COVER FOR
ECONOMIC &
SUPPORTING ANALYSIS VOLUME

Contents

Section 1. Economic Analysis 1
1.1 Inflation 1
1.1.1 Definition 1
1.1.2 How to Apply Inflation 1
1.1.3 Additional Resources 3
1.2 Trade Studies 3
1.2.1 Definition 3
1.2.2 Steps for Performing a Trade Study 3
1.2.3 Additional Resources 4
1.3 Cost as an Independent Variable (CAIV) 4
1.3.1 Definition 4
1.3.2 Steps in the CAIV Approach 5
1.3.3 Additional Resources 6
1.4 Learning Curves 6
1.4.1 Definition 7
1.4.2 Calculating the Learning Curve 7
1.4.3 Additional Resources for Learning Curves 9
1.5 Spreading Model (Based on Beta Curve) 9
1.5.1 Beta Curve Definition 9
1.5.2 Methodology 9
1.5.3 Additional Resources 11
1.6 Business Case Analysis 11
1.6.1 Definition 11
1.6.2 BCA Methodology 12
1.6.3 Additional Resources 13
1.7 Present Value 14
1.7.1 Definition 14
1.7.2 Calculating Present Value 14
1.7.3 Additional Resources 16
1.8 Net Present Value (NPV) 16
1.8.1 Definition 16
1.8.2 Calculating NPV 17
1.8.3 Additional Resources 18
1.9 Return on Investment (ROI) Metrics 18
1.9.1 Definition 18
1.9.2 Maximizing ROI 19
1.9.3 Additional Resources 20
1.10 Schedule Analysis 20
1.10.1 Definition 20
1.10.2 Purpose 21
1.10.3 Obtaining a Complete Schedule 21
1.10.4 Good Scheduling Practices 22
1.10.5 Analysis Methods 23
1.10.6 How Schedule Affects Cost 26

1.10.7 Additional Resources....26
1.11 Earned Value Management (EVM)....26
1.11.1 Definition....27
1.11.2 Steps in the EVM Process....28
1.11.3 Additional Resources....28
1.12 Affordability....28
1.12.1 Definition....28
1.12.2 Determining Affordability....29
1.12.3 Additional Resources....29
1.13 Real Option Valuation....30
1.13.1 Definition....30
1.13.2 Calculating the Value of a Real Option....30
1.13.3 Additional Real Option Valuation Reference....31
1.14 Lease Versus Buy Analysis....31
1.14.1 Definition....32
1.14.2 Lease Versus Buy Approach Considerations....32
1.14.3 Additional Resources....32
Section 2. Other Cost Estimating Considerations....33
2.1 Full Cost Accounting....33
2.1.1 Overview of Budget Planning in Full Cost....35
2.1.2 Service Pools....36
2.1.3 Summary....36
2.1.4 For Further Information....36
2.2 Construction of Facilities....37
2.2.1 Overview of the CoF Process....37
2.3 Software Estimating....39
2.3.1 Function Point Analysis (FPA)....40
2.3.2 Effort Estimation....41
2.3.3 Parametric Model Based Estimates....43
2.4 Estimating Operations and Support....43
2.4.1 Estimating O&S Costs for New Systems....44
2.4.2 Operations and Support Cost Estimation Issues/Challenges....47
2.4.3 Understanding the Supply Chain....47
2.4.4 Additional Resources....48

Figures and Tables

Figure 1-1. NASA New Start Inflation Index Excerpt and Example Calculations....2
Figure 1-2. Cost versus Performance 3
Figure 1-3. CAIV Process Tailored to NASA 5
Figure 1-4. CAIV Trade Space....6
Figure 1-5. Beta Curve Cost Spreading....10
Figure 1-6. BCA Framework....12
Figure 1-7. Cost Benefit Analysis Framework 12
Figure 1-8. Relationship between Present Value, Base Year, and Budget Year Dollars....15
Figure 1-9. Compounding and Discounting 16
Figure 1-10. Example of Discounting....16
Figure 1-11. Net Present Value Calculation Example....18
Figure 1-12. Discounted Pay Back Period....19
Figure 1-13. Gantt or Bar Chart....24
Figure 1-14. PERT Chart / Logic Diagram....24
Figure 2-1. Full Cost Simplification Methodology 34
Figure 2-2. Function Point Analysis Summary Diagram 40
Figure 2-3. The Dual Modes of O&S Cost Estimating 44
Figure 2-4. GOTS O&S Cost Model Capability....46

Table 1-1. Slope by Industry....8
Table 1-2. Types of Business Case Analysis: From the GAO Cost Assessment Guide 13
Table 2-1. Full Cost Points of Contact....36
Table 2-2. Converting Between Physical and Logical SLOC 40
Table 2-3. Function Point Advantages and Disadvantages 41
Table 2-4. Effort Adjustment Multipliers for Software Heritage....41
Table 2-5. Software Development Productivity for JPL and NASA Average Projects (Equivalent Logical SLOC)....42
Table 2-6. Software Development Productivity for Industry Average Projects (Equivalent Logical SLOC) 42

Section 1. Economic Analysis

One of the most important tasks for a cost analyst at NASA occurs when he or she performs the analyses described in this volume. These analyses help to make "apples to apples" comparisons of competing alternatives, and allow NASA cost analysts to present investment determinations and subsequent recommendations to decision makers on how estimated costs, benefits, and risks interact with each other for each alternative under consideration.

This volume presents various economic analyses used by NASA cost analysts in the course of their daily work in addition to other cost estimating techniques. Each section presented in this volume first defines the economic analysis or cost estimating technique, presents how the economic analysis or cost estimating technique is done, and concludes with additional resources for the NASA cost analyst to turn to for more information or in-depth discussions.

1.1 Inflation

NASA programs and projects cover many years. To have a meaningful discussion of cost, it is important that cost analysts calculate and apply inflation to their cost estimates.

> Inflation refers to a general rise in prices measured against a standard level of purchasing power and is measured by comparing two sets of goods at two points in time, and computing the increase in cost.

1.1.1 Definition

Inflation refers to a general rise in prices measured against a standard level of purchasing power and is measured by comparing two sets of goods at two points in time, and computing the increase in cost.

1.1.2 How to Apply Inflation

The NASA New Start Inflation Index has been created for the purposes of estimating new efforts and for normalizing historical cost from prior missions. The factors contained in this index should not be used to estimate NASA Civil Servant personnel costs or 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.

Figure 1-1 is an example of the calculation performed by the NASA New Start Inflation Index's Excel spreadsheet. The first example shows the escalation of costs, using inflation factors, from 1999 (Base Year [BY][1]) to 2007 (Then Year [TY][2]). The second example shows the discounting of costs from 2007 (BY) to 1999 (TY). It is important to note that the NASA New Start Inflation Index provides the compounded inflation rate given a specified BY and TY (e.g., the compounded inflation rate for a 1999 BY and a 2007 TY is 30.534%).

	Year	Amount
From	1999	100.000
To	2007	130.534

YEAR	1999	2000	2001	2002	2003	2004	2005	2006	2007
INFL.RATE	2.0%	3.3%	3.3%	3.5%	3.9%	4.2%	3.0%	2.7%	3.2%
FACTORS	1.020	1.033	1.033	1.035	1.039	1.042	1.030	1.027	1.032

= 1.033 * 1.033 * 1.035 * 1.039 * 1.042 * 1.030 * 1.027 * 1.032
= 1.30534

Base Year (1999) Cost $ 125,000.00
Then Year (2007) Cost $ 163,167.50 = 125,000 * 1.30534

	Year	Amount
From	2007	100.000
To	1999	76.608

YEAR	1999	2000	2001	2002	2003	2004	2005	2006	2007
INFL.RATE	2.0%	3.3%	3.3%	3.5%	3.9%	4.2%	3.0%	2.7%	3.2%
FACTORS	1.020	1.033	1.033	1.035	1.039	1.042	1.030	1.027	1.032

= 1 /(1.033 * 1.033 * 1.035 * 1.039 * 1.042 * 1.030 * 1.027 * 1.032)
= 0.76608

Base Year (2007) Cost $ 125,000.00
Then Year (1999) Cost $ 95,760.00 = 125,000 * 0.76608

Figure 1-1. NASA New Start Inflation Index Excerpt and Example Calculations

1 *A point of reference year whose prices form the basis for adjusting costs or prices from other years.*

2 *Includes a slice of inflation to cover escalation of expenditures over a multiyear period.*

1.1.3 Additional Resources

- NASA New Start Inflation Index is updated annually on the NASA Cost Analysis Steering Group website (requires membership) https://secureworkgroups.grc.nasa.gov/casg?go=156800

1.2 Trade Studies

Trade studies are at the heart of the affordability process, and their solutions are often represented in a multi-dimensional trade space bounded by a cost element and by one or more performance parameters. Figure 1-2 illustrates a simplified, two-dimensional trade space[3] with a plot connecting candidate design alternatives. A multi-dimensional trade space may be substituted to show the interaction of multiple cost drivers, including performance, schedule, and risk.

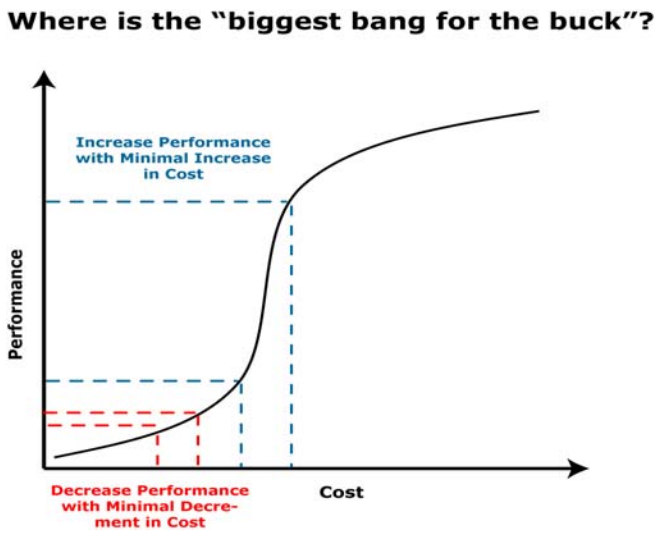

Figure 1-2. Cost versus Performance

Solutions (data points) at the far left of the trade space may show alternatives that look attractive from a cost perspective but that may not satisfy even the threshold (minimal required) 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 justified.

1.2.1 Definition

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

1.2.2 Steps for Performing a Trade Study

Cost estimates are key inputs during cost/performance trade studies, used to determine the most realistic and cost effective mission architectures and system designs. The objective of a trade

[3] *In real life, the alternatives shown may not be readily connected because their attributes are not orthogonal, but it helps to sort them out by establishing which alternatives offer only marginal performance improvement with relatively large cost expenditures.*

study is to obtain the merit of the worth (in a single figure) of each candidate and to select the one having the greatest relative value. The steps of conducting a trade study include:

1. Define the purpose.
2. State the problem.
3. Describe the selection scheme and criteria used.
4. Define the alternatives.
5. Estimate the costs and assess the performance of each alternative
6. Determine the preferred approach.
7. Formulate recommendation(s).

A cost/performance trade within a CAIV study (described in Section 1.4 below) can be viewed as being a special application of the cost/performance trade, one in which the cost is fixed, (i.e., independent) and the three other variables in the CAIV "equation", performance, schedule and risk levels, are dependent on that fixed cost. A less formal process than a traditional CAIV analysis can also be considered and used, if appropriate. Referred to as Business Case Analysis and Cost-Effectiveness Analysis (described in Section 1.8), this discipline covers studies often referred to as Target Costing and Value Engineering.

1.2.3 Additional Resources

- NPR 7120.5 NASA Program and Project Management Processes and Requirements
  http://nodis.hq.nasa.gov/displayDir.cfm?Internal_ID=N_PR_7120_005D_

- OMB Circular A-94
  http://www.whitehouse.gov/omb/circulars/a094/a094.html

1.3 Cost as an Independent Variable (CAIV)

The purpose of a CAIV study is to ensure that an affordable design solution meets threshold performance requirements. One key tenet to remember is that design can converge on cost rather than allowing cost to converge on design. In applying the CAIV process, NASA program leadership will be able to demonstrate the following:

- Performance is not sacred and certain performance requirements may be challenged if significant cost savings are possible

- The CAIV process continually challenges the requirements when affordability is at stake

1.3.1 Definition

CAIV is a system acquisition process that the U.S. government embraced in the mid-1990s to counter massive program acquisition and sustainment cost overruns. This process has been adopted by aerospace and 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, 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.

1.3.2 Steps in the CAIV Approach

Figure 1-3 depicts, at a high level, the CAIV process tailored to NASA.

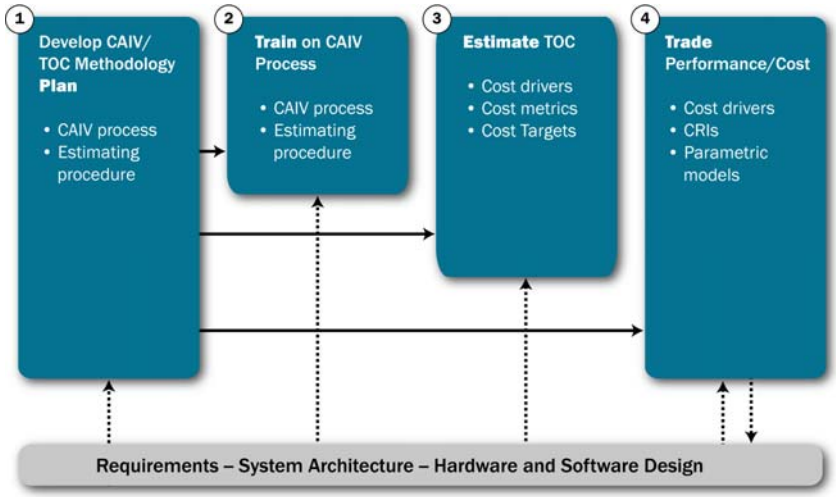

Figure 1-3. CAIV Process Tailored to NASA

Step 1 involves high-level planning and development of the CAIV/Total Ownership Cost (TOC) methodology that the contractor will use, the establishment of coarse goals and broad responsibilities, and agreement (buy-in) on CAIV procedures that the contractor will follow.

Step 2 involves CAIV training for systems engineers, technical discipline engineers, and managers within NASA. In order to for CAIV to be applied accurately and consistently, it is important that awareness training be provided at all levels. CAIV is tied closely to the existing parametric estimating process within the NASA Centers and its cost analysis support contractors.

Step 3 uses the cost baseline for the program and holds that variable (cost) constant while allowing identified cost drivers to be manipulated to see their effect on cost. A hierarchy of affordability metrics can be derived from this baseline as an outcome of the CAIV and consists of the following:

- Cost Targets – absolute values of cost, with a probability dimension, for specific programs, phases, contracts, or activities. An example of a Cost Target is to procure the Crew Exploration Vehicle (CEV) for a total acquisition cost of $9B (in Constant Year 2007 dollars), including all government and contractor expenses. Cost Targets can be expressed as a range of values that bound the "trade space;" the boundaries can be defined as follows:
  - Threshold Cost – the absolute highest cost allowable for an element if overall program estimated LCC goals can be achieved. Breaching the threshold cost gives reason to cancel the element or project
  - Objective Cost – a lower Cost Target that would be more difficult to achieve but that could offset overruns elsewhere in the program architecture
  - Cost Performance Measures (CPMs) – measures that combine absolute cost values with relevant performance measures. Examples include dollars per mission or flight, dollars per equivalent source line of software code (SLOC) developed or maintained, and dollars per pound of hardware developed or produced. These measures will change over time to reflect changing requirements, evolving design, and maturation of the program

Step 4 integrates CAIV trades with the mainstream of systems engineering trades. When managers have a complete understanding of system-level cost drivers and the application of experience-calibrated parametric cost estimating models, they can oversee the trade process, ensuring that affordable design options are identified and objectively considered in the trade process.

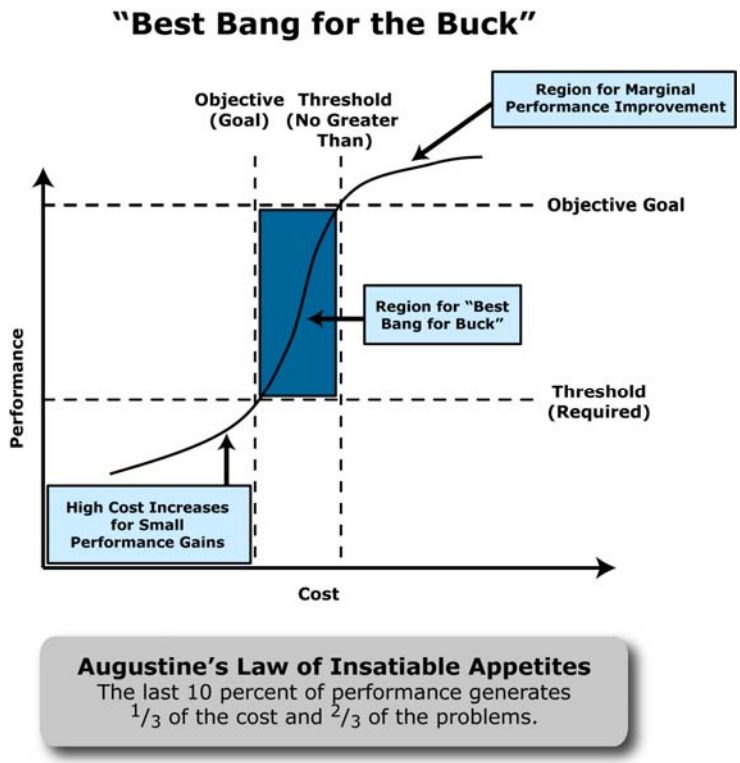

Figure 1-4. CAIV Trade Space

Figure 1-4 demonstrates the overall trade space that is defined by the objective and threshold performance parameters, as well as by the objective and threshold cost values. If enough alternatives can be compared, their relationship might indicate a curve that may detect the "knee," or point of diminishing return, i.e., where a slight performance improvement incurs an unacceptable cost increase. Initial performance-cost trades may be limited to the Key Driving Requirements (KDR) to focus on primary cost drivers and to validate (or challenge) the main requirements based on affordability.

1.3.3 Additional Resources

- Cost As An Independent Variable (CAIV) Principles and Implementation
  http://ceh.nasa.gov/downloadfiles/NASA_CEH_Downloadable_Files.htm#NASA_CEH_Downloadable_Files_2.htm

- Cost as an Independent Variable: Principles and Implementation
  http://www.dau.mil/pubs/arq/2000arq/kaye.pdf

- Controlling Costs – A Historical Perspective
  http://www.dau.mil/pubs/pm/pmpdf96/kausal2.pdf

1.4 Learning Curves

Learning curves, sometimes referred to as improvement curves or progress functions, are based on the concept that resources required to produce each additional unit decline as the total number of units produced increases.

1.4.1 Definition

The learning curve concept is used primarily for uninterrupted manufacturing and assembly tasks, which are highly repetitive and labor intensive. The learning curve effect states that the more times a task has been performed, the less time will be required on each subsequent iteration.

1.4.2 Calculating the Learning Curve

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

The two types of learning curve approaches are the cumulative average curve and the unit curve. The main difference between the two approaches is as indicated by their names, the cumulative average curve calculates the average unit value for the entire curve to a set point while the unit curve calculates the unit value for a specific quantity point. In other words, in the cumulative average curve, the cumulative average cost is reduced by the some constant percentage and in the unit curve, unit cost is reduced by the same constant percentage.

Over the first few units, the cumulative average curve equation will show a much greater reduction in cost than an operation following unit curve equation using the same slope. This difference decreases as the quantity increases.

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

- High proportion of manual labor
- Uninterrupted production
- Production of complex items
- No major technological change during the production repetitions
- Continuous pressure to improve

Cumulative Average Curve (T.P. Wright, traditional approach) calculates average unit value of production lot:

$\overline{Y}$ = Cum average unit value of the Xth unit

A = Theoretical first unit value (T1)

X = Cumulative Number of Units

b = Log(slope)/Log (2)

$$\overline{Y} = A * X^{b}$$

Unit Curve (J.R. Crawford / Boeing Approach) calculates unit value of specific point on curve:

Y = Unit value of the Xth unit

A = Theoretical first unit value (T1)
X = Unit number
b = log(slope)/log(2)

$$Y = A * X^b$$

The cumulative number of units produced can be used in the Unit Curve equation instead of the Xth unit to find the unit cost of a particular unit, but determining the unit cost of the last unit produced is not useful in determining the cost of a batch of units. The unit cost of each unit in the batch would have to be determined separately. This is obviously not a practical way to solve for the cost of a batch that may involve hundreds, or even thousands of units. A practical approach involves calculating the midpoint of the lot. Thus, the cost of the lot is found by calculating the cost of the midpoint unit and then multiplying by the number of units in the lot.

Midpoint Value is the point on the curve where the unit value represents the average of all units in the lot:

MPV = True lot midpoint value
X_e = End point (last unit in the lot)
X_b = Beginning point (first unit in lot)
b = log(slope)/log(2)

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

Rules of Thumb

Note that the Slopes by Industry listed below can be affected by the maturity of the product design, its manufacturing process, and the degree of automation.

Table 1-1. Slope by Industry

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

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

Approximation/Arithmetic Mean Approach:

Shortcut to calculating the midpoint

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

For subsequent lots: MPV = lot size / 2 + (# of prior units)

1.4.3 Additional Resources for Learning Curves

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

- Learning Curve Calculator
  http://cost.jsc.nasa.gov/learn.html
- Article on The Learning Curve
  http://www.computerworld.com/news/2001/story/0,11280,61762,00.html
- Department of Energy Office of Science Article on Learning Curves
  http://www.sc.doe.gov/sc-80/sc-82/430-1/430-1-chp21.pdf
- Defense Procurement & Acquisition Policy Contract Pricing Reference Guide
  http://www.acq.osd.mil/dpap/contractpricing/vol2chap7.htm#7.2
- FAA Pricing Handbook
  http://fast.faa.gov/pricing/98-30c18.htm

1.5 Spreading Model (Based on Beta Curve)

The Beta curve, also known as the Beta distribution curve, was developed at Johnson Space Center (JSC) in the 1960s. It is used for spreading parametrically derived cost estimates and for Research and Development (R&D) type contracts where costs build up slowly during the initial phases, and then escalate as the midpoint of the contract approaches.

1.5.1 Beta Curve Definition

A Beta curve is a combination of percent spent against percent time elapsed between two points in time. Although the actual mathematical formulation of the Beta curve is somewhat complicated, its shape can be specified by two easy-to-understand parameters: cost fraction, or the fraction of dollars spent by 50% time; and a peakedness coefficient, a measure of the peakedness of the curve shape.

1.5.2 Methodology

As an example, if estimating the software for a satellite program, a rule of thumb is to use a 60/40 Beta curve (60% of the funds spent in the first half of the project and the other 40% in the second half) for space software costs and 40/60 Beta Curve (40% of the funds spent in the first half of the project and the other 60% in the second half) for ground software costs spread between two designated dates (e.g., January 1, 2002 to December 31, 2006). This example is mapped out on the table below.

Beta Curve Cost Spread Factors

Spread Factor Categories

- (First Half/Second Half)
- 50:50
- 60:40 (40:60 use percents in reverse sequence)
- 70:30 (30:70, use percents in reverse sequence)

		Annual Factor (percent) By Year									
SPREAD	**Yrs**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
50:50	1	100									
	2	50	50								
	3	21	58	21							
	4	10	40	40	10						
	5	6	26	36	26	6					
	6	4	17	29	29	17	4				
	7	3	12	22	26	22	12	3			
	8	2	9	17	22	22	17	9	2		
	9	1	7	13	19	20	19	13	7	1	
	10	1	5	11	15	18	18	15	11	5	1
60:40	1	100									
	2	60	40								
	3	31	53	16							
	4	19	41	32	8						
	5	12	31	33	20	4					
	6	9	23	28	24	13	3				
	7	6	17	24	24	18	9	2			
	8	5	14	20	22	19	13	6	1		
	9	4	11	16	19	19	15	10	5	1	
	10	3	9	14	17	17	16	12	8	3	1
70:30	1	100									
	2	70	30								
	3	45	42	13							
	4	28	42	23	7						
	5	18	38	25	14	5					
	6	12	32	26	17	10	3				
	7	9	26	25	18	12	7	3			
	8	7	21	24	18	13	9	6	2		
	9	5	16	23	18	14	10	7	5	2	
	10	4	13	21	18	14	11	8	6	4	1

Figure 1-5. Beta Curve Cost Spreading

Another way of spreading costs using the Beta curve is to express the cumulative cost fraction as a function of the cumulative time fraction, T:

Cum Cost Fraction = 10T2(1 – T)2(A + BT) + T4(5 - 4T) for $0 \le T \le 1$

Where:

A and B are parameters (with $0 \le A + B \le 1$)

T is fraction of time

A=1, B= 0 gives 81% expended at 50% time

A=0, B= 1 gives 50% expended at 50% time

A=0, B= 0 gives 19% expended at 50% time

Regardless of with method is used to calculate the shape of the Beta curve, it is important to be aware of the potential risks introduced with an inefficient Beta curve. For example, a Beta curve that provides too little on the front end of the curve for a project with challenging technical designs can result in fewer tests that, in turn, can result in failures and cost overruns during integration.

1.5.3 Additional Resources

- NASA Systems Engineering Handbook: Beta Curve formula and methodology
  http://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/19960002194_1996102194.pdf

- Online Beta Curve Cost Spreading Calculator
  http://cost.jsc.nasa.gov/beta.html

1.6 Business Case Analysis

Business Case Analysis (BCA) is a method to aid decision makers in the comparison of alternative approaches, options, or projects.

1.6.1 Definition

A BCA considers not only all life cycle costs identified by a Life Cycle Cost Estimate (LCCE), but also other quantifiable and non-quantifiable benefits. It should be unbiased by considering all possible alternatives.

Benefits is an economic term that is generally understood to be measured in monetary units. Effectiveness is a multi-attributed construct used when the consequences of the choice are not or cannot be measured in dollars. Often, the terms benefits and effectiveness are used as if they are interchangeable and synonymous—they do in fact have different definitions within the cost estimating community. A valuable reference for cost benefit analysis guidelines in federal programs is OMB Circular A-94. To quote from OMB Circular A-94, Guidelines and Discount Rates for Benefit-Cost Analysis of Federal Programs[4], "benefit-cost analysis is recommended as the technique to use in a formal economic analysis of government programs or projects". Benefit-Cost Analysis of government programs is required by Circular A-94 in order to promote efficient resource allocation through well-informed decision-making by the federal government – this is the goal Circular A-94 and benefit-cost analyses are meant to achieve. In other words, OMB

4 *http://www.whitehouse.gov/omb/circulars/a094/a094.html*

wants to ensure that the government spends, i.e., invests, the taxpayers' money wisely when agencies decide which programs to fund.

1.6.2 BCA Methodology

Figure 1-5 illustrates the simple principle behind a BCA—to determine the preferred alternative among various alternatives based upon cost and benefit data.

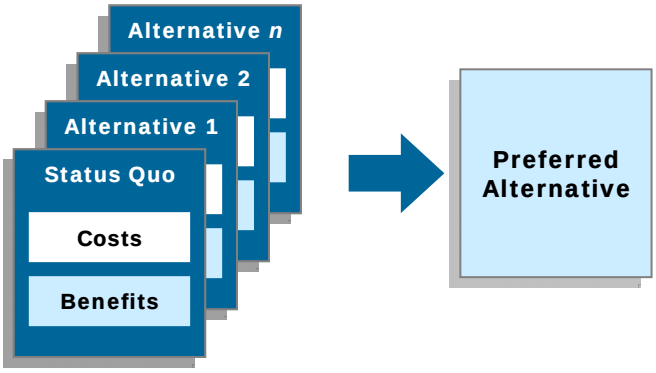

Figure 1-6. BCA Framework

As shown in Figure 1-7 on the next page, the benefit streams that are expected to flow from investments are typically comprised of multiple components, some of which can be characterized in terms of cost savings and cost avoidances (i.e., in financial terms), others that can be quantified, but not in cost or financial terms, and still others that simply can not be quantified.

For the benefit streams that can be quantified in financial terms, the concept of Present Value is applied to investment cash flows (costs) and cash flows from cost savings and cost avoidances (benefits) on a comparable basis with respect to timing.

The development of Return on Investment (ROI) metrics, typically in the form of a ratio, can help decision makers select among investment alternatives. ROI ratios, such as Savings/Investment and Payback Ratio can be used to identify attractive alternatives. The computation of any traditional ROI metrics can only take into account outcomes that are characterized in cost or financial terms. What is not immediately evident from Figure 1-7 is the fact that the generation of an ROI metric can only result from a comparison of two or more alternatives, one of which serves as a reference point and is typically defined as the "Business as Usual' or the Status Quo Alternative.

Financially quantifiable benefits and ROI metrics should not be the sole basis leaders rely upon when selecting alternatives for NASA. To paint the complete picture, the contribution to effectiveness of quantifiable, non-financial benefits and the contribution to effectiveness of typically non-quantifiable benefits should be measured using decision framework techniques such as the Analytic Hierarchy Process (AHP) or the Multi-Attribute Utility Theory (MAUT).

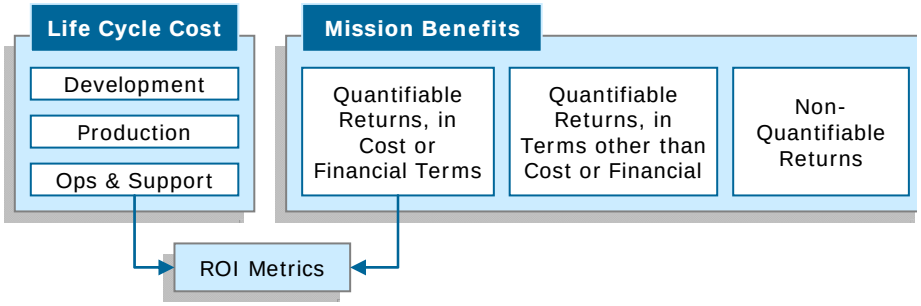

Figure 1-7. Cost Benefit Analysis Framework

These decision framework techniques bring structure to complex problems where multiple alternatives need to be considered across a range of goals and objectives. They also help to develop stakeholder buy-in and understanding of the project complexities and the decision making process. The techniques establish a structure that articulates and prioritizes the goals and objectives that different alternatives are expected to meet, and provide a mechanism to develop normalized scores of effectiveness.

The quantification of financial benefits, development of ROI metrics, and the measurement of the effectiveness of non-financial benefits and non quantifiable benefits serve the overall objective of making a sound recommendation in a BCA.

Table 1-2. Types of Business Case Analysis: From the GAO Cost Assessment Guide

Different Types of Business Case Analyses	Description
Analysis of Alternatives (AoA) Level of Effort: *Requires a large team, may take many months to accomplish, and addresses the full LCCE*	An AOA compares the operational effectiveness, suitability, and life-cycle cost estimate of alternatives that appear to satisfy established capability needs. Its two major components are a cost effectiveness analysis and a cost analysis. AOAs attempt to identify the most promising of several conceptual alternatives; its analysis and conclusions are then typically used to justify initiating an acquisition program. An AOA also looks at mission threat and dependencies on other programs. Many times, AOAs cannot quantify benefits. For example, there is no agreed upon monetary value for what a human life is worth. In this case, a cost-effectiveness analysis is more appropriate. CEAs are conducted whenever it is unnecessary or impractical to consider the dollar value of the benefits. This happens when the various alternatives have the same annual monetary benefits. Both the AOA and CEA should address each alternative's advantages and disadvantages and the associated risks and uncertainties of how these might influence the comparison.
Economic Analysis (EA) Level of Effort: *Requires a large team, may take many months to accomplish, and addresses the full LCCE*	This is a conceptual framework for systematically investigating problems of choice. Posing various alternatives for reaching an objective, it analyzes the life cycle cost estimate and benefits of each one usually with a Return On Investment (ROI) analysis. Present Value is also an important concept. Since there is time-value to money, it is necessary to determine when the expenditures for the alternatives will be made. Economic analysis expands cost analysis by examining the effects of the time-value of money on investment decisions. After cost estimates have been generated, they must be time-phased to allow for alternative expenditure patterns. Assuming equal benefits, the alternative whose Present Value cost is least is the most desirable, because it implies a more efficient allocation of resources.

1.6.3 Additional Resources

- NASA NPR 2830.1 NASA Enterprise Architecture Procedures - APPENDIX E: Approaches for Conducting Alternatives Analysis http://nodis3.gsfc.nasa.gov/displayDir.cfm?Internal_ID=N_PR_2830_0001_&page_name=AppendixE

- NPR 7120.5 NASA Program and Project Management Processes and Requirements http://nodis.hq.nasa.gov/displayDir.cfm?Internal_ID=N_PR_7120_005D_

- NASA Business Case Guide for Facilities Projects http://www.hq.nasa.gov/office/codej/codejx/Assets/Docs/Case_Guide_4-20-06.pdf
- OMB Circular A-94 http://www.whitehouse.gov/omb/circulars/a094/a094.html
- GAO Cost Assessment Guide
- Institute of Marketing & Innovation http://www.boku.ac.at/mi/ahp/ahptutorial.pdf
- An Analytical Hierarchy Process Approach to the Analysis of Quality in Telecommunications Systems http://ieeexplore.ieee.org/iel2/645/6841/00276672.pdf?arnumber=276672
- Multiattribute Utility Theory Tutorial http://ait.unl.edu/dolson/mcdm.ppt

1.7 Present Value

The Present Value concept captures the time value of money by adjusting through compounding and discounting cash flows to reflect the increased value of money when invested.

1.7.1 Definition

The Present Value of a cash flow reflects in today's terms, the value of future cash flows adjusted for the cost of capital. In essence, the time value of money reflects the fact that money in hand today is more valuable than an identical amount of money received in the future and that benefits and costs 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 Present Value. The time value of money reflects the idea that a dollar in hand today is worth more than a dollar in the future, even after making adjustments for inflation.

1.7.2 Calculating Present Value

To determine the Present Value of money, a discount rate must be applied to costs. There are two different types of discount rates:

Real discount rate is adjusted to eliminate the effects of expected inflation and used to discount Constant Year dollars or real benefits or costs.

Nominal Discount Rate
– Expected Inflation Rate
= Real Discount Rate

A nominal discount rate is adjusted to reflect inflation used to discount Then Year dollars or nominal benefits and costs.

Figure 1-8 illustrates this relationship between Present Value, Base Year, and Budget Year dollars.

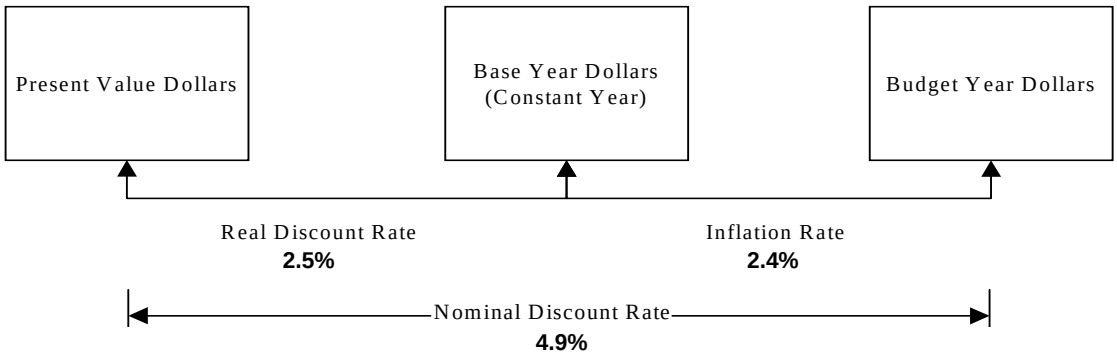

Figure 1-8. Relationship between Present Value, Base Year, and Budget Year Dollars

Budget Year dollars incorporate the effects of inflation and adjust for the time value of money – the concept that a given amount of money is worth more today than in the future due to inflation. Base Year dollars are adjusted for the time value of money, and Present Value dollars have the effects of inflation and time value of money removed.

Real and nominal discount rates are provided by the OMB in Circular No. A-94. The rates are updates each calendar year and can be found at: http://www.whitehouse.gov/omb/circulars/a094/a094_appx-c.html.

The purpose and goal of this Circular is to promote efficient resource allocation through well-informed decision-making by the federal government. It provides general guidance for conducting benefit-cost and cost-effectiveness analyses. It also provides specific guidance on the discount rates to be used in evaluating federal programs whose benefits and costs are distributed over time. The general guidance will serve as a checklist of whether an agency has considered and properly dealt with all the elements for sound benefit-cost and cost-effectiveness analyses.

The Present Value of an investment is calculated from the time series of projected cash flows using discount rates specified in the OMB Circular A-94, Appendix C http://www.whitehouse.gov/omb/circulars/a094/a094_appx-c.html

To estimate Present Value, future benefits and costs must be discounted. Discount factors can be reflected in real or nominal terms as defined by OMB Circular A-94 Appendix C. The discount rate used depends on the type of dollars to be adjusted.

Discounting translates projected cash flows into Present Value terms using specified discount factors., As illustrated Figure 1-9, the discount factor is equal to 1/(1+ i)n or (1+ i)-n where i is the interest rate and n is the number of years from the date of initiation for the project. Figure 1-10 provides an example of how discounting is applied.

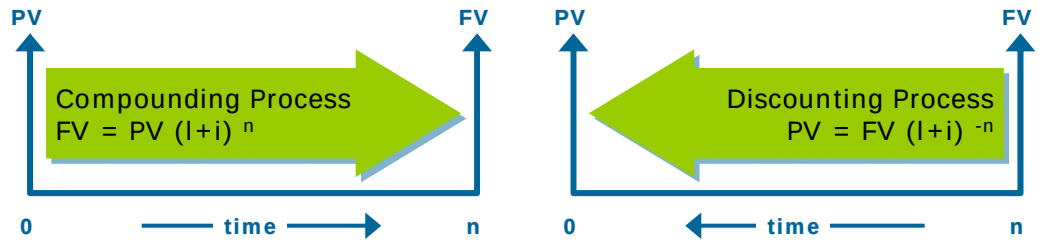

Figure 1-9. Compounding and Discounting

Costs are in Budget Year Dollars

	2006	2007	2008	2009	2010
Total Annual Outlays	**$250,000**	**$256,000**	**$262,144**	**$268,435**	**$274,878**
E-O-Y Discount Factor	0.9533	0.9088	0.8663	0.8258	0.7873
Present Value	$238,322	$232,642	$227,098	$221,686	$216,403
Cumulative Present Value	$238,322	$470,965	$698,063	$919,749	$1,136,151
	0.9533 = 1 / (1+4.9%)^1	0.9088 = 1 / (1+4.9%)^2	0.8663 = 1 / (1+4.9%)^3	0.8258 = 1 / (1+4.9%)^4	0.7873 = 1 / (1+4.9%)^5

4.9% Nominal Discount Rate
End of Year Discount Factor

TOTAL ANNUAL OUTLAY
$1,311,457

NPV
$1,136,151

Figure 1-10. Example of Discounting

1.7.3 Additional Resources

- NASA NPR 2830.1 NASA Enterprise Architecture Procedures - APPENDIX E: Approaches for Conducting Alternatives Analysis http://nodis3.gsfc.nasa.gov/displayDir.cfm?Internal_ID=N_PR_2830_0001_&page_name=AppendixE
- GAO Cost Assessment Guide
- OMB Circular A-94 http://www.whitehouse.gov/omb/circulars/a094/a094.html

1.8 Net Present Value (NPV)

NPV allows the comparison of different alternative's costs as it reflects the total cost of an alternative over a given timeframe of analysis in terms of today's dollars. It is important to note that benefits used in the NPV calculation be quantified in cost/financial terms.

1.8.1 Definition

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

1.8.2 Calculating NPV

To estimate NPV, future benefits and costs must be discounted. Discount factors can be reflected in real* or nominal terms as defined by OMB Circular A-94 Appendix C. The discount rate used depends on the type of dollars to be adjusted.

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

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

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

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

Mathematically, NPV is calculated as shown:

PV(Annual Benefits)
– PV(Annual Cost)
NPV

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

[PV(Internal Project Cost Savings, Operation) + PV (Mission Cost Savings)]
– PV(Investment)
NPV

Projects with positive NPV increase social resources are generally preferred. Projects with negative NPV should generally be avoided."

The simplified NPV accept/ reject criterion is:

NPV > 0 → Accept
NPV < 0 → Reject

Figure 1-11 illustrates the NPV calculations. Investment costs and cost savings are in Budget Year dollars (include the inflation and the time value of money, i.e., nominal inflation rate). The Present Value of the sum of the difference between the initial investment costs and cost savings equals the NPV.

Costs are in Budget Year Dollars							
Year	**2006**	**2007**	**2008**	**2009**	**2010**	**Total**	**NPV**
Initial Investment	$250,000	$256,000	$262,144	$268,435	$274,878	$1,311,457	$1,136,151
Cost Savings	$0	$0	$0	$760,678	$776,653	$1,537,331	$1,239,635
Savings Minus Investment	-$250,000	-$256,000	-$262,144	$492,243	$501,775	$225,873	$ 103,484
E-O-Y Discount Factor	0.9533	0.9088	0.8663	0.8258	0.7873		
Present Value of Savings Minus Investment	-$238,322	-$232,642	-$227,098	$406,516	$395,031		$103,484
NPV	**$103,484**						

Figure 1-11. Net Present Value Calculation Example

1.8.3 Additional Resources

- NASA NPR 2830.1 NASA Enterprise Architecture Procedures - APPENDIX E: Approaches for Conducting Alternatives Analysis http://nodis3.gsfc.nasa.gov/displayDir.cfm?Internal_ID=N_PR_2830_0001_&page_name=AppendixE
- GAO Cost Assessment Guide
- OMB Circular A-94 http://www.whitehouse.gov/omb/circulars/a094/a094.html

1.9 Return on Investment (ROI) Metrics

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

1.9.1 Definition

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

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

It is the incremental financial gain from an investment, divided by the cost of the investment. The ROI for a project using the figures from Figure 1-11 equals 9.1%.

Present Value of the investment = $ 1,136,151
Present Value of the cost savings = $ 1,239,635
NPV = $ 103,484
ROI = $ 103,484 / $ 1,136,151 = 9.1%

The Savings to Investment Ratio (SIR), a popular ROI metric, represents the ratio of savings to investment. In terms the basic NPV formula, "Savings" represents PV of the cost savings and "investment" is PV of the investment costs.

SIR = PV cost savings/PV investment
SIR = $ 1,239,635/$ 1,136,151 = 1.09

Computing the amount of time it takes for a project to pay for itself (or return its initial investment) is another commonly used criterion for selecting among alternative courses of action. Typically, the relevant time period is expressed in terms of the number of years it takes before an investment breaks even. Assuming that one is using discounted cash flows as the basis for the calculation of the payback period, the basic question to be answered is at what point in time do the PV(cost savings) equal the PV(initial investment)? In the simplest of cases, the benefits (or returns) begin predictably at the completion of the investment phase and occur in an equal amount each time period. However, in the analyses we typically do, especially for large projects that take years to complete, benefits begin accruing prior to completion of the investment phase and do not occur in equal annual amounts. In both simple and complex situations, the Payback Period in years, x, can be found in accordance with the following formula (where t = time periods in years):

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

This formula may require solution by iteration and is likely to result in an answer that represents a fraction of a year and is found by interpolation. The mathematically correct answer to this equation can also be portrayed graphically in a form that generates a more approximate answer. An example of such a graph is shown in Figure 1-12.

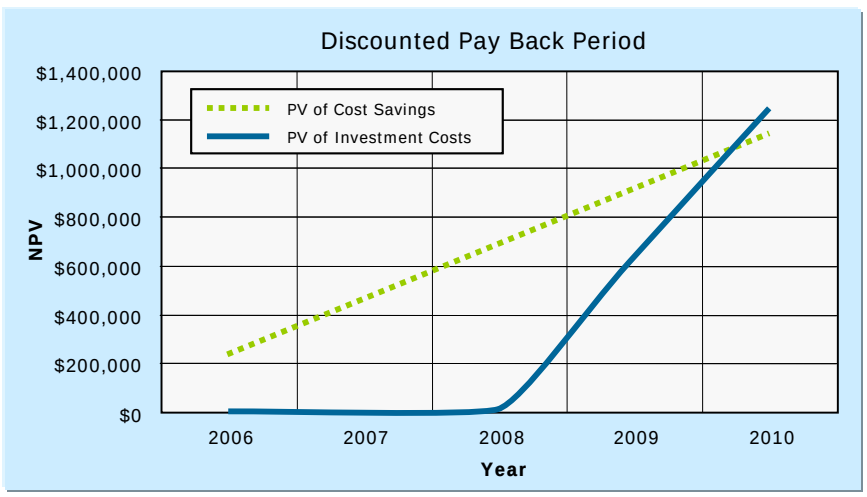

Figure 1-12. Discounted Pay Back Period

1.9.2 Maximizing ROI

The ROI of an investment can be maximized by:

- Minimizing Costs
- Maximizing Returns
- Accelerating Returns

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

1.9.3 Additional Resources

- GAO Cost Assessment Guide
- Capability-Development Return on Investment for the NASA Aeronautics Program http://ieeexplore.ieee.org/iel5/10446/33170/01562857.pdf?isnumber=&arnumber=1562857

- Return on Investment for Software IV&V http://pmchallenge.gsfc.nasa.gov/Docs/2006attendee-presentations/2006presentationsCD-attendee/Ken.Costello.pdf

1.10 Schedule Analysis

Project schedules play an important role in the development of any project. The cost estimator needs to understand how to estimate schedule realism as well as to understand the effects proposed compressions or delays in a project schedule will have on cost. A cost estimator/analyst must be able to quantify the impacts that schedule changes will have on the cost and risks of the project and translate them in terms of impact to the cost estimate. Schedule analysis should occur throughout the life cycle of a project. Many software tools exist to track, calculate, and predict impacts to schedule and for every tool there are multiple methodologies for each to be effective, but before any of these tools can be used, a firm understanding of the WBS is imperative as well as the resources needed and the dependencies among the planned elements. These interdependencies are critical to successful project planning.

In every industry area, there is a body of knowledge that associates the accomplishment of known work efforts with a time duration. In some industries, there are books recording industry standards for use by cost and schedule estimators. Interviewing those who have had experience with similar projects is an effective way to determine how long things should take.

A properly resource loaded and complete scope-defined schedule is vital to the execution and success of any project or technical task order. For effective project controls, the scheduler and the cost estimator must work in concert in the development of the work flow of each component of the project's scope. The final project costs will be determined by the identification and validation of direct and indirect labor, materials, and other direct costs. This identification and validation must be performed in a time-phased evaluation of the schedule and its resources. The potential costs for initial project risks and requirements external to the project must be identified, documented, and quantified. During the execution of the project, these known risks and external requirements must be monitored and validated in conjunction with new, modified, or deleted schedule and cost related project issues. The schedule and resource analysis is an on-going component of project management controls that are essential to the successful evaluation of the project's estimated final delivery date and cost.

1.10.1 Definition

Schedule analysis is the analysis, validation, and updating of the intended work flow and resource loading plan that are established with the project management and team, and all internal and external shareholders in the proposal phase of the project. All known scope

requirements, risks, and assumptions should be documented during the inception of the schedule and cost development. The schedule, resource loading, and associated costs should be baselined shortly after project award to provide a historical perspective of the intended work and cash flow plans. The schedule and resource plans are dynamic and will be impacted and adjusted during the execution of the project through changes to assumptions, discovery of unknown internal and external issues, and reassessment of the initial plan. Any deviation from this baseline must be analyzed to ensure the resource and cost components are not impacted. The identified schedule deviations and cost impacts should be presented in a timely manner to project management and any internal or external shareholders. The consistent and validated schedule and cost analyses will provide valuable insight to the project management team on potential delays or improvements to interim milestone and project completion schedule and cost forecasts.

1.10.2 Purpose

A project schedule validates that the project is executing to the plan. Any deviation from the schedule likely introduces cost and technical risks to the project. The purpose of schedule analysis is to identify these areas of potential cost impact and account for them in the cost estimate by manipulating impacts to risk or degree of difficulty of design in most software estimating suites. When a project is completed early, there may be cost savings associated with using fewer resources, unless resources were fully utilized in a more compressed time period. More often, schedules impact cost when projects are late and more resources are consumed in an effort to come in on time or when the timeframe is expanded to make time to catch up on the tasks.

For example, imagine a project that is scheduled to be completed in one year. Instead, assume that the project is actually completed in one year and three months. If the original schedule was used to estimate total costs, then there are three months of cost unaccounted for in the original estimate. Even if no additional project materials were necessary, there would still be three months of time-related costs for labor, facilities, utilities, etc., which were not included in the original estimate. Schedule analysis helps answer the questions of how long will the project be

1.10.3 Obtaining a Complete Schedule

To conduct a detailed schedule analysis, the cost estimator needs to first verify that there is a schedule with a completion date and that the schedule is complete. A complete schedule should cover the entire scope of work to be performed – or the lifecycle of the estimate being conducted. It should have defined all logical dependencies between the inner tasks, such as specifying a predecessor and successor and defining the relationship type (e.g., finish to start, finish to finish etc.). A complete schedule should also identify external dependencies, which are those things that are outside the control of the project management but that can influence the project's success.

To create a complete schedule, detailed information related to the project management and technical approach needs to be defined. To determine if the schedule is complete (and accurate), the cost analyst may need to speak with project management personnel or technical experts subject matter experts (SMEs) to determine if the schedule accurately captures all of the pertinent information. This can help identify items that are often neglected in schedule preparation such as the transition time between tasks. When developing the schedule, organizations or resources outside of the direct control of the project may not share the sense of schedule adherence and

their work may take longer to complete. Ultimately, being aware of all external dependency relationships helps refine the schedule with a considerable level of realism and with the risk assessment of the schedule.

1.10.4 Good Scheduling Practices

Ideally the cost analyst will receive a schedule from an experienced scheduler. Sometimes this is not the case so the analyst is faced with creating a schedule from scratch or compiling a complete schedule from existing pieces. This section describes 'best practices' to follow if faced with creating a complete project schedule. Consistent use of good scheduling practices will lead to effective schedules and will enable all parties to comprehend the intent of the work flow.

The intent of the schedule is to communicate to all internal and external shareholders a detailed view of the project execution plan and sequence of events to make that execution possible. The scheduler should read and reference the project proposal and the project contract in the development of the schedule and utilize these documents as reference points throughout the continuing schedule analysis. The scheduler should be involved in the development of all scope changes and will need to reference the proposal and contract documents in the validation of the proposed change. The scheduler should have knowledge of or access to SMEs in any internal and client-required processes and any code or industry standards. If applicable, the requirements of these processes and standards should be incorporated into the schedule.

A schedule should include activities that are generally no longer than 10 business days in duration. These activities should have a discrete functional description that will allow for progress measurement by management. The activity should include only one entity, one discipline, or one action. The ability to assign resources and costs to each activity should exist in the schedule development. For example; the scope 'Develop and Test' should be two activities as this is usually two different disciplines that are executing this scope of work. A definite end to the Develop scope will precede the commencement of the Test scope. The discrete activities with durations no greater than 10 days should reveal timely schedule indicators for management intervention.

With respect to logical relationships, each activity should have at least one preceding and at least one succeeding activity relationship. The only activity without a predecessor should be the contract start and the only activity without a successor should be the contract finish. The absence of logic relationships is a flag to a possible schedule validation issue. The specific type of relationship is usually a finish to start relationship, but start-to-start and finish-to-finish relationships can be used. There also exists a start-to-finish relationship, but it is rarely used. Lead and lag times are permissible with the relationship types and positive lead or lag durations are preferred.

The duration should not be the best case forecast, but rather the most likely or worst case to help mitigate risk. Risk aversion should be included in the schedule duration and any updates. The duration should be validated with a unit rate comparison of the assigned resources.

In the analysis of the schedule, float is a valuable component utilized in the execution and management of the project. Total float does not exclusively belong to one individual entity and should be a shared commodity that is addressed in communications with project management.

Total float is defined as the duration that a series of activities can be delayed without impacting the interim milestone or project completion dates. Free float is a component of total float and is the duration an activity can be delayed without impacting the start date of its succeeding activities. The identification and proper use of free float will allow the project manager or task lead to temporarily redirect resources to execute more critical activities.

The critical path is defined as the sequence of activities that potentially will delay the contractual project or interim milestone completion dates. The sequences of activities that will lead to and set the date for the end of the project or task are considered the critical path. The critical path is usually defined as the sequence of activities with a total float equal to or less than 0 days. Near critical paths can be defined as a sequence with a total float equal to or less than five days. Project management will set the expectation for the identification of critical paths. A project can have more than one critical path.

The schedule should be updated and analyzed on a consistent basis (preferably weekly) and the update duration is dependent on the criticality of addressing schedule slippage. Progress on all current schedule activities should be maintained through the current date of schedule analysis. This will allow for proper schedule analysis and validation. In addition, all schedule and resource assumptions and deviations in the execution plan should be documented for future reference. Written records of schedule and resource assumptions and discussions are critical components in the internal and external auditing processes and potential dispute resolutions.

1.10.5 Analysis Methods

The schedule and the cost estimating analysts are facilitators for the review and validation of the project's schedule and resources. The entire project team should be consulted and provide input to the review and validation process for schedule and resources. The schedule and cost estimating analysts should be able to acknowledge the identification of potential and actual additions, modifications or deletions in scope, and their impact on the current project schedule and cost forecasts. Proper inclusion, analysis, and validation of the identified deviation are essential to the effectiveness of the schedule and cost analysis roles.

After the inclusion of the identified scope deviation, the scheduler may use one of three commonly used components of a scheduling software package to analyze the impact of this deviation. These components are the Gantt chart (see Figure 1-13), the PERT chart (shown in Figure 1-14), and the resource profiles.

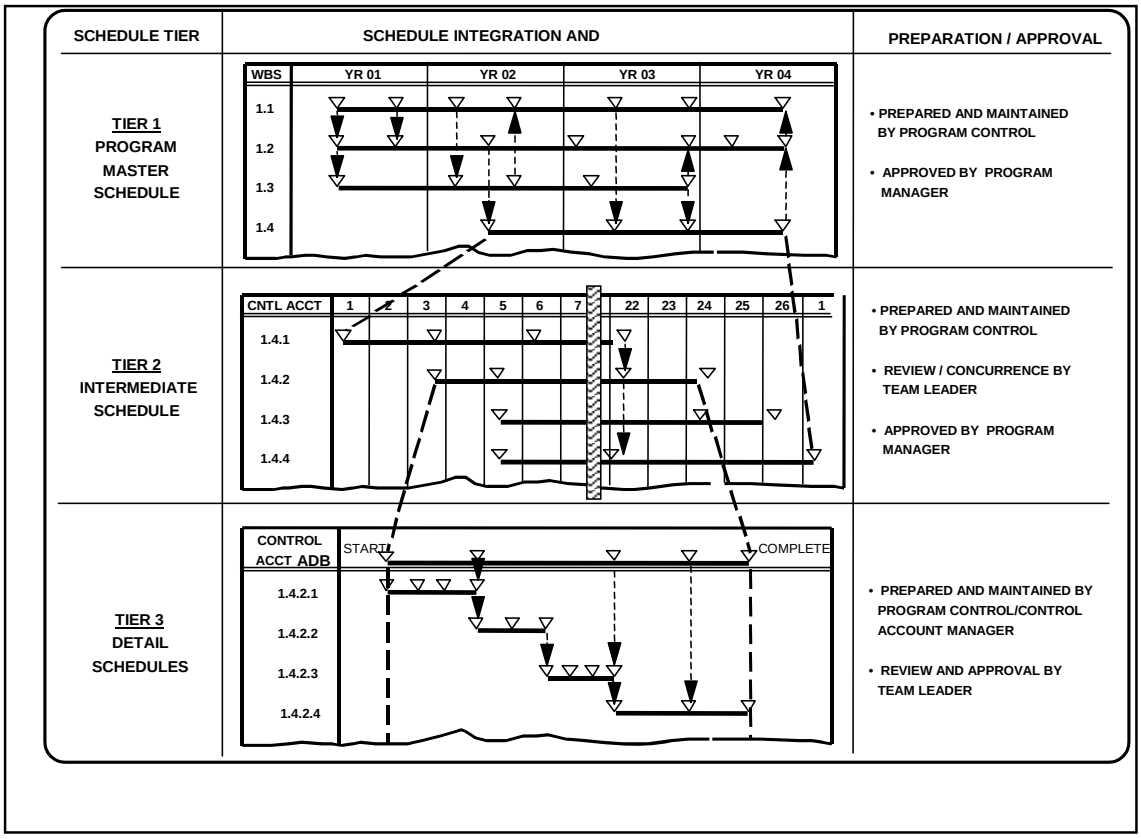

Figure 1-13. Gantt or Bar Chart

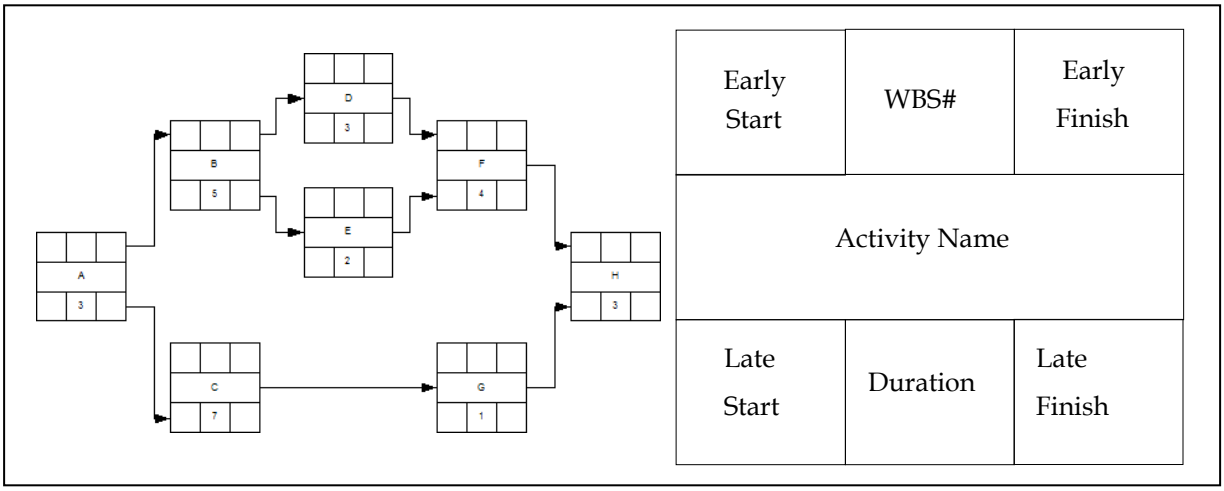

Figure 1-14. PERT Chart / Logic Diagram

The scheduler should also ensure the schedule activities have properly coded activity codes to assist in the dissection of the project schedule. If the schedule is loaded with labor and unit rates, the cost analysis can be conducted in conjunction with the schedule analysis. Due to the sensitivity of labor rates and contractual burden rates, many cost analyses are conducted in

separate cost software packages or components. The cost software package will utilize the output of the schedule package and will provide analysis results that may need to be reincorporated in the scheduling software. With the absence of sensitive cost information, the schedule can be transmitted to all parties for review, comment and execution purposes.

The Gantt chart or the bar chart provides a time-phased sequence of the work scope. It can be customized to reflect any activity related information that will assist in the analysis of the schedule. Some of these customized columns include dates, durations, resources, predecessor and successor activities, and activity codes. The Gantt or bar chart can provide logical relationships but the lines drawn from these relationships may not be easily traced. A Gantt chart is the mostly commonly used communication means for a project schedule. Its benefits are quick insights to the project activities' start and finish dates. Its deficiencies include possible deficiencies in the representation of the logical flow of work, and no total representation to the resource levels or costs required to complete the scope. As shown in Figure 1-13 above, the Gantt chart displays information for a project at various levels of detail. It also provides guidance on who might provide input and approval for the schedules at the various levels.

The PERT chart depicts the schedule in a logical flow between the project's work activities. Figure 1-14 above shows a simple PERT logic example on the left, on the right is the information that is generally included in each square. It can be customized to reflect information that will assist in the schedule analysis and is similar to the aspects of the Gantt chart customization. A PERT chart is missing a time phase perspective that will assist in the analysis. In the development of the schedule or any subsequent modifications, the PERT chart will assist in inserting or modifying the current sequence of work. The inclusion of the correct sequence or logic into the schedule is the most significant component to successful schedule analysis. The PERT chart can be cumbersome in size as the scheduling software may automatically place the activities to match an effective page sizing.

Another helpful view of the schedule is the time-phase logic diagram, which is a combination of the Gantt and PERT charts. This diagram allows representation of all logic relationships within a time sequence representation of the schedule. This is a very beneficial diagram with a small number of activities. As the quantity of displayed activities increases, the complexity and size of the printout will also increase. This view should be used to analyze a small dissection of the scope.

The resource profile provides valuable insight to any over- or under-usage of a project resource. The profile can be customized to include individuals, disciplines, WBSs, or parameters required by the scheduling analyst. Any leveling of the resources should be done through the addition/deletion of resources or duration and logic adjustments to the schedule. Software-generated leveling is not recommended as the software may not have all of analyst-required parameters.

Calendars and constraints are two scheduling software conditioning components that are not usually graphically represented. These components will have a significant impact on the schedule and must be reviewed during all analyses. The activity and resource calendars allow for schedule inclusion of periods of inactivity or unavailability. The activity calendar will reflect common holidays and any expected project inactivity (e.g., plant shutdowns). A resource's

vacation or project related availability would be included in the resource calendar. The constraint dates are included in the schedule whenever the schedule activity logic or the respective calendars do not properly provide the required start or finish date or project calendar condition.

The scheduling analyst will utilize all of these views, profiles, and conditions in the analysis of the schedule. For proper and complete schedule analysis, the analyst must understand all of inherent features of the schedule's logic, durations, and resource availability and the scheduling software's conditioning and output aspects.

1.10.6 How Schedule Affects Cost

Once the schedule analysis has been completed, a cost and risk impact must be assigned to any schedule delays for cost estimating or assessment purposes. Once again there are several methodologies for estimating this impact, based on available data, resources, and project knowledge. One of these methods is calculating an average burn rate for the project. A very simplistic approach would be to divide the total cost of the project by the number of weeks (or days) the project has been open, to arrive at an average weekly burn rate. This rate can then be multiplied by the number of weeks of schedule delay identified as likely, to derive an estimate of the total cost of the schedule delay. This method is too simple for most complex projects in NASA. It is not recommended for use except in Rough Order of Magnitude (ROM) estimates of delay impact. This type of estimate should always be followed by a more detailed examination of the impact of schedule delay to cost. A more detailed estimate of the burn rate may be calculated by identifying the resources impacted by a particular schedule delay (only labor, or labor, facilities and material) and calculating the burn rate based only on the cost of those resources impacted. It can also be complicated by what phase the project is in and the development, manufacturing, and storage costs that are indicative of those phases. In all cases, schedule analysis relies on clearly documented assumptions and methodologies so that the estimates may be more easily reusable, transferable, and understood by all relevant stakeholders.

1.10.7 Additional Resources

- Schedule Risk Analysis: Why it is important and how to use it
  http://sunset.usc.edu/GSAW/gsaw2002/s11a/book.pdf

- PERT Charts Take Precedence
  http://appel.nasa.gov/ask/issues/11/practices/index.html

1.11 Earned Value Management (EVM)

All acquisition programs have risk and managing those risks is a fundamental task of project managers and NASA centers. The Earned Value Management (EVM) methodology is a project management technique that allows decision makers to:

- Integrate performance, cost, and schedule with risk management
- Perform an objective assessment and quantification of current project performance
- Predict future performance based on trends

1.11.1 Definition

EVM is a project management technique that measures forward progress objectively. EVM has the unique ability to combine measurements of technical performance (i.e., accomplishment of planned work), schedule performance (i.e., behind/ahead of schedule), and cost performance (i.e., under/over budget) within a single integrated methodology. If implemented properly, EVM provides an early warning of performance problems while there is still time for corrective action.

The genesis of EVM dates back to the 1960s and Cost/Schedule Control System Criteria (C/SCSC). All cost, schedule, and technical reporting requirements were organized into 35 system criteria, which later evolved into the industry standard-American National Standards Institute/Electronic Industries Alliance (ANSI/EIA) -748, Earned Value Management Systems. This standard establishes 32 minimum management guidelines for an Earned Value Management System (EVMS) to ensure the validity of the information used by management. The US government has adopted the guidelines in ANSI/EIA-748 for use on government programs and contracts through OMB Circular A-11, Part 7, Section 300. It requires EVM on all capital asset acquisitions, and states "Agencies are expected to achieve, on average, 90 percent of the cost, schedule and performance goals for major acquisitions."

NPR 7120.5 describes the implementation of Earned Value Management (EVM) and requires:

- The project's EVM approach is consistent with the participating Center's best practices
- If the project's primary NASA Center has a fully validated Earned Value Management System (EVMS), the project uses that system rather than EVM principles
- The project's EVM approach is in-place by KDP C and implemented in Phase C through KDP E
- Project EVM reporting begins within 60 days after the start of Phase C
- As a minimum, EVM principles, as defined by ANSI/EIA-748, Earned Value Management Systems apply from KDP C through KDP E, if the project's life-cycle cost is at or greater than $20M
- For development or production (including flight and ground support) contracts and subcontracts valued at $20M or more, the contractor EVMS must comply with the guidelines in ANSI/EIA-748
- For development or production (including flight and ground support) contracts and subcontracts valued at $50M or more, the contractor EVMS has been formally determined compliant with ANSI/EIA-748 by the cognizant Federal contract management agency

1.11.2 Steps in the EVM Process

NASA policy requires that contractors' management systems be compliant with the current version on ANSI/EIA-748 whenever EVM is required. This standard covers the organization, planning and budgeting, accounting considerations, analysis and management reports, and revisions and data maintenance management guidelines.

1.11.3 Additional Resources

- NPR 7120.5 NASA Program and Project Management Processes and Requirements http://nodis.hq.nasa.gov/displayDir.cfm?Internal_ID=N_PR_7120_005D_
- OMB Circular No. A-11 Preparing, Submitting, and Executing the Budget http://www.whitehouse.gov/omb/circulars/a11/current_year/a11_toc.html
- NDIA PMSC ANSI/EIA-748-A Standard for Earned Value Management Systems Intent Guide http://www.ndia.org/Content/ContentGroups/Divisions1/Procurement/PDFs10/NDIA_PMSC_EVMS_IntentGuide_Jan2005.pdf
- NASA EVM Overview http://evm.nasa.gov/index.html
- Defense Acquisition University EVM Gold Card https://acc.dau.mil/CommunityBrowser.aspx?id=19577

1.12 Affordability

The Vision for Space Exploration (February 2004) calls on NASA to implement "a sustained and affordable human and robotic program to explore the solar system and beyond."

Affordability should be incorporated into all programmatic decisions as sound affordability practices have proven highly beneficial when developed and implemented as part of complex programs and projects. Much of the LCC associated with human space systems occurs during program/project operations and sustainment. 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.

1.12.1 Definition

Affordability can be defined as the engineering process or management discipline which assures the final system, program, project, product, or service can be delivered (or owned, operated, developed, and produced) at a cost which 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 helps a program/project to achieve the following:

- Optimal system performance for total LCC while satisfying scheduling requirements and managing risks
- Methodologies to acquire and operate affordable systems by setting aggressive yet achievable cost objectives and managing those objectives throughout the full program/project life cycle
- A balance between cost objectives and mission needs with projected out-year resources, taking into account anticipated product and process improvements
- Cost as a principle input variable in the program/project structure and in the design, development, production, operation, and support of a system
- Cost becoming 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

1.12.2 Determining Affordability

Affordability is achieved by establishing top-level affordability goals that are then flowed down to projects and by challenging unaffordable requirements through cost-driven trade studies. Useful affordability tools include parametric cost estimating models, historic cost databases, cost trade processes and modeling and simulation. Modeling and Simulation (M&S) includes adapting and applying models and simulations to a variety of applications (types of analyses and domains) and, if needed, developing new models and simulations for new domains not previously analyzed/quantified; and performing verification, validation, and accreditation (VV&A) of models and simulations. Models and simulations provide a powerful tool for assistance in cost estimating as well as performing cost/performance trades and CAIV studies.

- The Interim NASA Technical Standard provides uniform engineering and technical requirements for processes, procedures, practices and methods to meet urgent program and project technical needs. The Standard for Models and Simulations (NASA-STD-(I)-7009), ensures that the credibility of the results from M&S is properly conveyed to those making critical program and project decisions. In addition, the M&S standard assures that the credibility of the results from M&S meets the project requirements

1.12.3 Additional Resources

- The Standard for Models and Simulations (NASA-STD-(I)-7009) http://standards.nasa.gov/public/public_detail.taf?Documents_uid1=6365&doc_name=NASA-STD-(I)-7009#
- NASA Program and Project Management Processes and Requirements NPR 7120.5 http://nodis.hq.nasa.gov/displayDir.cfm?Internal_ID=N_PR_7120_005D_
- NASA Systems Engineering Processes and Requirements NPR 7123.1 http://nodis.hq.nasa.gov/displayDir.cfm?t=NPR&c=7123&s=1A

1.13 Real Option Valuation

Real option valuation has already been applied to a variety of investment decisions by industry, and is widely taught as part of a modern curriculum in business investment analysis. Only recently, though, has real options modeling and analysis been applied to space systems[5] and NASA investments.[6]

1.13.1 Definition

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

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

1.13.2 Calculating the Value of a Real Option

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

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

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

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

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

---

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

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

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

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

1.13.3 Additional Real Option Valuation Reference

- A Real Options Approach for NASA Strategic Technology Selection
  http://trs-new.jpl.nasa.gov/dspace/bitstream/2014/18213/1/99-1681.pdf

- A Real Options Framework for Space Mission Design
  http://ieeexplore.ieee.org/iel5/10432/33126/01559307.pdf?arnumber=1559307

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

- Timothy A. Luehrman, "Investment Opportunities as Real Options: Getting Started on the Numbers", *Harvard Business Review*, July-August 1998.

- Timothy A. Luehrman, "Strategy as a Portfolio of Real Options", Harvard Business Review, September-October 1998.

For more advanced reading, see:

- Avinash K. Dixit and Robert Pindyck, Investment Under Uncertainty, Princeton University Press, Princeton, NJ, 1994.

- Lenos Trigeorgis, Real Options: Managerial Flexibility and Strategy in Resource Allocation, MIT Press, Cambridge, MA, 1996.

- Eduardo S. Schwartz and Lenos Trigeorgis, eds., Real Options and Investment Under Uncertainty: Classical Readings and Recent Contributions, M.I.T. Press, Cambridge, MA, 2001.

1.14 Lease Versus Buy Analysis

A lease versus 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 (IT) projects. While the process of analyzing the economics of buying an asset has been discussed in this document, the analysis behind the decision is slightly different. For a lease versus buy analysis, various tradeoffs need to be examined.

1.14.1 Definition

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

1.14.2 Lease Versus Buy Approach Considerations

Sample factors to consider when making the decision to lease or buy:

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

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

1.14.3 Additional Resources

- NASA Business Case Guide for Facilities Projects
  http://www.hq.nasa.gov/office/codej/codejx/Assets/Docs/Case_Guide_4-20-06.pdf

Section 2. Other Cost Estimating Considerations

2.1 Full Cost Accounting

In response to NASA requirements and federal guidance, NASA began budgeting and recording cost using Full Cost in FY 2004. Cost estimates done after FY2004 reflect full cost at a level consistent with the data available. Full cost will impact much of what we do but the ability to operate in a full cost environment is not meant to be a substitute for sound management practices as defined in the Strategic Management Handbook and the Program/Project Management Handbook (NPR 7120.5).

After three years of full cost implementation, NASA conducted a review of the implementation and effects of full cost management on Agency operations. The primary finding from that review was that the overhead allocations were more complex than necessary, and that the overhead allocation approach created disadvantages for NASA's smaller research Centers.

The original full cost approach allocates the cost to run each Center to projects based upon their workforce at the Center. Since costs to operate a Center are not solely a function of the size of the workforce, the overhead costs for the smaller Centers were significantly higher than for the larger Centers. To eliminate the cost advantages/disadvantages between Centers, beginning in fiscal year 2007, NASA is managing Center overhead costs with a single rate for all nine Federal centers. (The overhead for NASA's Jet Propulsion Laboratory is included in its contract rates as a Federally-Funded Research and Development Center). A single Agency-wide rate for Center Management and Operations (CM&O) will be allocated to each of the Agency's non-JPL projects and programs based on each project's direct budget.

The other change implemented for FY 2007 was to re-balance the allocation of responsibilities between the Centers and Mission Directorates. Management of the technical capabilities of the Center, primarily for Engineering and Safety and Mission Assurance, was moved to the Center Director, with associated budgets transferred to CM&O. This re-allocation of overhead costs was content neutral for the Mission Directorate projects. Those projects based at the smaller Centers will see a net reduction in allocated overhead, and thus full cost budget. Projects at the larger Centers will receive additional overhead allocations, increasing their total full cost budget, but their direct content remains unchanged. The total budget for each Center, both for Center operations and for conducting projects, remains unchanged. The change in the full cost methodology is outlined in Figure 2-1.

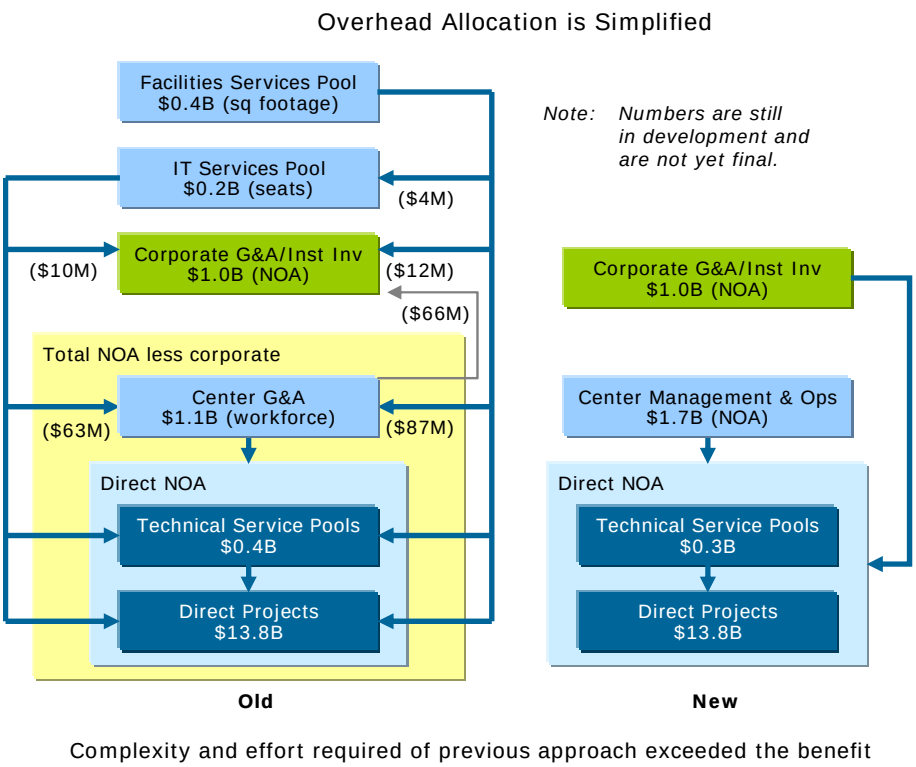

Figure 2-1. Full Cost Simplification Methodology

Key Full Cost Simplification points include:

- Substitute Center G&A with a new Center Management and Operations (CM&O) budget that consolidates the overhead costs from the nine NASA field Centers
- Allocate CM&O to Agency's (non-JPL) projects on basis of each project's direct budget
- Establish Center-specific CM&O budgets during Agency's annual budget process
- Promote competition based on quality of capabilities rather than costs at Centers
- Maintain the Agency's research capabilities and share proportionally across all Agency projects

The concept of full cost ties all Agency direct and indirect costs (including civil service personnel costs) to major activities called cost objects. These cost objects are NASA's programs and projects. In the past, civil service personnel costs and certain other costs of the institution were not tied to projects. However, now they are charged or allocated. Cost estimators and financial managers need to include these costs in project/program estimates and must also conduct adequate reviews of proposals to ensure that these costs are included.

QUESTION: What is the full cost of a project?

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

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

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

1. **Direct Costs –** Direct costs are costs that are obviously and physically related to a project at the time they are incurred such as purchased goods and services, contracted support, and direct civil service salaries/benefits/travel.
2. **Service Costs –** Service pool costs are costs that cannot be specifically and immediately identified to a project, but can subsequently be traced or linked to a project and are assigned based on usage or consumption. Each pool carries all supporting costs for that function including: civil service salaries/benefits; contractor labor; travel; purchases; pool management; facility related costs. Note that the NASA Full Cost Simplification has eliminated/reduced many Center specific service pools.
3. **Center Management and Operations (CM&O) Costs –** CM&O costs are costs that cannot be related or traced to a specific project, but benefit all activities. Such costs are allocated to a project at the Headquarters level using a standard rate for all projects. Project CM&O dollars remain at NASA Headquarters when project budgets are sent to the implementing Centers.

2.1.1 Overview of Budget Planning in Full Cost

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

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

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

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

d. **Service Pools –** specific infrastructure capabilities that support multiple programs/projects at a Center. These costs can be traced/linked to a given project based on usage/consumption. NASA Full Cost Simplification has eliminated/reduced many Center specific service pools.

e. **CM&O –** CM&O costs captures Center costs that cannot be related or traced to a specific project, but benefit all activities. The following standard types of costs/functions are included in the CM&O account: CM&O civil service salaries/benefits/travel; center training and awards; grounds maintenance; pavement/roads; fire protection; library; public affairs; non-program CoF; transportation services; human resources department; financial management, equal opportunity; educational outreach; medical services; procurement, security, and legal. CM&O costs are aggregated at the Agency level and are allocated to the projects using an Agency rate for all projects.

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

Although CM&O and Corporate G&A are assessed to projects at the Agency level, during the estimating process for a new initiative, it may be requested by the solicitor to be included. For example, when submitting proposals for NASA Research Announcements (NRA) or

Announcements of Opportunity (AO), CM&O and Corporate G&A may be required to support the cost evaluation of the proposals.

2.1.2 Service Pools

Full Cost Simplification has allowed several Centers to eliminate all service pools while the number of service pools at the Center level have been reduced from six to two or less at most Centers. Test Service and Manufacturing Service are the two common service pools remaining at Centers still employing service pools.

Full Cost Simplification has also eliminated the complicated flow down of costs from pool to pool.

2.1.3 Summary

NASA Full Cost Simplification has resulted in the following:

- Moved service pool overhead into the CM&O account
- Eliminated or reduced service pools at all Centers
- Eliminated Center level G&A
- Created the Agency level CM&O account
- Changed the method of allocation from the old Center G&A approach (direct workforce) to the new CM&O approach (percentage of project direct cost)
- Eliminated the pool to pool assessment process

2.1.4 For Further Information

- NASA FY 2008 Budget Estimates (Supporting Data)
  http://www.nasa.gov/pdf/168652main_NASA_FY08_Budget_Request.pdf

- NASA Financial Management Requirements
  http://www.nasa.gov/offices/ocfo/references/ocfo_fmr_detail.html

- NASA Full Cost Initiative website
  http://www.hq.nasa.gov/fullcost/

Table 2-1. Full Cost Points of Contact

Center	Contact Name	Email
NASA Headquarters	David Schurr	david.schurr@nasa.gov
Ames Research Center	John Lee	john.j.lee@nasa.gov
Dryden Flight Research Center	Steve Sterk	steve.sterk-1@nasa.gov
Glenn Research Center	Bob Sefcik	robert.j.sefcik@nasa.gov
Goddard Space Flight Center	Garry Gaukler	garry.l.gaukler@nasa.gov
Jet Propulsion Laboratory	n/a	n/a
Johnson Space Center	Grace Martinez	grace.martinez-1@nasa.gov
Kennedy Space Center	Janice Robertson	janice.j.robertson@nasa.gov
Langley Research Center	Debbie Schroeder	debra.h.schroeder@nasa.gov
Marshall Space Flight Center	Michael White (Labor) Karen Dugard (Reimbursables)	michael.c.white@nasa.gov karen.d.dugard@nasa.gov
Stennis Space Center	Rena Perwien	rena.l.perwien@nasa.gov

2.2 Construction of Facilities

Construction of Facilities (CoF) cost estimating is different in discipline and methodology than space cost or research and development of technology (R&T) estimating. In contrast to most space cost and R&T estimating, which is guided by NPR 7120.5, NPR 8820.2 Design and Construction of Facilities, is the guidance for most CoF design and implementation estimating.

Most CoF estimators have little in common with space system cost or R&T estimators; except in offices that have oversight into all NASA functions. In addition to the RS Means published lists of tables and regional metrics, Centers have access to various guidelines and tools used to create facilities cost estimates. "Success Cost Estimator" is a tool developed for Kennedy Space Center (KSC) which can be used for estimating the cost of facilities construction. "Standards for Facility Project Cost Estimating" is a manual as well as standard estimating template developed at Johnson Space Center for use in creating construction estimates. The needs and considerations in creating a facilities cost estimates vary somewhat depending on the type and use of the facility.

CoF Lessons Learned
Input provided by Dan Tweed, KSC

1. In preparing your cost estimate, remember that the construction schedule must be coordinated with not only project stakeholders but with the Center's mission and operational schedules (Including State Historical Preservation Office, Real Estate Office, Environmental Office, Energy Office, Security, Health, Fire and Life Safety Office etc). Build those interruptions and associated costs into the estimate and schedule by adding money and additional contingencies for schedule integration needs. In KSC's launch processing environment, we have to coordinate implementation schedules with shuttle operations schedules and payload processing schedules or space station element processing. Sometimes we have to start and stop construction around launches.
2. Remember to estimate for support costs during construction. For example, if during construction a utility service has to be taken offline, then temporary facilities must be provided and paid for that out of the construction budget. This includes items like temporary road closures, rerouting roads, sidewalks, pavements, utility service interruptions, scheduled outages, temporary power etc.)
3. Estimate and plan to spend more money initially on soil borings to get enough of a distribution on a building's footprint and find any unsuitable materials. During a building construction, KSC received an unpleasant surprise with a muck layer that was in between soil borings we took; the resulting fix cost a lot more money.
4. When estimating maintenance, rehabilitation, or revitalization for older structures, be aware of human safety needs and special handling requirements for components like lead paint or asbestos. Identify and estimate for these additional costs.

This section of the handbook is intended to provide an overview of the five year CoF process as well as describing some of the lessons learned, special considerations and tools used when creating a CoF estimate.

2.2.1 Overview of the CoF Process

The CoF process is based on a five-year cycle. The cycle begins when a budget call is initiated to determine the priority of CoF projects. Approved projects are prioritized and assigned a year of

execution. This information is included in the 5-year budget submitted by each Center on an annual basis.

At a Center, the Facilities Division is responsible for CoF projects, which are directed by a program manager, with a facility project manager assigned to each project. Project managers have cradle to grave responsibility for each project. If needed, a support contractor does Independent Cost Estimates (ICEs). In addition, the center's independent assessment team may be asked for additional support.

The Center's CoF program manager requests input from individuals across the Center. A list of required CoF projects is prepared, including associated parametric estimates. In addition to the parametric estimate, the engineering staff will prepare a Rough Order of Magnitude (ROM) estimate. Included in the CoF program manager's submission is an estimate for civil servant labor costs for each program year.

The Facilities Division collects and prioritizes the input received based on a risk assessment matrix provided by Headquarter's Facilities Engineering and Real Property Division. The Center Director and his team prioritize and approve those projects that will be submitted for budget inclusion. The CoF portion of the budget request is sent additionally to Headquarters FERP (Facilities Engineering and Real Property Division) for evaluation and prioritization. The funded project list is sent back to the Center after FERP approval.

CoF cost estimating, project planning and design can begin two years out, when HQ Facilities Engineering and Real Property Division authorizes Facilities, Planning and Design (FP&D) money based on 2-year out project approved budget. (For example, in FY04, the centers will receive FY04 construction money and FY06 design money.) Cost estimating, project planning and design are paid for by FP&D allocations.

After FP&D money is received, the Facilities Division project manager issues a SOW for the design of each project. This SOW identifies project budget, scope and an estimated construction price based on approved budget amount (current cost estimate or CCE). The CCE includes construction contract award budget (must include construction escalation), approximately 10% for contingency, and 10% for supervision, inspection, and engineering services (SEIS). These values are approximations and can vary greatly from Center to Center.

Architecture/Engineering or Civil, Structural, Mechanical, and Electrical firms may hold on-call design services contracts. Some Centers have in-house NASA engineers that will comprise the design team. The SOW includes the target cost available to the design team for the effort. The team will estimate and design to this budgeted amount. The project is competitively awarded through procurement with advice from the Facilities Division.

Following the design contract award to a firm, the Facilities Division project manager will hold a kickoff meeting –which can include the design team, Facilities Division office representatives and other stakeholders to start a process for establishing the detailed scope. Reviews usually follow at 30, 60, and 90% design and cost milestones, but can vary from Center to Center.

Typically, a design team prepares a detailed ground-up estimate, initially based on square foot estimates (at the 30% review.). Then, the designer creates detailed estimates, incorporating material take-offs and linear square foot costs against each system and vendor quotes for different building components. Information is gathered from tools like RS Means and local vendor's estimates, historical data from past projects, and estimates include calculations for present year cost versus future year costs and expected inflation. Each project estimate is always

separated into both CoF funded and non-CoF funded estimates. (Non-CoF funded examples include outfitting an office building and activation activities after facility construction.)

At the 100% design and cost milestone, the facilities division project manager will review the design team's cost estimate, giving input on design and tracking changes. When reviewing the cost estimate, the project manager looks for anything out of the ordinary, such as costs higher than those budgeted, and what elements are CoF funded and what elements are non-CoF funded. It is important for the facilities division project manager to review all source documents used in preparing the cost estimate to make sure that all costs can be traced back to their source/origin and can be easily referenced from the source document for auditability/reproducibility. All unit costs (e.g. units of measure and quantities for each significant item should be the norm vs. using "lump-sum" estimates whenever feasible. This due diligence will assist the Contracting Officer (CO) during the procurement phase of this project which includes contract negotiations and making a best value contracting decision

2.3 Software Estimating

Software represents a substantial portion of the cost for space systems. Estimating the cost, schedule, and effort associated with a proposed software development project is a challenging task.

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

The most comprehensive process for software estimation is documented in Jet Propulsion Laboratory's (JPL's) Software Cost Estimation Handbook [6]. Marshall Space Flight Center's (MSFC's) Flight Software Group uses tool-driven estimation, in this case the Constructive Cost Model or COCOMO[7]. Finally, JSC's Flight Software Group uses a "Rule of Thumb" based on historical data for mostly small developments (only one development greater than 200K software lines of code (SLOC).

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

7 *MSFC FSG Software Project Estimating Guide.*

Whatever method used, it must to be applied consistently and its counting rules be clearly documented. The most common sizing method within NASA is based on PSLOC[8]. The PSLOC metric is very simple to count (carriage returns excluding comments and blanks) and easily lends itself to automated counting tools.[9] Also historical physical SLOC data is available to support analogical comparisons and calibrating models. There are variations in Logical statements counting rules, which can cause differences in the number of lines counted between tools but logical SLOC measures more consistent across languages. FPA provides a sizing methodology that is tied to a functional design but the counting is subjective and the bases of counting in not well known to most reviewers making it more difficult to communicate. A table for converting between physical and logical SLOC is provided in Table 2-2.

Table 2-2. Converting Between Physical and Logical SLOC

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

2.3.1 Function Point Analysis (FPA)

Function points were established in the late 1970s as an alternative to SLOC, but only recently have they gained more attention and use. Function points measure software size based on the functionality requested by and provided to the end user. Functions are categorized as data or transactions. Data functions include logical data groups that are captured and stored by the application being estimated and external data referenced by the application. Transaction functions encompass inputs (add, change, and delete), outputs (reports), and inquiries (searches or retrievals).

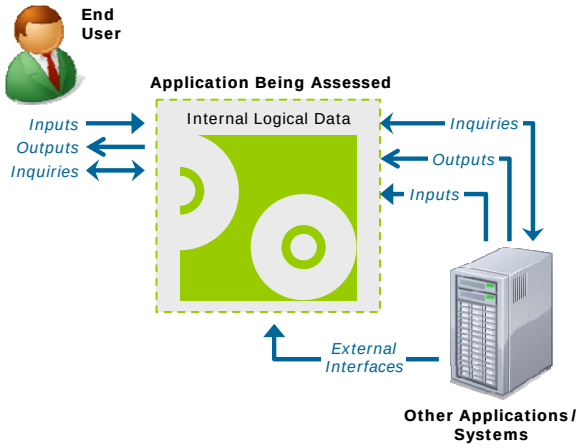

Figure 2-2. Function Point Analysis Summary Diagram

One of the key benefits of using function points as the sizing method is that counting standards are established and maintained for the technique. The International Function Point Users Group (IFPUG)[10] manages, regulates, and issues updates to these standards, making function points

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

9 *Jones, T. Capers (1998), p. 319.*

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

fully documentable and traceable. Many resources can avail themselves to function point analysis at various stages in the development life cycle, including user or estimator interviews, requirements and design documents, data dictionaries and data models, use cases and user guides, and even screen captures or the actual software. Function points, like SLOC, offer certain advantages and disadvantages, which are detailed in Table 2-3.

Table 2-3. Function Point Advantages and Disadvantages

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

2.3.2 Effort Estimation

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

- A traditional engineering estimate typically based on a bottom-up decomposition
- A model based estimate
- An analogical comparison to other similar tasks

JPL and other Centers track the size of development efforts and can derive a size estimate based on analogy to the historical data. Sizing by analogy, however, does not address all the relevant issues. What requires effort is the amount of code that needs to be written, modified and tested, not the amount of code that gets delivered. To estimate the development effort, the number of Equivalent SLOC needs to be derived, which is based on weighting the cost of an inherited line relative to the cost of delivering a new line of code. Historically, there is a tendency to over estimate the amount of inheritance and to underestimate the cost of inheritance, so be conservative. The cost models have algorithms built in to compute equivalent SLOC. For a simplified approach to computing equivalent SLOC, apply the adjustment factors displayed in Table 2-4.

Table 2-4. Effort Adjustment Multipliers for Software Heritage[11]

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

11 *Based on Team X's ACS Cost Model, which is based mainly on Discovery-class missions.*

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

The key to translating the number of SLOC into development effort (labor months) is the productivity factor, that is the assumption made on SLOC per labor (work) month.[12] The JPL Cost Estimation Handbook offers two productivity averages, one based on historical experience at JPL and NASA[13] and another based on industry averages. Additionally, JSC's Flight Avionics Group has noted a productivity factor ranging from a low of 165.5 SLOC/LM to a high of 8,333 SLOC/LM. As can be seen in the tables below, the productivity ranges are very large. Hence, it is very important that software cost metrics repositories be established so that the estimator has access to data consistent with their environment.

Table 2-5. Software Development Productivity for JPL and NASA Average Projects (Equivalent Logical SLOC)

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

Table 2-6. Software Development Productivity for Industry Average Projects (Equivalent Logical SLOC)

Characteristic	Software Development Productivity (SLOC/WM)
Classical rates	130-195
Evolutionary approaches[14]	244-325
New embedded flight software	17-105

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

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

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

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

Once the development effort is calculated, the effort is costed using labor rate information. Either burdened civil service rates, contractor bid rates (if known) or industry average rates.

2.3.3 Parametric Model Based Estimates

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

The main drawback to software cost estimating tools is the cost and the need for users training. Some tools are expensive and complex. Many commercial software estimation tools are available on the market. Currently, NASA has agency-wide licenses for both PRICE and SEER estimating suites, which both include software estimation tools. These two specific tools trend toward the higher side of the cost-complexity spectrum, but there are several other models available to estimate software costs. Although PRICE and SEER are the two agency-wide licensed tools, JPL, MSFC, and JSC also use the COCOMO, which was developed by the Center for Software Engineering (CSE) at the University of Southern California, headed by Dr. Barry Boehm[15]. Training on COCOMO is available through NASA Training programs. Included in the licensing agreement with PRICE and SEER is access to training on the tool. Please see the *NASA Cost Model Prospectus* in the Reference Volume for more information on the many models available.

2.4 Estimating Operations and Support

Within the space costing community, greater attention has always been placed on development costs rather than O&S costs. Still, O&S costs can often be the majority component of the LCC when long operations periods are involved and therefore, it is important for the NASA cost

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

analyst to understand O&S cost concepts, tools, models, and sources of cost risk to accurately estimate O&S costs.

Another reason to focus attention on O&S costs is that the decisions made early on in a program with regard to system design can have tremendous impacts, both negatively and positively, on the level of O&S support required for the remainder of the program/project. These decisions may result in a fixed or difficult to amend operational consequences. Therefore, it is the job of the analyst to ensure these consequences, good or bad, are visible to a program/project as early as possible while decisions can still be altered. Choosing the system design based solely on development costs has been detrimental to NASA in the past, so the objectives of examining O&S costs should be to:

- Identify O&S cost drivers and consider all the O&S costs of alternatives in the selection of the preferred alternative
- Prepare accurate O&S cost estimates that reflect alternative design and operations concepts that have examined trade offs among program/project development costs, O&S costs, and operational risks

To achieve these objectives, the NASA cost analysts should participate in the creative design process where design, technologies, concepts of operation, schedule, and performance requirements are determined.

Figure 2-3 shows the dual mode creative process creates the Design Structure Matrix (DSM) and allows the NASA cost analysts to interject the operations perspective throughout the process.

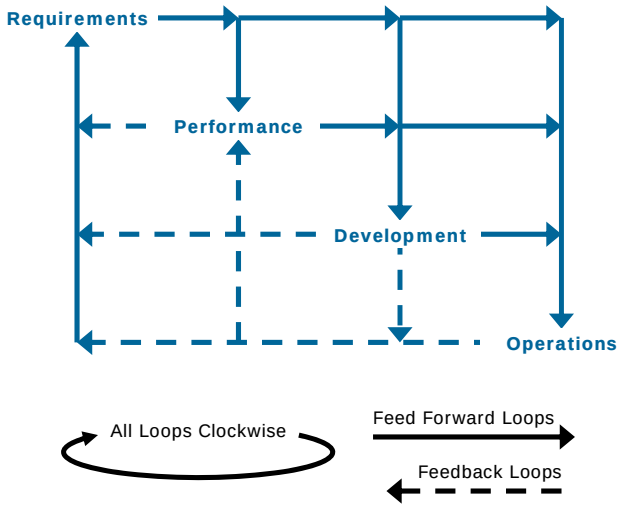

Figure 2-3. The Dual Modes of O&S Cost Estimating

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

2.4.1 Estimating O&S Costs for New Systems

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

Project Definition Tasks (1, 2, and 3)

The analyst should understand not only the systems in the program/project, but be involved in the development of the program/project's operations concepts. At a minimum, the analyst should help to shape the program/project's approach to:

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

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

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

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

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

The cost analyst should understand the Ground Rules and Assumptions (GR&A) with regard to O&S costs. This includes defining:

- The period of operations and start date of operations
- The types of dollars needed to be consistent with the development cost estimates
- The inflation rates and discounting assumptions
- The lengths/types of mission epochs, as applicable
- The planetary: spiral out/in, cruise, orbit insertion/encounter, Entry, Descent, and Landing (EDL), surface operations, extended operations, disposal
- For Earth-Orbiting and Observatories: deployment, routine operations, servicing/logistics operations, disposal
- For human rated Space Stations: launch and assembly, mature operations, phase-out operations, disposal
- Whether operations are multi-mission (e.g., Are facilities costs to be shares, such as the STS and ISS Mission Control Center? Are operations teams to be shared across several missions?)
- The cost-sharing arrangements with partners
- The Government or Non-Government Organization (NGO) operations
- The planned degree of Government oversight

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

A number of Government off-the-shelf (GOTS) models listed in the *NASA Cost Model Prospectus* in the Reference Volume are available to NASA costs analysts to deal with O&S costs for a wide variety of NASA missions. These models are capable of providing O&S cost estimates at different levels of resolution and fidelity. Generally, early in the project life cycle when information is scarce, only a ROM cost estimate may be possible or needed. For the CAIV study, the O&S cost model selected should at a minimum provide sufficient information to support architectural trades. Sometimes, more depth in the O&S cost model is needed to address critical system design and supportability issues. To populate O&S cost model inputs, the cost analyst can check to see if CADRe data is available for similar projects, interact with the development team for system characteristics, and interact with the O&S team for operations/logistics concepts and ground system characteristics. Figure 2-4 shows the capability of various GOTS O&S models to support trade studies. Other O&S assessment tools listed in the *NASA Cost Model Prospectus* may be very useful in providing data for lower resolution models.

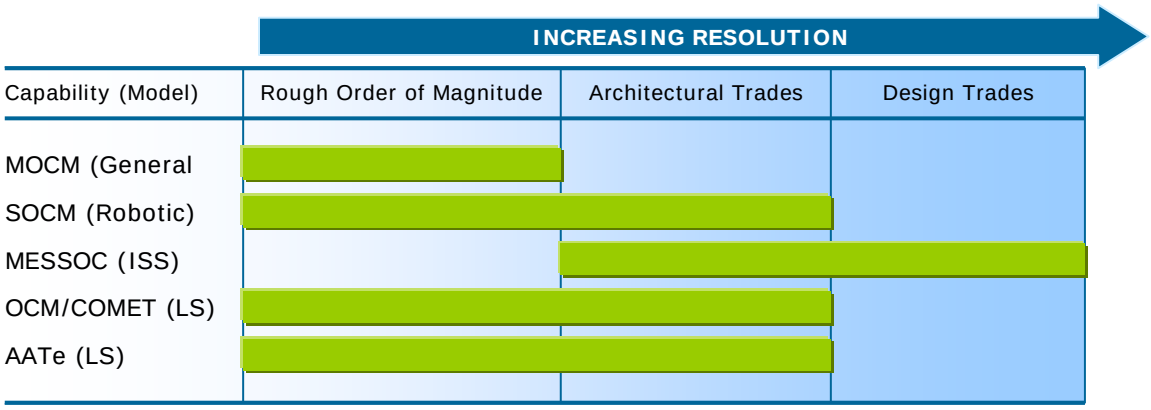

Figure 2-4. GOTS O&S Cost Model Capability

The Estimate Tasks (8, 9, 10, 11, and 12)

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

Because O&S trade-offs tend to affect a program/project's more visible and near-term factors in exchange for benefits that may not be proven out until many years down the road, the need for defendable, measurable, credible estimation becomes especially critical. Examining R&M means examining if a more reliable system may be traded for one that fails more often but is easier to maintain by virtue of its layout or design. Alternatively, a more maintainable system may affect performance through the addition of a feature that adds weight to the system. Trading for a more reliable system and improved O&S may reduce weight, but requires many more test/fail/fix cycles to evolve, thereby affecting development cost, and schedule. The O&S analyst must work with performance, development, and production focused leads to consider all these factors and their costs when conducting CAIV studies and developing and documenting cost estimates.

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

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

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

2.4.2 Operations and Support Cost Estimation Issues/Challenges

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

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

2.4.3 Understanding the Supply Chain

A unique and daunting O&S cost estimation challenge involves estimating the supply chain costs of a future system. Traditionally, program/projects have considered factors such as sustaining engineering, logistics, and communications among others, as areas that are less visible, but which

can easily comprise significant O&S costs. As more precise and comprehensive estimates are required of programs/projects, it is no longer sufficient to estimate components of a systems support functions as gross percentages of more direct functions such as hands on activity. Nor is it sufficient any longer to estimate these areas as independent components of a broader system, each devoid of interaction with other support functions. The supply chain design and the factors considered as affecting its nature and cost can be viewed from an operations perspective as equal to and as critical as the design of a flight system or of a facility in which a flight system is worked upon.

One of the main factors contributing to the operations cost of exploration architectures is the cost of shipping required cargo and supplies, especially for long-duration missions. It is important that logistics be taken into account at an early stage in the design process, because the exploration architecture and vehicle design can impact logistics-related operations costs. In order to understand the specific logistics costs associated with various exploration architecture choices, a modeling framework and planning tool for logistics is required.

Because of the recognized need to reduce lifecycle operations costs for future programs, and the mounting complexity of supplying exploration missions, logistics operations must be streamlined. Both the military and commercial enterprises have been highly successful in reducing costs and increasing efficiency through the implementation of supply chain management. Generally these gains have been achieved by simultaneously reducing shipping costs, reducing inventory holding costs while increasing service levels.[16]

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

2.4.4 Additional Resources

- The NASA Exploration Supply Chain, SCOR, Simulation & Analysis
  http://science.ksc.nasa.gov/shuttle/nexgen/Nexgen_Downloads/SCOR_Conv_Forum_Oct_06_Zapata_Galuzzi_r2.ppt

- Foundations of Supply Chain Management for Space Application
  http://science.ksc.nasa.gov/shuttle/nexgen/Nexgen_Downloads/Foundations_of_SCM_for_Space_Application.doc

- A Modeling Framework for Interplanetary Supply Chains
  http://spacelogistics.mit.edu/pdf/Gralla_Space2006.pdf

[16] *Erica L. Gralla, Sarah Shull, Olivier de Weck, Gene Lee, and Robert Shishko "A Modeling Framework for Interplanetary Supply Chains"*