Appendix F: Phasing of Cost Estimates

Developing a cost estimate requires more than just determining the total cost. The estimate must also address how those costs are phased over the time period of the development, and NASA has developed tools to assist the estimator with phasing.[1] The phasing profile is important for budget formulation. For example, if the phasing profile for a project is constrained due to budget limitations in particular years, the result may be an increase the overall development cost due to inefficiencies of stretching out or delaying work to stay within available resources in a particular year. In addition, cost estimates and phasing profiles reflect when resources will be expended or costed, and they need to be adjusted to reflect the New Obligation Authority (NOA) that is represented by the budget requests for any particular year, as there is a lag between when funds are available for obligation and when they are costed.[2] Cost-phasing is therefore an important element to be considered in the budget formulation process. In a February 2010 report titled *Assessments of Selected Large-Scale Projects*, the U.S. Government Accountability Office (GAO) found that nearly 50 percent of recently assessed projects had issues due to "budgets [that did] not match the work expected to be accomplished."[3] The report concluded that these funding issues are some of the primary challenges that can contribute to cost and schedule growth within NASA.

As part of a quality cost estimate, Ground Rules and Assumptions (GR&A) should cover the phasing of the cost (commonly referred to as time phasing).

> Estimates are time phased, because program costs usually span many years. Time phasing spreads a program's expected costs over the years in which they are anticipated. Depending on the activities in the schedule for each year, some years may have more costs than others. Great peaks or valleys in annual funding should be investigated and explained, since staffing is difficult to manage in such variations from one year to another. Anomalies are easily discovered when the estimate is time phased. Cost limitations can also affect an estimate's time phasing, if there are budget constraints for a given fiscal year. These conditions should be addressed by the estimate and their effects adequately explained.[4]

In general, there are two methodologies for time-phasing an estimate: Engineering Build-Up and Parametric. Most time-phasing will typically consist of a mix of both methodologies, which should be considered two ends of one spectrum. At one end, the engineering build-up, or bottom-up approach would be essentially a summation of a detailed resource-loaded schedule (sometimes called a bottom-up estimate), and, at the other end, a top-down approach would be essentially a parametric or heuristic of a program or high-level element.

F.1. Engineering Build-Up Time-Phasing

An analyst who has developed a grassroots estimate generally has also developed or been provided with a schedule. In this case, the analyst can cost-load the scheduled activities to develop a phasing plan. The basic process for cost-loading the schedule is to (1) determine the key milestone with which to spread the costs, (2) estimate the percent of total effort required to complete each milestone, and (3) allocate the

[1] NASA Phasing Model, available via the ONCE Model portal at www.oncedata.com and described in a paper by presented at the 2013 NASA Cost Symposium http://www.nasa.gov/sites/default/files/files/08_PERFT_Cost_Symposium_Final_TAGGED.pdf.

[2] Burgess, Erik. 2004. "Time Phasing Methods and Metrics." Paper presented at 37th Annual DoD Cost Analysis Symposium, Williamsburg, VA, February 10-13.

[3] GAO. 2010. *Assessments of Selected Large-Scale Projects*. Washington, DC: GAO, pp. 74–75.

[4] Ibid.

cost to the appropriate fiscal year by multiplying the Work Breakdown Schedule (WBS) cost element by the percentage of effort for each milestone task.

For the Engineering Build-Up method, if a project schedule has not yet been developed, there are two alternative methodologies that can be used. The first alternative is to use a schedule provided to the project by the contractor, which can be useful during source selections where a contractor is providing a cost proposal to the Government. Keep in mind that cost elements such as Government Furnished Equipment (GFE), NASA Test and Evaluation (T&E), and education and public outreach will not be on the contractor's schedule and need to be accounted for separately. The second alternative method involves using an analogy. Analogies are based on the similarity of tasks, technical parameters (e.g., mass or power), key milestones, program length, magnitude of cost, and other program/technical parameters. This method allows the analyst to select an analogous project to use as the pattern for the fiscal-year spread.

F.2. Parametric Time-Phasing

In practice, there are three types of distributions used to approximate a program's time-phasing: Beta, Rayleigh, and Weibull. Studies have shown that cumulative project expenditures follow a Rayleigh[5] or Weibull[6] distribution quite closely. Both distributions model the linear ramp-up, peak, and exponential rampdown that are typical of most projects. Other distributions, such as the Beta distribution and 2nd- and 3rd-order polynomials, can mirror this same pattern and have been used by cost analysts to spread costs over a schedule and determine annual phasing requirements. Cost analysts at Johnson Space Center pioneered the use of this quantitative technique for NASA in the 1960s by using a Beta distribution (curve) to spread the point estimate from a parametric cost estimate over a project schedule.

Heuristics, typically expressed in percent cost for a percent time, are also commonly used. For example, several NASA studies[7,8] show that space systems typically *expend* 45–55 percent of their funds within the first 50 percent of time. A typical distribution (Rayleigh, Weibull, or Beta) illustrates the percentage spent and the elapsed time between two points in time. By way of illustrating the concept, if an analyst has developed an estimate of $100 million for a satellite, without any other knowledge of funding needs, the analyst could use the rule of thumb that assumes a 60:40 Beta Curve (60 percent of the cost at the halfway mark and 40 percent for the remainder of the project). The rule of thumb for a ground-based system is 40:60. Table F-1 below illustrates three examples of Beta distributions: 50:50, 60:40, and 70:30.

Some of the NASA parametric models or other tools also offer spreading functions; however, it is recommended that the analyst examine several of them carefully prior to selecting the approach for spreading the early cost estimate.

[5] Lee, D., Hogue, M., and Gallagher, M. 1997. "Determining a Budget Profile from a R&D Cost Estimate." *Journal of Cost Analysis*.

[6] Brown, T., White, E., and Gallagher, M. 2002. "Weibull-based Forecasting of R&D Programs Budgets." *Journal of Cost Analysis*.

[7] Kellogg, B., Hayhurst, M., Roeum, V., and Miller, M. 2013. "Generic Cost Profiles Based on Actual Costs in NASA CADRes." NASA Cost Symposium. Pasadena, CA.

[8] Burgess, E., Krause, C., Sterburzel, J., and Elliott, D. 2013. "Phasing Estimation Relationships." NASA Cost Symposium. Pasadena, CA.

PDF Curve Shapes	Years	Percentatge Cost Per Year									
		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	16	17	16	12	8	4	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

Table F-1. Selected Annual PDF Cost Distributions for Selected Curve Shapes

One specific NASA phasing tool is the Phasing Model, available via the ONCE Model portal at www.oncedata.com. The Phasing Model generates Phasing Estimating Relationships (PERs) that can be used to help the analyst estimate annual funding for a mission, given a cost and schedule estimate. The relationships developed by the Phasing Model are based on historical data and do not necessarily represent "optimal" phasing. The time period for the PERs is System Requirements Review (SRR) to Launch, and the content can include two options:

Option 1: Total project excluding launch

Option 2: Spacecraft and instruments only

The Phasing Model can be used to support, assess, and/or defend budgets, and is also a good starting point for analyzing cost & schedule ramifications.

Other Government agencies[9] as well as NASA[10,11] have demonstrated distribution fitting and Phasing Estimating Relationship analysis. These phasing methodologies should only be used before detailed statements of work and schedules are created or as a macro crosscheck. It is preferable to resource load the schedule milestones and deliverables as the basis for either annual or monthly cost phasing.

The analyst also needs to be cognizant that these tools are intended to provide a spread of costs and are not to be confused with obligations and further adjustments that may need to be made to convert the costs to obligations so that long lead purchases and the execution of contracts can be accounted for. Furthermore, these tools typically provide phasing in calendar year (CY) dollars, which must be translated to Real Year (RY) dollars before being used for obligations or budgeting purposes.[12,13] Relating budgets (obligations) and expenditures (cost) is extensively covered in available literature.[14]

F.3. Phasing Model

The Phasing Model[15] generates Phasing Estimating Relationships (PERs) that can be used to help the analyst estimate annual funding for a mission, given a cost and schedule estimate. The relationships developed by the Phasing Model are based on historical data and do not necessarily represent "optimal" phasing. The time period for the PERs is System Requirements Review (SRR) to Launch, and the content can include two options:

Option 1: Total project excluding launch

Option 2: Spacecraft and instruments only

The Phasing Model can be used to support, assess, and/or defend budgets, and is also a good starting point for analyzing cost & schedule ramifications. The Phasing Model is available on the ONCE Model Portal at www.oncedata.com.

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9 Burgess, E. 2006. "R&D Budget Profiles and Metrics." *Journal of Parametrics*, pp. 11–30.

10 Burgess, E., Krause, C., Sterburzel, J., and Elliott, D. 2013. "Phasing Estimation Relationships." NASA Cost Symposium. Pasadena, CA. http://www.nasa.gov/sites/default/files/files/08_PERFT_Cost_Symposium_Final_TAGGED.pdf

11 Kellogg, B., Hayhurst, M., Roeum, V., and Miller, M. 2013. "Generic Cost Profiles Based on Actual Costs in NASA CADRes." NASA Cost Symposium. Pasadena, CA. http://www.nasa.gov/sites/default/files/files/04_Hayhurst_Cost_Profile_Briefing-2013_NASA_Cost_Symposium.pdf

12 NASA New Start Inflation Index, posted on the CAD website at http://www.nasa.gov/offices/ooe/CAD/Publications.html#.VOuu_Do1-gQ .

13 Whenever dollars are being spread across two or more fiscal years, the calculations must be performed in CY dollars. After the CY dollars are spread into each fiscal year, they can be inflated to RY.

14 Unger, J., Gallagher, M., and White, E. 2004. "R&D Budget-driven Cost and Schedule Overruns." *Journal of Cost Analysis*.

15 More details can be found in a paper on the Phasing Model presented at the 2013 NASA Cost Symposium. http://www.nasa.gov/sites/default/files/files/08_PERFT_Cost_Symposium_Final_TAGGED.pdf.