than a World War II battleship can be found for use in estimating the cost of a modern surface combatant.

- Applicability. Homogeneity of data in terms of factors such as mission, operating environment, and platform type are important considerations. Using manned aircraft costs for estimating the cost of an unmanned aerial vehicle system, for example, would be a mismatch of mission and would likely yield poor estimating results.

- Accuracy. Very often, cost, technical, and programmatic data are inaccurate, inconsistent, incomplete or of otherwise dubious quality. Try to obtain the same piece of information from various sources. Concurrence or divergence will shed important light on the quality of the data sought. Further, *context* in cost analysis is vitally important. Ship prices in a sole-source environment may have very different meaning than ship prices in a winner-take-all competitive source selection.

1.3.2.3 Normalize Data

Regardless of source, data need to be made consistent and comparable to other data being used in the estimate. Data normalization may occur along many dimensions of homogeneity, with some of these depicted in Figure 5.

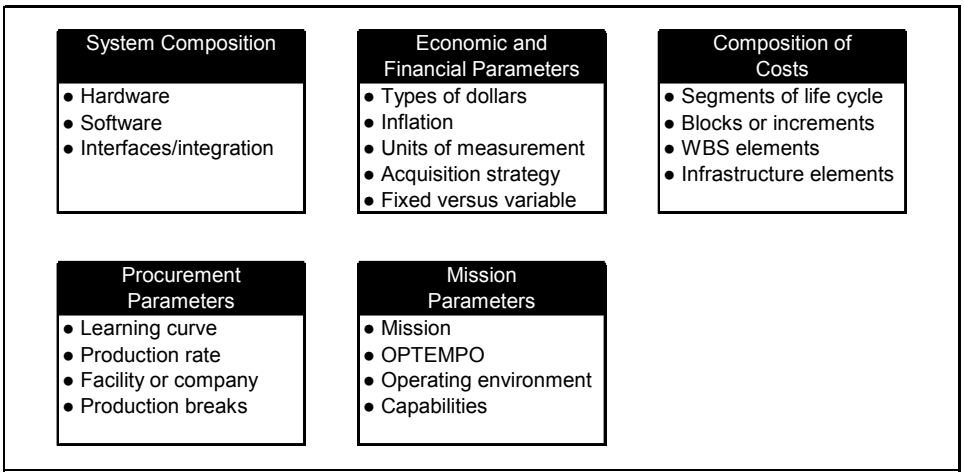

Figure 5- Dimensions of Homogeneity

Examples of normalization include

- Adjusting costs in one year to reflect the level of prices in another.
- Adjusting costs to reflect differences in the configuration of a weapon system between production lots.
- Adjusting for changes in quantity.
- Adjusting for differences in system size or density.
- Adjusting for variances in mission type and operating environment.

Regardless of how data are normalized, document the procedure exactly and completely. Serious errors often occur when data are not properly understood and interpreted. It is vitally important to understand the source, context, and meaning of data.

1.3.2.4 Analyze Data

After collecting, validating, and normalizing data, perform exploratory data analysis. The primary focus of this activity is to discover patterns in data or to *narrow the gap* between the *collection* of data and the *understanding* of it. This understanding, in turn, helps to

- Suggest hypotheses regarding the initial specification of regression equations for explaining changes in dependent variables such as cost

or manhours of effort;

- Support the selection of appropriate statistical tools and techniques;
- Provide a basis for further data collection.

A wide range of statistical techniques is available in executing exploratory data analysis. These include scatter plots, influence diagrams, classification trees, outlier analysis, and modern data-mining algorithms.

1.3.2.5 Establish/Maintain Databases & Methods

As data are gathered and methodologies developed, update databases accordingly to maintain historical records.

1.3.3 Develop CERs and Analyze Risks and Uncertainties

A number of techniques may be used to estimate the costs of a weapon system. The suitability of a specific approach will depend to a large degree on the maturity of the program and the level of detail of available data. Most estimates are built using a combination of parametric, analogy, and engineering build-up techniques. It's good practice to employ more than one cost-estimating method to serve as a cross-check. Analogy estimates often serve in this capacity, even for estimates of mature systems.

Assess risk and uncertainty in this step, both in the input parameters and in the resulting CERs. Further, document methodology, data sources, and assumptions as each cost element is estimated.

1.3.3.1 Develop or Select Cost Estimating Relationships (CERs)

Develop CERs, as illustrated in Figure 6, based on appropriate historical data and statistically-sound techniques.

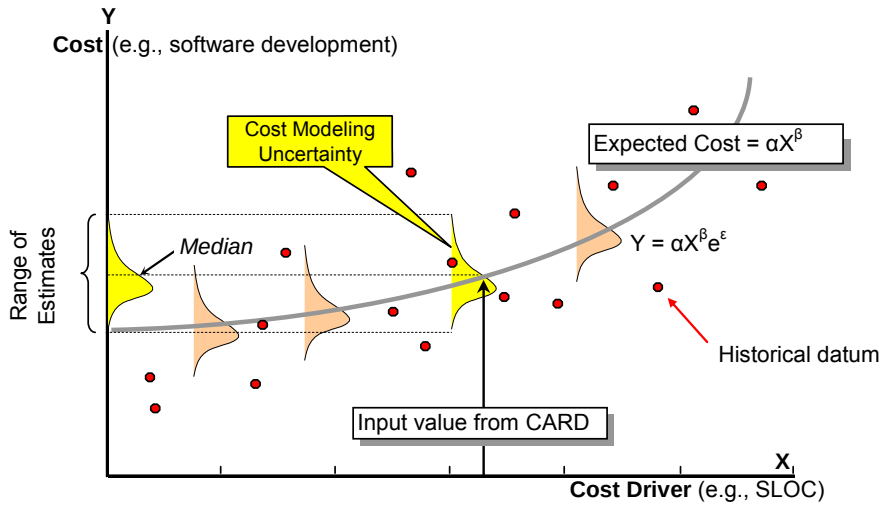

Figure 6- Cost Estimating Relationships

When regression analysis of whatever form or complexity is used, such as simple or multiple, linear or non-linear, present results using these standards:

- Show a scatter plot and the estimated regression equation.
- Present, explain, and justify the functional form of the equation, such as[9]

$$Y_i = \alpha + \beta X_i + \varepsilon_i, \text{ where}$$

Y is the dependent variable, X is the explanatory variable, α and β are parameters to be estimated, and ε is the stochastic disturbance ~ $N(\mu,\sigma^2_\varepsilon)$, where μ is the mean of ε and σ^2_ε is its variance.

[9] A simple, linear regression equation is used here for simplicity of expression.

- Report statistical results, as a minimum, by writing out the estimated regression equation with either estimated standard errors or t-statistics in parentheses under the respective coefficients.[10] Follow with the value of R^2. Other useful values to show include the F-statistic, standard error of the estimate, coefficient of variation, and the Durbin-Watson statistic in cases where the presence of serial correlation might be suspected.

$$\hat{Y}_i = \underset{(t)}{\hat{\alpha}} + \underset{(t)}{\hat{\beta}X_i} \qquad R^2 = \cdots .$$

1.3.3.2 Document Development of CERs

Fully explain the development of CERs. Include data sources, rationale for the exclusion of outliers, and regression equations that were estimated but later rejected. Present rationale for the selection of the regression equation used in the cost estimate.

1.3.3.3 Analyze Risks and Uncertainties

If Monte Carlo simulation is to be used in the estimate, select the distribution type and distribution parameters (e.g., low, most-likely, and high values for a triangular distribution) for each CES item. To the greatest degree possible, use historical data, results of statistical analyses, and engineering inputs to select parameter values. The practice of simply varying a point-estimate up and down by a few percentage points is completely unacceptable.

Assess risk and uncertainties for each element of the estimate *at the same time* that the point estimate is developed.

1.3.3.4 Conduct Methodological Review Meeting

As a cost team, meet with appropriate subject matter experts such as a Technical Director to review the CERs that will be used to develop the cost estimate. Review CER documentation for completeness.

[10] Elements of Econometrics. Kmenta, Jan; The Macmillan Company, New York 1971; page 242.

1.3.4 Develop the Cost Model

Select, refine, or build a cost model that meets stakeholder requirements in terms of scope, flexibility, and ease of use.

1.3.4.1 Analyze Modeling Requirements

Identify a modeling approach based on an evaluation of the quantity and complexity of inputs, calculations, and outputs required to meet stakeholder requirements. Determine whether a new model is required or if an existing model can be updated.

1.3.4.2 Choose Modeling Medium

Determine which modeling platform best meets requirements. Possibilities include Excel, ACEIT, and other commercial models.

1.3.4.3 Design/Refine Model Architecture

Design a cost model that allows for flexibility, change in input parameters, real-time analysis, efficient treatment of risk and uncertainty, and cogent and clear displays of outputs. Take advantage of "canned" templates wherever reasonable.

1.3.4.4 Create Model

Implement the model architecture by coding it in the selected modeling platform.

1.3.4.5 Validate/Verify Model

Validate the model to ensure that all calculations are performed accurately. Compare results to test cases and step through the calculations by hand.

1.3.4.6 Document Model

Generate documentation that will allow other analysts to produce estimates and update the model. Include instructions for using the model.

1.3.4.7 Conduct Model Review Meeting

Review the model for accuracy and completeness using subject matter experts such as the Branch or Division Chief and the Technical Director.

1.3.5 Run the Model

Run the model to produce a baseline life-cycle cost estimate for the program, prior to executing top-level risk and uncertainty analysis.

1.3.5.1 Select CER Inputs

Typically, there are a range of plausible "most-likely" values to use as cost drivers in regression equations. An example might be source-line-of-code (SLOC) count in a CER for estimating software development effort. Determine which values to employ based on historical studies, stakeholder consensus, and subject matter experts. Document the rationale for all choices.

1.3.5.2 Select Acquisition Values

Use the program of record and current budgeting and programming documents to select baseline development and procurement quantities, schedule dates, and so on, tempered by an assessment of the accuracy of these figures.

1.3.5.3 Generate Outputs

Produce the analytical and budgetary displays that will be required by the stakeholder. Do not provide to the stakeholder until the steps of risk and uncertainty analysis and validation and verification of the estimate have been completed.

Agents.

- Cost Competency
- Program Office or IPT
- Financial, logistics, engineering, and personnel communities
- SYSCOM, OPNAV, SECNAV, and OSD principals
- OSD Cost Assessment and Program Evaluation (CAPE)
- Assistant Secretary of the Navy for Research, Development and Acquisition (ASN (RD&A))
- Assistant Secretary of the Navy for Financial Management and Comptroller (ASN(FM&C))
- Assistant Secretary of the Navy for Manpower and Reserve Affairs (ASN(M&RA))
- Assistant Secretary of the Navy for Installations and Logistics (ASN(I&E))
- Industry

Output and Stakeholders.

Output	Stakeholders
• Cost Estimating Methodology Matrix (CEMM), or similar product, that presents methodologies for each cost element	Cost competency
• Cost estimating relationships, factors, databases	Cost competency
• Analysis of risk and uncertainty for each cost element	Cost competency
• Initial documentation or notes for each cost element	Cost competency
• Aggregate cost model	All stakeholders

Exit Criteria.
This sub-process is complete upon development of the aggregate cost model.

Tools.
- Spreadsheets and other common office software; Internet; commercial and government models
- Databases
- DoD guidance and instructions on work breakdown structures for development, procurement, and operating and support costs
- Statistical packages for estimating regression equations and learning curves.

1.4 Conduct Risk and Uncertainty Analysis

Description.

The terms "risk" and "uncertainty" are often used interchangeably, but they're not the same.

- **Uncertainty** is the indefiniteness or variance of an event. It captures the phenomenon of observations, favorable or unfavorable, high or low, falling to the left or right of a mean or median value.

- **Risk** is exposure to loss. Or, in a weapon-system acquisition context, it is "A measure of future uncertainties in achieving program performance goals within defined cost and schedule constraints. It has three components: a future root cause, a likelihood assessed at the present time of that future root cause occurring, and the consequence of that future occurrence." [11]

Risk and uncertainty, then, are related. Uncertainty is probability while risk is probability and consequence.

Probability distributions of cost, according to one school of thought, are "… rarely, if ever, known [with significant precision] ... for … investment projects."[12] This contention remains an open issue within the international defense cost analysis community. Some practitioners concur but others don't.[13] Amidst this spectrum of opinion, valid techniques for conducting risk and uncertainty analysis of life-cycle cost estimates of defense acquisition programs include sensitivity analysis, Monte Carlo simulation, and scenario-based analysis. [14]

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[11] "Risk Management Guide for DoD Acquisition, Sixth Edition, August 2006; USD(AT&L), Systems and Software Engineering, Enterprise Development, page 33.

[12] Economic Theory and Operations Analysis, Baumol, William, Prentice-Hall, 1977, page 621.

[13] Several representatives from the OSD CAPE and from many European Ministries of Defense question the ability to know, with any reasonable degree of certitude, probability distributions in a defense cost-estimating environment. Monte Carlo simulation is more popular in the U.S. DoD than in the ministries of defense in other NATO countries where use of sensitivity analysis predominates.

[14] "Cost Risk Analysis without Statistics," and "A Scenario-Based Method for Cost Risk Analysis," Garvey, Paul, MITRE, October 2003 and September 2005, respectively.

Each technique, if used properly, can yield scientifically-sound results. But, first a word of caution. Based on our collective experience in the naval cost-estimating community, it's fair to say that the sophistication and underlying theory of many popular models often *far exceeds* the *quality* of the basic data inputs.[15] There's simply no substitute for taking the time and effort to understand the technical risks and challenges in developing and producing sophisticated defense systems.[16] Historical analogies must be obtained. Information from subject matter experts must be elicited. Risk and uncertainty analysis can't be relegated to an eleventh hour exercise based on *flimsy* inputs. Section 1.4.2 below presents additional details on this important step of data collection.

Purpose.

It's essential to convey to senior leadership the notion that cost estimates are uncertain, that acquisition programs can and do incur difficulties, and that the probability of a cost estimate becoming reality, when expressed as a single number, is precisely zero.

A review of scores of major defense acquisition programs, as reflected in Selected Acquisition Reports, reveals that only a small percentage come in under or on budget. The reasons are many and varied and include

- Immaturity of critical technologies at the start of development
- Inadequate understanding of design challenges at the start of development , often due to the absence of prototyping
- Requirements uncertainty, instability, or creep
- Failure to acknowledge or deal with funding shortfalls
- Funding instability in the programming, budgeting and appropriations processes
- Failure to detect or deal with unrealistic contractor cost proposals
- Excessive concurrency between development and procurement schedules
- Inadequate understanding of software development size and integration challenges
- Failure to achieve design stability by the time of the critical design review
- Failure to achieve stable manufacturing processes by the time of early production.

Because of factors like these, risks need to be analyzed and their cost implications estimated.

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[15] Survey by Dr. Brian Flynn of the Naval Center for Cost Analysis in 2004 of 12 cost-estimating organizations in the DoD, representing at the time roughly 1,000 billets, and "Portfolio Management for New Product Development: Results of an Industry Practices Study," Drs. Cooper, Edgett, and Kleinschmidt, Product Development Institute, 2001, page 20. The "popular models" referenced by these authors are Crystal Ball and @Risk, two commercial models frequently used in defense cost analysis.

[16] Biery, Hudak, and Gupta refer to this as "the most crucial … but generally overlooked" step in performing risk and uncertainty analysis. "Improving Cost Risk Analyses," 1994, page 1.

Inputs and Suppliers.

Inputs	Suppliers
• Distribution types and parameters	• Databases of analogous programs • Results of regression analyses
• Identification of risk events	• Stakeholders; industry subject matter experts • Analogous programs
• Correlations among cost elements	• Estimates of statistical relationships between elements, based on historical data • Previous studies
• Specification of scenarios	• Stakeholders • Analogous programs

Entry Criteria. This sub-process is initiated upon generation of the baseline point estimate.

Primary Sub-processes.

1.4.1 Choose Method of Analysis

Popular techniques include sensitivity analysis, Monte Carlo simulation, and scenario-based analysis.

Employment of more than one technique, such as the latter two which are fundamentally different in approach, will add insight into the analysis and credence to the results. This, indeed, is a best practice.

1.4.2 Collect Data

Data is the raw material of risk and uncertainty analysis. It is critical to every estimate. Without good, solid data, whether based on historical analogies or on sound engineering understanding of the acquisition at hand, the risk and uncertainty estimate will be merely a guess or an opinion of the cost analyst. The more solid the data, the better will be the estimate. At the start, it is important to understand the fundamental objectives of the program, including requirements, scope, schedule, technical goals, and evolutionary phases. With this backdrop in mind, the following steps should be executed:

1.4.2.1 Identify Risk and Uncertainty Variables

Identify all potential variables in the cost model affected by risk and uncertainty. It's usually helpful to have these in a single input area in a workbook.

1.4.2.2 Identify Potential Data Sources

Identify potential data sources for estimating risk and uncertainty for each of these variables. That is, identify various ways of trying to determine a

variable's type of probability distribution and its associated parameters such as high, low, and most-likely values.[17] Options include:

- Using statistical equations from the cost model that give estimated means and variances,
- Using scorecards, and derivatives thereof,
- Culling ideas and information from subject matter experts, and
- Finding good historical analogies.

1.4.2.3 Identify Correlations

In the case of Monte Carlo simulation, identify and estimate correlations between stochastic cost elements. Correlation matrices might be based on engineering knowledge of the relationships between components of a platform or on statistical analyses of historical time-series data on the cost elements.

1.4.2.4 Identify Cross-Checks

Identify sources for cross-checks. These might include use of alternative methodology, comparisons with historical cost growth on similar programs, and sanity checks for completeness and reasonableness with subject matter experts.

1.4.2.5 Collect Data

Develop and execute a data collection plan. As mentioned in the previous chapters, this step should be executed in conjunction with activities supporting the generation of the baseline point estimate.

1.4.3 Run the Analysis

- Sensitivity Analysis

Typically, there are a few critical assumptions that often drive the results of the cost analysis, and it is important to understand and point out how variations in these assumptions affect the results. An example might be the number of SLOC required for the development of a new military pay and personnel information system. Cost drivers, such as SLOC count, should not be changed by arbitrary plus or minus percentages, but rather by a careful assessment of the underlying risks. That is, carefully analyze the variability of key parameters based on a nexus of historical analogies and engineering knowledge, striving always to minimize subjectivity.

[17] For more details, see the Air Force's Cost Risk and Uncertainty Handbook, July 2007, or similar references.

- Monte Carlo Simulation

Each of the factors, ratios, and CERs in a cost-estimating model is usually stochastic. The uncertain or random nature of these variables can be expressed as a probability distribution with a certain mean and variance. Combining the probability distributions of each of the variables in a large cost model for a major weapon system acquisition program to obtain a total cost probability distribution cannot be done mathematically. The number of variables is simply too numerous and the resulting calculus intractable. A statistically sound alternative is Monte Carlo simulation. In this technique, a random sample is taken from the probability distribution associated with each CER and each risk variable. Based on the functional form of the factor or CER, arithmetic operations are performed to obtain a single estimate of the cost of that element. This is done for each uncertain factor and CER in the model. Results are summed into a single estimate of the cost for the entire weapon system. This estimate, then, is one observation or experimental result out of an infinite number available. The procedure of random number selection and subsequent cost computation is repeated thousands of times to develop a histogram, and in the limit, a probability density function, of total system cost.

Figure 7 presents an overview of a process for estimating risk and uncertainty.[18] While other techniques and variations of this process are available,[19] the below paradigm provides outputs that have proven useful in responding to demands for relevant information on budget risk on major acquisition programs. More specifically, the process enables decision makers to budget a program at a specific cumulative percentage level of risk, or, to fully understand the consequences of living within an already established budget. And it enables them to know the financial impact of specific, discrete risk events such as failure to successfully design a new fighter engine within fiscal and schedule constraints.

[18] For more details, see the U.S. Air Force's Cost Risk and Uncertainty Analysis Handbook, 2007, and NATO's Methods and Models for Life Cycle Costing, 2006.

[19] A common and perfectly acceptable alternative is to combine risk and uncertainty analysis in one step rather than using the two distinct steps (uncertainty analysis followed by risk analysis) shown here.

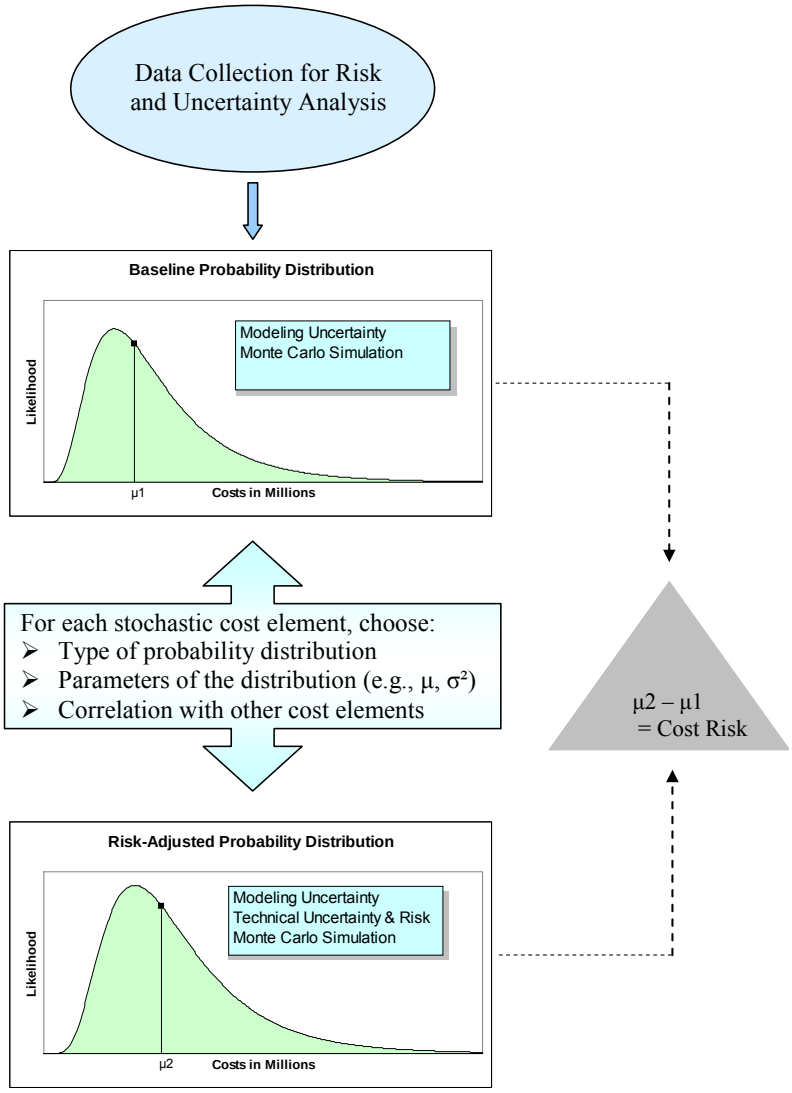

Figure 7- Estimating Risk and Uncertainty Process

In this process, first generate a *baseline* probability density function using Monte Carlo simulation. Regard as *fixed* the values of the explanatory or independent variables (Xs) in each of the cost model's CERs, as shown in Figure 8.

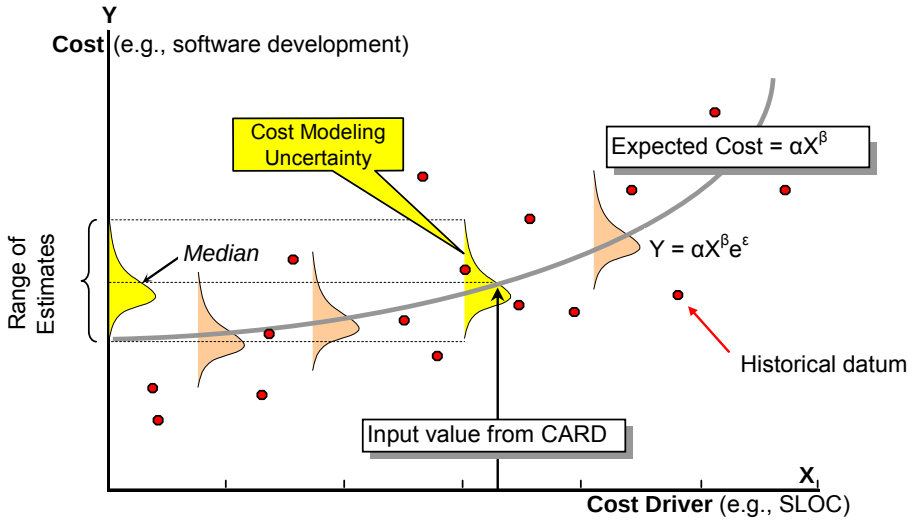

Figure 8- Cost Estimating Relationships

Values of the Xs are usually found in the program's CARD. The *baseline* estimate *does* capture *uncertainty* in the relationship between dependent and independent variables in each CER. This uncertainty, in turn, results from three possible, though not mutually exclusive, sources:

- Limited data. In explaining changes in the values of cost elements over time, the list of relevant factors may be extended *ad infinitum*. However, due to data availability, perhaps only two or three of these factors are included in the analysis. Indeed, sometimes we're lucky to get just one relevant explanatory variable. The CER, then, becomes an over-simplification of the complexities of reality.

- Human unpredictability. Over and above the total effect of missing relevant factors, there is a basic and unpredictable element or randomness in human or contractor responses that can be adequately characterized only by the inclusion of uncertainty in the analysis. This will hold as long as people rather than machines acquire and build weapons systems.

- Errors of observation or measurement. Cost and technical data are almost always difficult to obtain and are often of less than perfect accuracy. For example, overhead costs from different contractors may not be of the same scope or consistency due to differences in ways of doing business. Further, even data from the same contractor may differ significantly over time due to changes in rules of accounting.

In generating a *risk-adjusted* cost estimate, not only is basic CER uncertainty captured, as above, but technical risk and uncertainty as well, as shown in Figure 9.

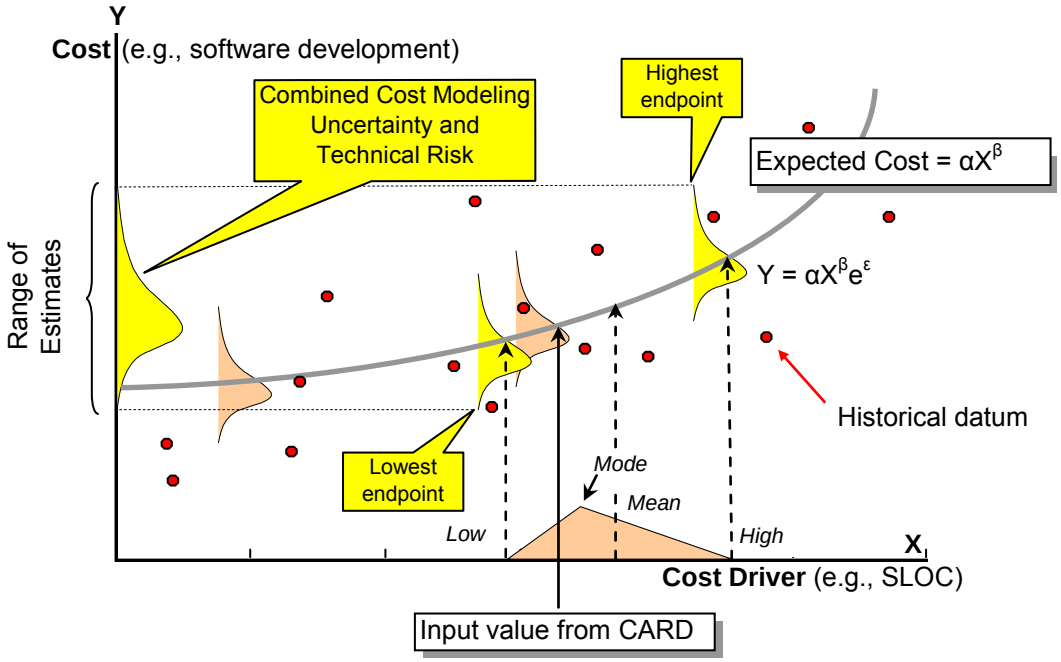

Figure 9- Cost Estimating Relationships: Technical Risk & Uncertainty

Unlike before, the Xs in each of the model's CERs are now treated as stochastic. Technical, acquisition, and cost-estimating risks are now considered. Affected variables might include:

- Quantity of units to be developed or procured
- Weight of a platform or system
- External parameters such as the price of oil
- System-to-platform integration challenges
- Number of drawings
- Number of SLOC or percentage of SLOC reuse
- Number of test flights
- Key schedule milestones such as date of critical design review or date of first flight
- Cost parameters such as learning curve rates and T1s.

Further, discrete risk events such as failure to effectively design a new aircraft engine or a new circuit card are captured here as well. As before, for each of these risk variables, probability distributions are estimated or selected, and Monte Carlo simulation is used to generate a probability density function.

Finally, the difference in mean values of the two probability distributions, *risk-adjusted* and *baseline*, represents *cost risk*, as shown in Figure 10.

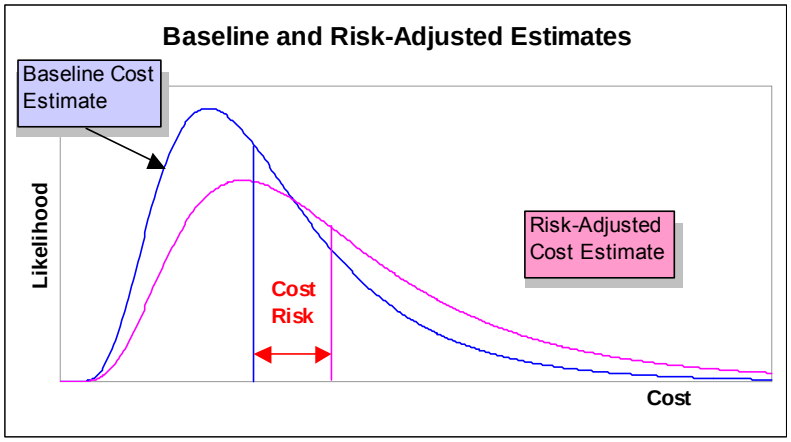

Figure 10- Baseline and Risk-Adjusted Estimates

The baseline cost estimate contains modeling uncertainty while the risk-adjusted cost estimate contains both modeling uncertainty *and* technical uncertainty and risk. The risk-adjusted probability distribution will therefore have a higher mean value and a higher variance than the baseline estimate. Its distribution will typically appear flatter and more skewed to the right. Cost risk can be expressed in either monetary or percentage terms.

- Scenario-Based Analysis

This top-down methodology encourages and emphasizes a careful specification of baseline, optimistic, and pessimistic risk and uncertainty scenarios. Rather than building up risk and uncertainty element by element as in Monte Carlo simulation, an often time consuming and arduous task, this methodology instead shifts attention to what can go right and what can go wrong with an acquisition program from a high-level management point of view. "Without the need to define scenarios, cost risk analyses can be superficial with its basis not well-defined or carefully thought through. Scenario definition encourages a discourse on program risks that otherwise might not be held. It allows risks to become fully visible, traceable, and 'costable' to program managers and decision-makers."[20]

In this technique,

1. Identify major cost drivers or key variables that influence total cost of the acquisition program, just like in sensitivity analysis.
2. Group these variables or potential events into scenarios. Each scenario "… is a well-defined set of technical and programmatic conditions that collectively affect a number of cost-related variables …

[20] Garvey, page 6.

in a way that increase [or decrease] cost beyond what was planned." The baseline scenario is the most-likely outcome based on CARD parameters.

3. Estimate a variance for the risk-adjusted probability distribution using historical data for a set of analogous acquisitions, with an example shown in Figure 11.
4. Calculate a cumulative probability distribution using relatively straight-forward algebraic techniques, based on estimated mean and variance.

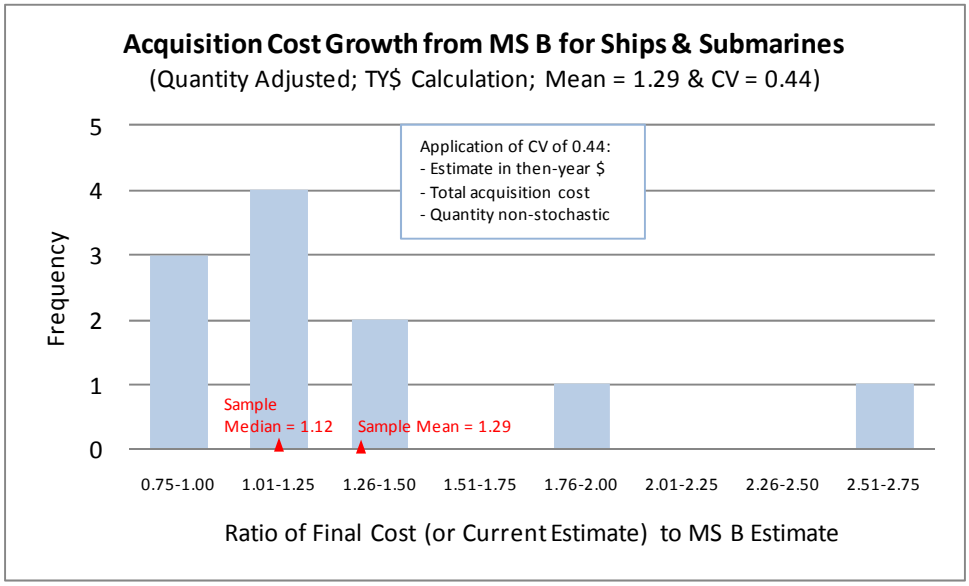

Figure 11- Acquisition Cost Growth from MS B for Ships & Submarines

1.4.4 Analyze Results

Analyze results of risk and uncertainty analysis along the dimensions of accuracy, clarity, and completeness. If coefficients of variation (CVs) in probability distributions, for example, are significantly higher or lower than norms for analogous platform types and for the same phase in the acquisition process, investigate and explain the delta.

1.4.5. Choose Risk-Adjusted Point Estimate

Choose a point on the risk-adjusted probability distribution, or from the domain of results of sensitivity analysis, that will serve as a single-number "best estimate" of the unknown cost of the program. Unless directed otherwise, use the risk-adjusted mean, which usually lies between the 50th and 60th percentiles in a log-normal cumulative probability distribution.

In theory, the choice of a point estimate depends upon the *loss function*, or the penalty incurred by DoD in making an incorrect estimating and budgeting

decision. In practice, however, this function is seldom if ever estimated, a glaring omission in a set of sound practices. As a rule of thumb, the loss function, all else equal, increases with the urgency and importance of an acquisition program to the joint warfighter. In the case of armored vehicles, for example, which can save life and limb, estimating and budgeting to a point significantly higher than the mean μ may be in order. The penalty of estimating and budgeting too low in this case could be additional time required to request additional funds, amend contracts, and work Nunn-McCurdy issues. The ultimate effect could be a slip in schedule in designing, producing, and fielding ground vehicles urgently needed in theatre to better combat IEDs.

As a corollary to selecting a point estimate, calculate and display budget risk. Budget risk is the probability that the actual cost of a weapon system acquisition program will end up exceeding a given budget, as Figure 12 shows. In this case, the budget is set at the mean value of the risk-adjusted cost estimate. Costs to the right of the mean are all legitimate possibilities, as are those to the left of the mean. Since the budget is finite, there's a certain probability it will be exceeded. The percentage of the area of the distribution to the right of the budget is defined as *budget risk*. It's usually expressed as a number such as 40%, or 50%, or 60%. The value of risk analysis is that it *quantifies* this probability. Decision makers can then determine what *degree* of risk to accept, given the value of the weapon system and given the values and risks of alternative systems in a warfighting portfolio. A low budget implies a high probability of an overrun while a high budget implies a low probability of an overrun. It's up to the decision maker to decide where to set the budget.

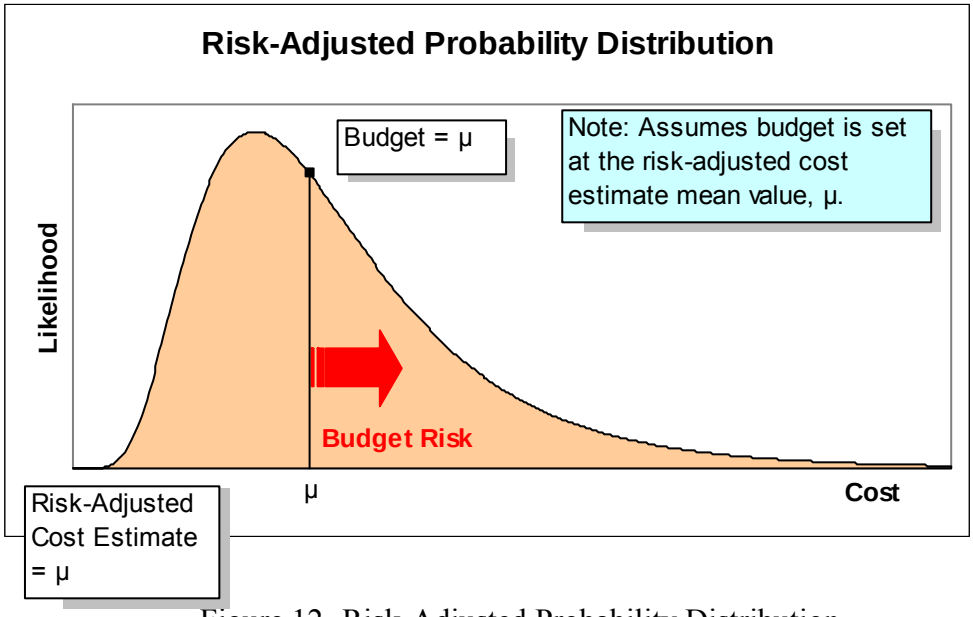

Figure 12- Risk-Adjusted Probability Distribution

1.4.6 Allocate and Phase Costs

Finally, allocate total estimated costs by appropriation and year.

Agents.

- Cost Competency
- Program Office or IPT
- Financial, logistics, engineering, and personnel communities
- SYSCOM, OPNAV, SECNAV, and OSD principals
- OSD Cost Assessment and Program Evaluation (CAPE)
- Assistant Secretary of the Navy for Research, Development and Acquisition (ASN (RD&A))
- Assistant Secretary of the Navy for Financial Management and Comptroller (ASN(FM&C))
- Assistant Secretary of the Navy for Manpower and Reserve Affairs (ASN(M&RA))
- Assistant Secretary of the Navy for Installations and Logistics (ASN(I&E))

Output and Stakeholders.

Output	Stakeholders
• Analysis of impact on cost of changes in cost drivers	All stakeholders
• Estimate of probability distributions	All stakeholders
• Specification of scenarios representing plausible outcomes of the acquisition	All stakeholders
• Choice of point estimate from a probability distribution	All stakeholders
• Assessment of discrete risk events	All stakeholders

Exit Criteria.
This sub-process is complete upon an assessment of risk and uncertainty.

Tools.
- Databases
- Government and commercial models designed to assess risk and uncertainty
- Scorecards for eliciting scientifically sound inputs from subject matter experts.

1.5 Verify and Validate Cost Estimate

Description.

Verification and validation, or V&V, is a quality control and assurance process. Verification helps ensure that the life-cycle cost estimate is credible, accurate, timely, and well documented. That is, verification focuses on the quality of the estimate, and its compliance with DON cost-estimating standards. Validation checks that the estimate meets stakeholder requirements. In short, validation ensures "doing the right estimate" while verification ensures "doing the estimate right."

In defense cost analysis, verification typically entails a bottom-up scrub of the estimate, employment of cross-checks from a set of analogous programs, and peer review. Validation entails obtaining acceptance of the estimate's scope and content from users. To a large degree, V&V is conducted throughout the estimation process, as the previous chapters have indicated. However, additional steps can be taken during the "end-game" to increase credibility and confidence in the estimate.

Purpose.

Defense cost analysis, in its highest form, is an amalgam of knowledge, data, application of sound scientific principles, and good judgment regarding a wide variety of issues and factors that are often known with limited precision. Since uncertainty and subjectivity are always present in the cost-estimating process, sound procedures for verification and validation are essential to ensure the delivery of *quality* products, and, importantly, to capture and store *reliable* metadata on the estimate for future use and continual process improvement. Verification and validation should be conducted along the dimensions of:

- **Completeness.**
  Ensure that the estimate covers all cost elements in the program baseline while double counting none, and, that the estimate covers all elements in any excursions to the baseline, as required by stakeholders.

- **Accuracy.**
  Ensure that the cost model is mathematically sound, or error free, and that the cost estimate is neither biased upward nor downward, in terms of both the point estimate and its associated probability distribution.

- **Credibility.**
  Ensure that the estimate meets stakeholder requirements, maximizes the use of scientifically-sound principles while minimizing subjectivity, tests and revisits assumptions, and assesses risk and uncertainty.

- **Documentation.**
  Ensure that the estimate is completely documented, including data sources, methodology, and groundrules and assumptions. Ensure that the documentation package includes all relevant reports and correspondence from beginning to end of the estimation effort.

Inputs and Suppliers.

Inputs	Suppliers
• Verification tools such as top-level models	• Cost community
• Databases of historical CVs and actual costs from analogous programs	• Cost community
• List of requirements for the cost estimate	• Stakeholders
• Procedures for detecting computational errors	• Cost community

Entry Criteria. This sub-process is initiated upon completion of risk and uncertainty analysis.

Primary Sub-processes.

1.5.1 Execute Bottom-Up Scrub

A best practice, although admittedly time consuming, is to explain every calculation in the life-cycle cost-estimating model to an independent, knowledgeable analyst who has not been involved in the development of the estimate. Evidence suggests that a significant number of computational errors will be uncovered.[21]

1.5.2 Perform Peer Review

Explain the analysis, including generation of the point estimate and associated probability distribution, to subject matter experts.

1.5.3 Compare Cost to Analogous Systems

Compare the life-cycle cost estimate to actual costs from similar programs. This can be done at various levels of detail, with an example shown in Figure 13. Metrics for comparison might include aggregate cost, dollars per pound, or system engineering/program management as a percentage of procurement cost. Explain anomalies. For example, an acquisition program with mature technology but "outlier" costs and one with advanced technology but "ballpark" costs might both raise flags.

[21] Dr. David Chu, former USD(Personnel and Readiness), and Mr. Robert Hale, USD(Comptroller), employed this practice during their tenure at the Congressional Budget Office [conversation with Dr. Brian Flynn of NCCA].

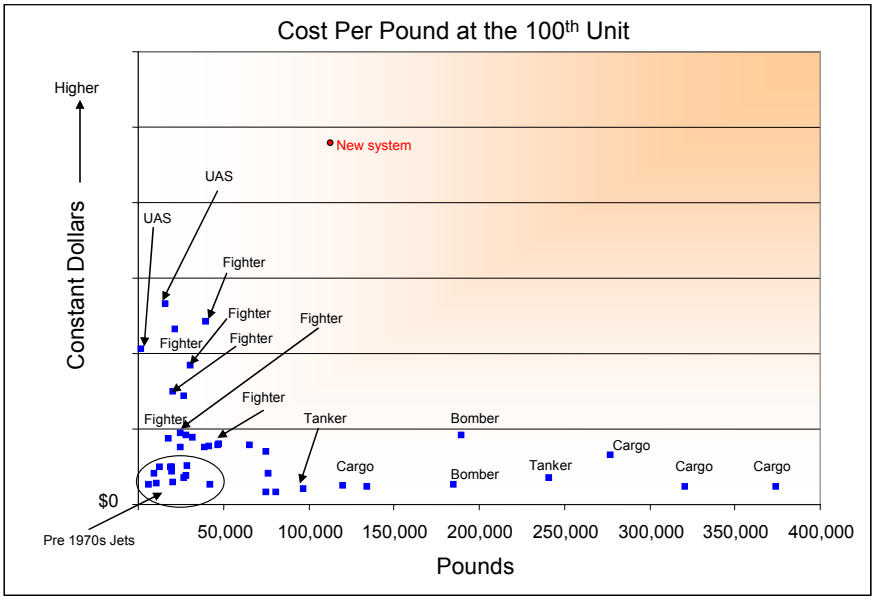

Figure 13- Cost Per Pound at the 100th Unit

A more sophisticated cross-check, and a best practice, is to use the results of top-level multivariate estimation, such as "decision trees and regression analysis. A simple two-leaf example of this application is shown in Figure 14.[22]

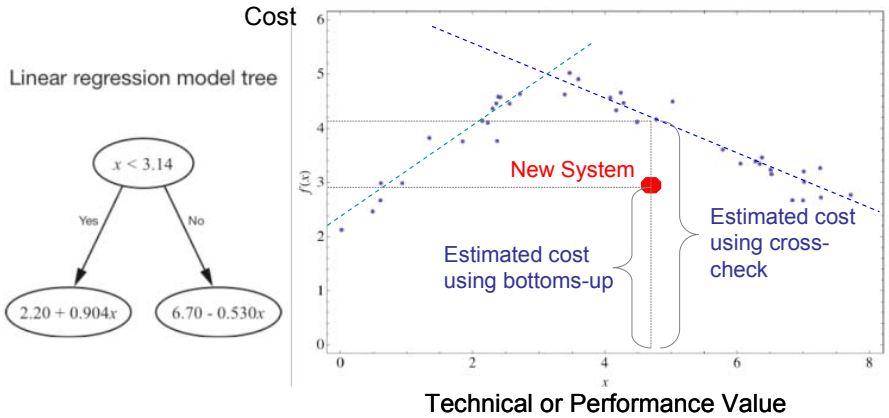

Figure 14- Two-Leaf Example of Decision Tree

[22] In a current application of this technique for NATO's SAS-076 Task Group, Dr. Bohdan Kaluzny of Defence Research and Development Canada has estimated a decision tree for total ship construction cost based on an analysis of over 100 technical and performance characteristics from over 30 ship platforms worldwide.

In this procedure, vectors of performance and technical characteristics of historical weapon systems are analyzed in terms of their impact on cost, with two distinct samples of data identified in the example to the left and right of the "leaf" value (x = 3.14). The cost estimate from this verification model is compared to the point estimate generated from a different procedure, such as bottoms-up engineering or traditional parametric analysis. A flag is raised and explanation required if a new acquisition program produces anomalous results when fed into the decision-tree model, as the example shows.

As an added and perhaps beneficial twist, this verification model could be employed independently within a cost competency, that is, by a group responsible for true independent V&V that operates as a separate entity from the team that generates the cost estimate.

1.5.4 Evaluate Quality of Risk and Uncertainty Analysis

In cases where cumulative probability distributions are generated, compare the coefficient of variation (standard error divided by mean) for the estimate with estimated CVs from analogous programs at similar stages in their life cycle, as exemplified in Figure 15. Any significant variation in this normalized measure of dispersion of the probability distribution, from historical norms, could indicate a flaw in methodology. That is, either the acquisition program is free of risk to an unusual degree, or, alternatively, risk and uncertainty have not been properly taken into consideration in generating the cost estimate. In either case, an explanation is required.

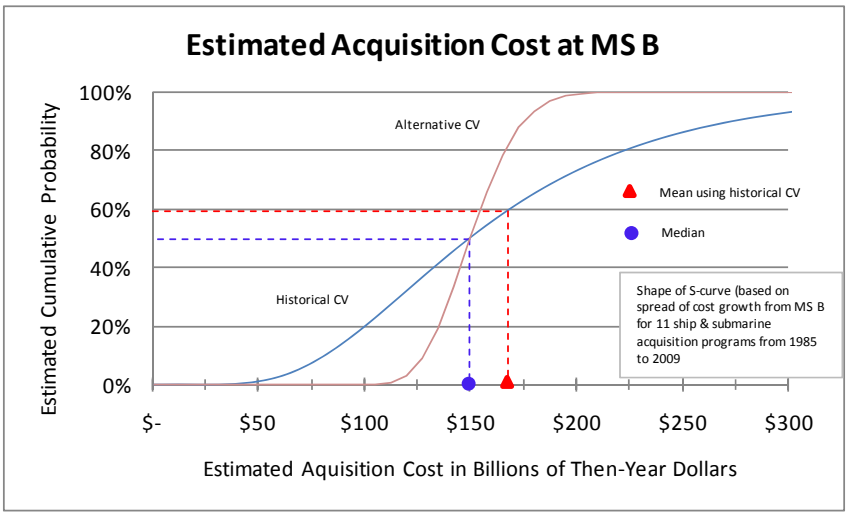

Figure 15- Estimated Acquisition Cost at MS B

A best practice is to employ more than one technique for executing risk and uncertainty analysis, and to compare results. For example, detailed Monte Carlo simulation and scenario-based cost analysis both yield S-curves. Yet, the two techniques are fundamentally different in approach, the former bottoms-up and the latter top-down. If aggregate results of the two procedures don't jibe, further work is required to determine why. Finally, results of sensitivity analysis should also be consistent with results from other techniques.

Agents.

- Cost Competency
- Program Office or IPT
- Financial, logistics, engineering, and personnel communities
- SYSCOM, OPNAV, SECNAV, and OSD principals
- OSD Cost Assessment and Program Evaluation (CAPE)
- Assistant Secretary of the Navy for Research, Development and Acquisition (ASN (RD&A)))
- Assistant Secretary of the Navy for Financial Management and Comptroller (ASN(FM&C))
- Assistant Secretary of the Navy for Manpower and Reserve Affairs (ASN(M&RA))
- Assistant Secretary of the Navy for Installations and Logistics (ASN(I&E))

Output and Stakeholders.

Output	Stakeholders
• Results of validation	All stakeholders
• Results of verification	Cost-estimating team
• Verified and validated cost estimate	All stakeholders

Exit Criteria.

This sub-process is complete upon finding that the cost estimate meets verification and validation standards.

Tools.

- Commercial and government models for analyzing risk and uncertainty analysis.
- In-house top-level cost models for performing verification.

1.6 Present and Defend Estimate

Description.

The final steps in the cost-estimating process, to be executed with clarity and precision after validating and verifying the accuracy and completeness of the life-cycle cost estimate, are to

- Finish documentation,
- Develop presentation media, and
- Communicate and defend results.

Purpose.

Documentation serves several important purposes. These include re-enforcing the validity of the estimate by providing a step-by-step account of how the cost estimate was generated; providing a basis for making further changes to the estimate in response to what-if drills and changes in program content; and providing an important data point for use in future cost analyses of similar programs.[23]

Use of meaningful, thoughtfully-prepared visual displays is important in communicating the results of detailed cost analyses to stakeholders. Briefing slides should reveal the basis and results of analysis, induce the viewer to focus on substance and decision space, and should avoid any distortions in either data or analysis.

Input and Suppliers.

Inputs	Suppliers
• Validated and verified life-cycle cost estimate	• Cost competency
• Documentation standards	• Naval Center for Cost Analysis; others
• Templates on displaying the results of cost analyses	• Cost competency

Entry Criteria. This sub-process is initiated upon acceptance of a validated and verified cost estimate.

[23] For more details, see "Guide for the Documentation of Independent Cost Estimates (ICE's)" at http://www.ncca.navy.mil.

Primary Sub-processes.

1.6.1 Complete the Documentation Process

A best practice is to start documenting the cost estimate as it is developed. Trying to recapture rationale, judgments, and the details of intricate statistical analyses after the fact is, at best, extremely difficult and time consuming. At worst, critical estimation steps might need to be re-executed. Therefore, this step entails completion of a process instituted from the "get-go."

1.6.2 Develop Presentation Media

The level of detail presented depends on the audience. More detail is required for technical peer reviews and less for communication with senior-level decision makers. In either case, however, a good presentation will:

- Demonstrate the thoroughness and professionalism of the effort
- Show completeness and consistency
- Explain ground rules and assumptions
- Present findings in an understandable fashion
- Convey the stochastic nature of the estimate.

1.6.2.1 Generate Probability Distributions

In cases where Monte Carlo simulation or scenario-based analysis is employed, useful displays include probability density functions and cumulative probability distributions, with a simple example shown in Figure 16 for a normal distribution.

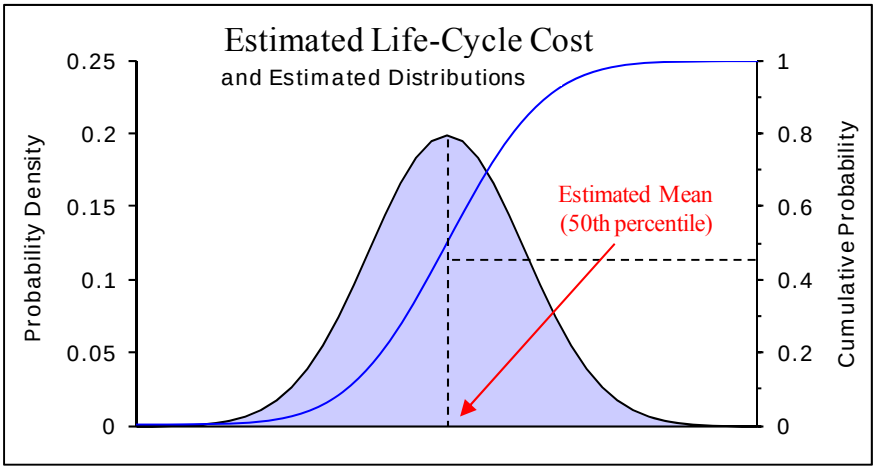

Figure 16- Estimated Life-Cycle Cost and Estimated Distributions

Since the precise distribution of the cost estimate is never known with absolute certitude, it's perhaps helpful to provide context through the use of historical norms. Figure 17, for example, compares an estimated probability distribution for a current acquisition program to one based on the same point estimate (such as the median or mean) but using a variance based on sample CVs from analogous, historical programs. Because the distribution is typically lognormal in cost analysis, use of a different variance could result in a new point estimate.[24] Any significant deltas, of course, should have passed muster in the validation and verification phase.

The intent of this kind of graph, which might be relegated to back-up depending on the audience, is to reinforce to decision makers the notion that the probability distribution itself is stochastic.

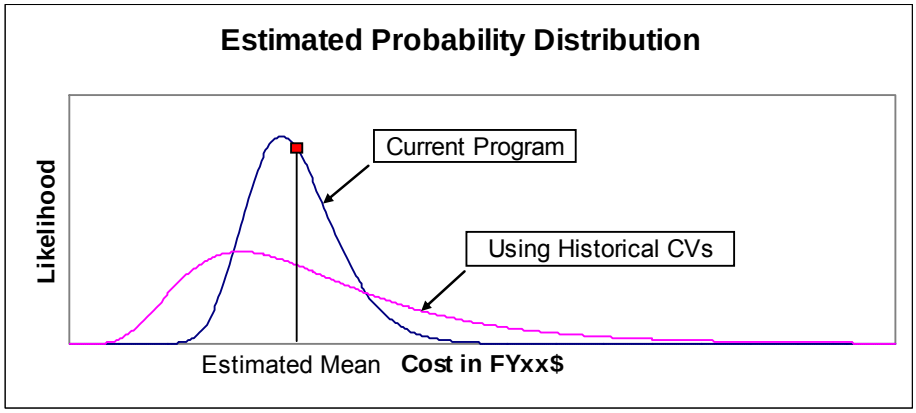

Figure 17- Estimated Probability Distribution

[24] If Y is a random variable, where $\ln(Y) \sim N(\mu,\sigma^2)$, then Y is lognormally distributed with mean $E(Y) = e^{\mu + (\sigma^2)/2}$. Thus, E(Y) will change if the value of σ^2 changes. Note, however, that if the median of the probability distribution is employed as the point estimate of cost, then use of a different variance will have no impact on this value. That is, $M(Y) = e^{\mu}$.

1.6.2.2 Generate Tornado Charts

Other useful displays include tornado charts as shown in Figure 18, where risk elements are displayed according to their relative influence on cost.

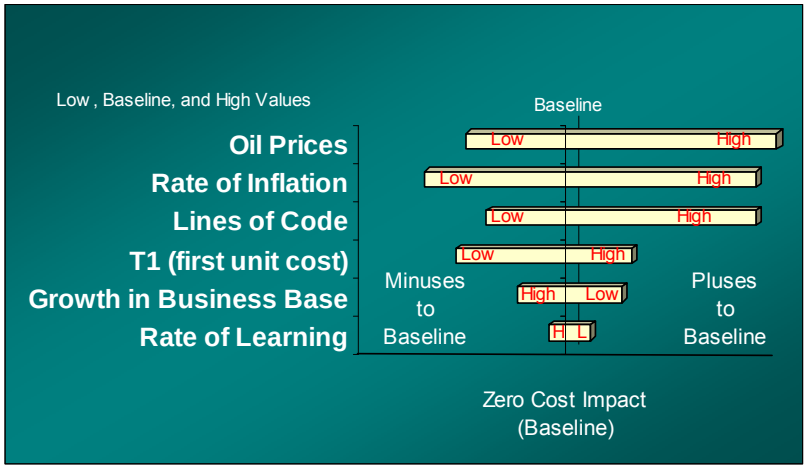

Figure 18- Tornado Chart

1.6.2.3 Generate Other Displays

Other displays, in addition to those presented in Step 1.4, Conduct Risk and Uncertainty Analysis, might include funding profiles and deltas, a comparison of the ICE to the program office estimate, and details on how a Service Cost Position was reached.[25]

1.6.3 Communicate and Defend Results

Communicate and defend the results of analysis through documentation and briefings. Depending on the skill and experience of the analyst, dry-runs for presentations to senior leadership might be required. Scripts, in some cases, might be useful.

Agents.

- Cost Competency
- Program Office or IPT
- Financial, logistics, engineering, and personnel communities
- SYSCOM, OPNAV, SECNAV, and OSD principals
- OSD Cost Assessment and Program Evaluation (CAPE)

- Assistant Secretary of the Navy for Research, Development and Acquisition (ASN

[25] A Service Cost Position (SCP) is required for DON ACAT ID, IC, IA, and selected ACAT II programs. For a description of processes and procedures for generating SCPs, see "Department of the Navy Service Cost Positions," 7 Jan 2010, ASN(FM&C) and ASN(RD&A).

(RD&A))
- Assistant Secretary of the Navy for Financial Management and Comptroller (ASN(FM&C))
- Assistant Secretary of the Navy for Manpower and Reserve Affairs (ASN(M&RA))
- Assistant Secretary of the Navy for Installations and Logistics (ASN(I&E))

Output and Stakeholders.

Output	Stakeholders
• Documentation	All stakeholders
• Presentation media	Stakeholders; senior leadership; cost competency

Exit Criteria.
This sub-process is complete upon delivery of final documentation and upon presentation of results.

Tools.
- Documentation standards.
- Templates for documentation and briefings.

References

- DoDD 5000.01, “The Defense Acquisition System” of 12 May 2003
- DoDI 5000.02, “Operation of the Defense Acquisition System” of 2 December 2008
- DoD 5000.4-M, “Cost Analysis Guidance and Procedures” of 1992
- DoD 5000.4-M-1, “Cost and Software Data Reporting (CSDR) Manual” of Apr 2007
- SECNAVINST 5223.2 of 16 December 2008
- SECNAVINST 5000.2D, “Implementation and Operation of the Defense Acquisition System and the Joint Capabilities Integration and Development System” of 16 October 2008
- OUSD(AT&L)/Acquisition Resource Analysis policy memo “Required Signed and Documented Component-level Cost Position for Milestone Reviews” of 12 March 2009
- Draft MIL-HDBK-881, “Department of Defense Handbook, Work Breakdown Structure”
- “Operating and Support Cost-Estimating Guide,” October 2007, Office of the Secretary of Defense, Cost Analysis Improvement Group
- “Department of the Navy Service Cost Positions,” 7 Jan 2010, ASN(FM&C) and ASN(RD&A)