Programmatic Estimating Tool (PET):

Conditional Estimates of Cost, Schedule & Phasing

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Short Abstract

The Programmatic Estimating Tool (PET) provides a method for adjusting cost estimates in scenarios where programs face rigid schedule and/or budget phasing constraints. PET integrates program cost, schedule, and budget phasing into a single user friendly tool. Using historical correlation between cost, schedule, and phasing model residuals to generate a tri-variate conditional distribution, PET can be used to estimate the impact of:

- Schedule and/or phasing constraints on cost
- Cost and/or phasing constraints on schedule

Long Abstract

The NRO CAAG developed an NRO-specific version of the Programmatic Estimating Tool (PET) (extending previous research completed for NASA) as an enhancement to our Agency Cost Position (ACP) process. As part of the development of ACPs, we estimate program cost, schedule, and the associated budget phasing profiles. To support these efforts, we have developed rigorous analytical cost, schedule, and phasing methods and models. However, they are typically developed and applied independently. The challenge this creates is insufficient understanding of the impact of programmatic constraints along one dimension on the output of the other two dimensions. The primary advantage of PET is that it provides an integrated approach to addressing these challenges.

The foundation of PET is the implementation of a conditional probability distribution in three-dimensional space. Using matrix algebra and the correlation between each dimension pair (cost and schedule, cost and phasing, schedule and phasing), PET computes the ***conditional mean*** of any dimension (cost, schedule, phasing) given the other two. Additionally, it allows computation of the conditional probability of any dimension (cost, schedule, phasing) given the other two. Using this approach ensures cost, schedule, and budget phasing are internally consistent in our estimates or in estimates being assessed.

I. Introduction

The National Reconnaissance Office (NRO) is a Joint Department of Defense/Intelligence Community organization responsible for developing, launching, and operating America's intelligence satellites to meet the national security needs of our nation. Within the NRO, the Cost and Acquisition Assessment Group (CAAG) is the office responsible for developing Agency Cost Positions (ACPs) and (when delegated by the Office of the Director of National Intelligence (ODNI)) Independent Cost Estimates (ICEs) for select satellite systems. The CAAG employs a robust, data-driven process that has evolved over three decades to develop ACPs. For all Major Systems Acquisitions (MSAs), and other programs as required, the CAAG develops parametric estimates of program cost, schedule, and phasing. The foundation of these estimates are rigorously developed estimating methodologies that constantly evolve as new data becomes available.

In addition to evolving existing estimating methodologies, the CAAG routinely seeks to improve our estimating process through the development and addition of new tools and/or estimating methodologies that take into account situations that the traditional estimating methodologies may lack. For example, the CAAG has developed, and now employs, a methodology for adjusting system estimating based on the level of acquisition complexity and mission assurance that is planned as part of the program. This Mission Assurance and Acquisition Complexity (MAAC) model was briefed at the ICEAA International Conference and Symposium in Portland, Oregon in June 2017. [1]

Similarly, the Programmatic Estimating Tool (PET) seeks to implement a methodology to account for a potential gap in current estimating techniques. PET, initially developed in support of NASA [2], integrates program cost, schedule, and budget phasing into a single tool in support of the CAAG ACP process for estimating Space Systems. This integration is necessary because, while cost, schedule, and phasing are all estimated parametrically, they are developed mostly independently. Therefore, the traditional CAAG approach does not explicitly model the correlation between cost, schedule, and phasing. This is especially the case when the official program of record reflects cost, schedule, or phasing plans that differ significantly from those resulting from CAAG methodologies.

The remainder of this paper provides a detailed introduction to PET. Section II provides a general overview of PET and how it fits into the CAAG ACP process. Section III describes the mathematical foundations of PET, which would remain identical regardless of application. Section IV walks through an example of the application of PET. Although this paper describes PET in detail in the context of the NRO ACP process, PET is a very flexible tool and can be applied in any situation where separate parametric estimates for cost, schedule, and phasing are available and where sufficient historical data exists to estimate correlation between these three dimensions. Section V discusses other uses of the trivariate distribution for cost, schedule, and phasing analysis

II. Description

PET uses historical correlation between cost, schedule, and phasing estimate ***residuals*** to generate a tri-variate conditional distribution. The resulting distribution can be used to estimate the impact of deviations due to practical realties from the estimates of any two of the dimensions on the third dimension. For example, PET can be used to estimate:

- Schedule and/or phasing deviations (from CAAG models) on the cost estimate
- Cost and/or phasing deviations (from CAAG models) on the schedule estimate

The primary use for PET within the CAAG is to estimate the cost and/or schedule impact of a constrained budget profile. In this case, PET would be used to add cost and/or schedule to the existing ACP to account for a constrained budget profile. To understand the value of the tool, and why the need arises, it is useful to take a step back and explain the CAAG ACP process. This will make clear those elements of the estimating process (as it applies to the NRO) that are untouched by PET, those that are improved by PET, and those that are (almost) entirely new as a result of PET. This will also make clear why the application of PET may be narrower in cases, such as the NRO, where the ACP informs the budget. In cases where the ACP does not inform the budget, PET would become more valuable (the application in these cases will be discussed in a later section).

Figure 1 provides an outline of the CAAG ACP process. Areas highlighted in red are those that are either newly integrated or improved by PET.

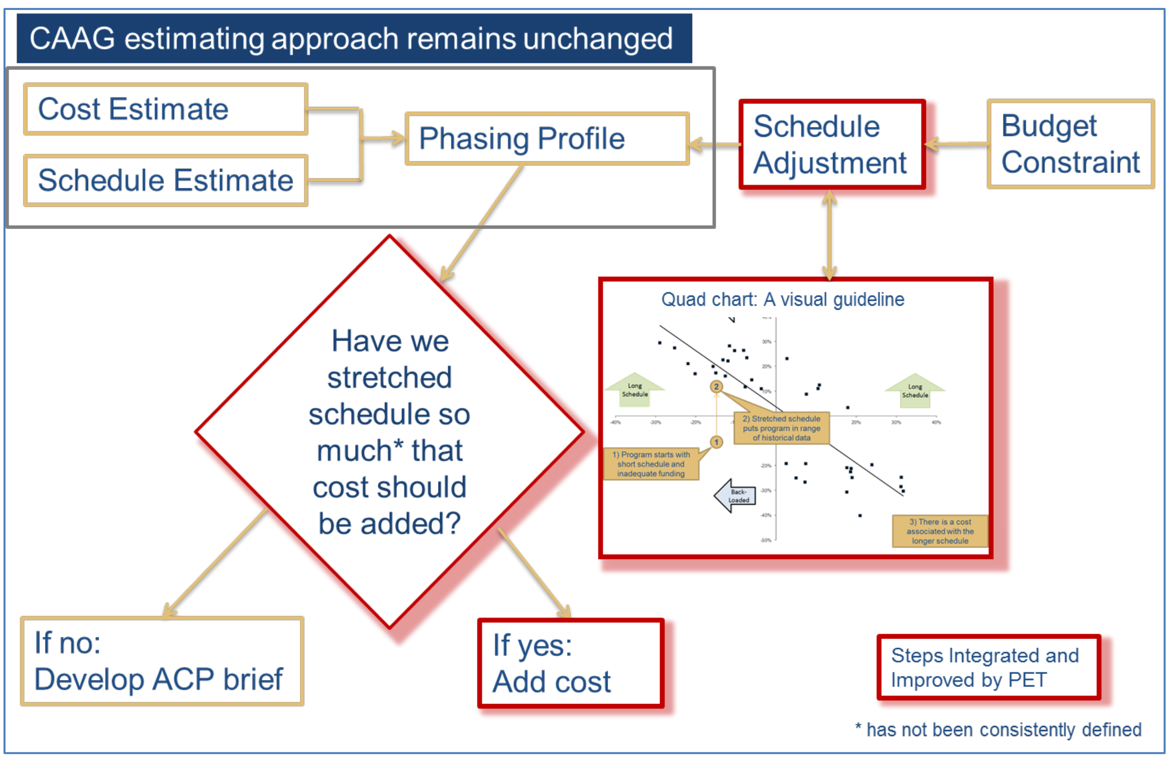

Figure 1: CAAG ACP Process Overview (w/PET Integrated)

The process starts with the development of parametric estimates of the cost, schedule, and phasing profile of a system. These estimates are derived separately, but are related functionally and therefore reflect some level correlation between cost, schedule, and phasing. However, if the cost, schedule, or phasing profile of a program of record deviates significantly from the estimate, the effect of this on the other two dimensions is not fully captured through functional correlation. The purpose of PET is to use the correlation between historical cost, schedule, and phasing residuals to provide an estimate of this effect. The underlying premise (which is borne out by historical program data) is, when the actual phasing (for example) of a program is more back-loaded (for example) than indicated by CAAG models, the actual program cost and schedule cannot be expected to deviate from their respective models randomly. Rather, the cost and schedule residuals are correlated with phasing-model residuals. Specifically, a program with a profile that is more back-loaded than data-driven phasing models otherwise indicate will have a tendency to also be more costly and take longer than similar data-driven cost and schedule models.

Deviations from the modeled cost, schedule, or phasing arise for multiple reasons. Program cost, schedule, and phasing plans may come from program office estimates or potentially from contractor estimates. Estimates from these sources may have the tendency to be overly optimistic and back-loaded to fit within available budgets. In some environments, the independent estimate may not be taken seriously, with the result often being programs that are under-funded, optimistically scheduled, and inappropriately phased. This situation, fortunately, is less likely than in the past, with the growing focus in the past decade on the impact of credible cost and schedule analysis on acquisition outcomes. In particular, at the NRO, programs are required to be budgeted to the Independent Cost Estimate (ICE), whether done by the ODNI or the NRO CAAG. In cases where the budget is set by ODNI, the CAAG performs an ACP that serves as a robust cross-check on the ICE. In other words, the value placed on independent cost estimating in this environment is high. Even in this case however, an initial program is put in place prior to completion of the ICE. The ICE will result in a change to the baseline program cost, and can certainly influence the schedule and the phasing profile. However, there may be limitations to the extent to which altering the phasing profile are possible. Phasing profiles, especially in execution year and the budget year may be locked and be extremely difficult to change. This may result in a profile that is significantly different from the estimates.

While PET offers a new and enhanced approach to this problem, the understanding that the problem exists is not new to the CAAG. In particular the relationship between schedule and phasing has been recognized and a method for adjusting estimates accordingly is a standard part of the CAAG process. Schedule and budget residuals are positively correlated. Figure 2 illustrates the relationship and outlines the CAAG approach to addressing it.

The third dimension (not shown in Figure 2) is cost. We know a longer schedule is associated with higher cost. Further, a back-loaded profile is correlated with higher cost. Therefore, cost should be added in those cases where a schedule estimate is increased as a result of a back-loaded phasing profile. With PET, CAAG now has an explicit data-driven method for dealing with this.

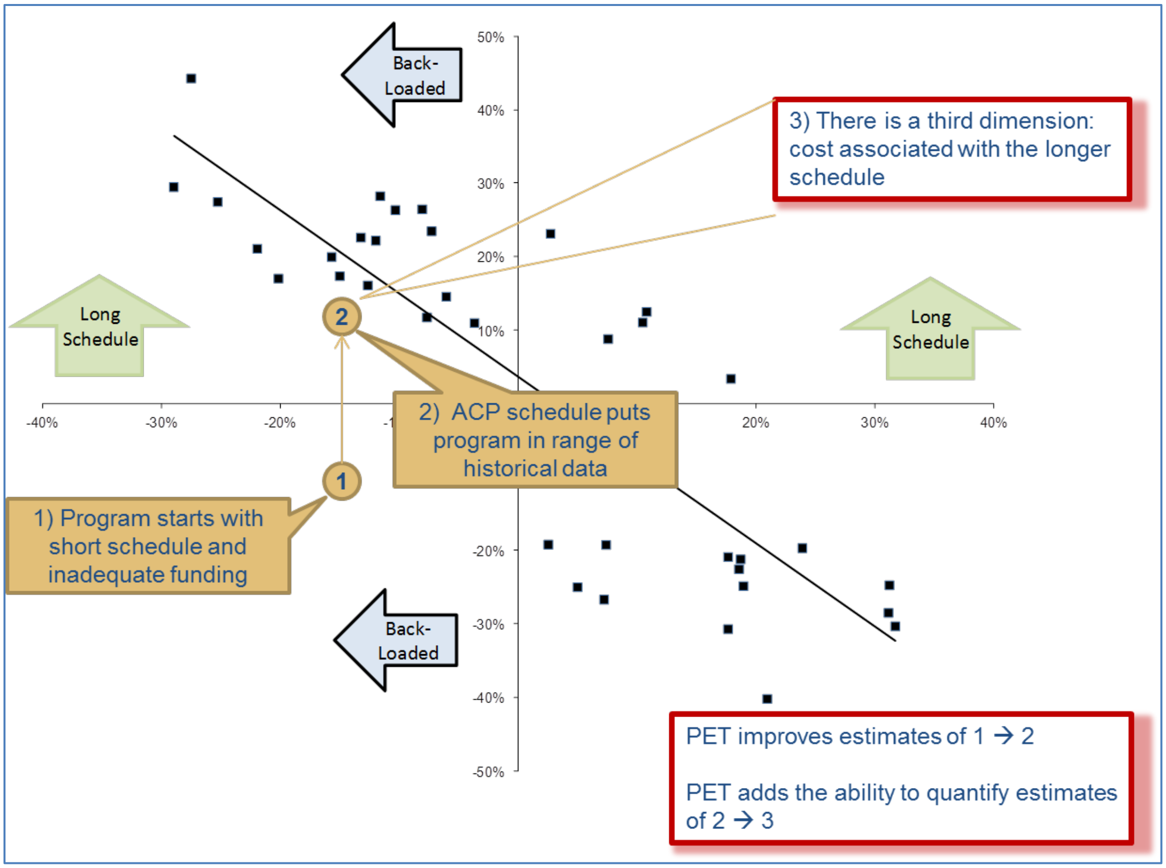

Figure 2: Schedule and phasing residuals from CAAG models. Back-loaded programs tend to have longer schedules than the baseline schedule models would predict.

III. PET Methodology

In 1993, Garvey [3] described a set of models that calculate conditional probability in the bivariate case of cost and schedule. PET uses the same underlying methodology expanded to a third variable of phasing. PET forms and applies a tri-variate probability distribution of the residual values of historical actuals vs. parametric models. The three axes of the tri-variate probability distribution are the following:

- Axis 1: Residual errors from cost estimating relationships (CERs)
- Axis 2: Residual errors from the parametric schedule estimating relationships (SERs)
- Axis 3: Residual errors from the parametric phasing estimating relationships (PERs)

Residual error distributions from these models are well approximated by normal or lognormal distributions, and these distributional assumptions underlie this version of PET. Other "distribution-free" options are available using discrete sampling, but they are computationally intensive to implement and are beyond the scope of this paper. With our distributional assumptions (verified by the usual tests), PET uses matrix algebra and Excel's built-in statistical look-up functions to:

- Compute conditional mean of any dimension (cost, schedule, phasing) given the other two
- Compute conditional confidence level of any dimension (cost, schedule, phasing) given the other two
- Compute the joint confidence level of any two dimensions (e.g., cost and schedule) given the other one (e.g., phasing)

The key capability of this approach is a quantifiable inter-relationship between cost, schedule, and phasing that goes beyond functional correlation. This allows adjustments to cost, schedule, or phasing in those cases where one or more are constrained. A key note of caution: PET is not a causal model of the impact of schedule changes on cost. They are treated as correlated random variables. PET cannot be used, for example, to estimate the cost impacts of schedule compression.

The tri-variate conditional distribution is defined as follows: [4]

$X = (X_1, X_2, X_3)$ is a 3-dimensional random vector where;

- X_1 is the cost estimate (CER-based)
- X_2 is the schedule estimate (SER)
- X_3 is the phasing estimate (PER)

The expected vector of X is μ. The variance-covariance matrix is $\Sigma = \mathrm{Cov}(X_i,X_j)$, i, j = 1, ..., 3.

From here we partition using the following:

- Say X_1 is a sub-vector of X with dimension 1 (e.g., SER)
- Then X_2 is the remainder of X with dimension 2 (e.g., PER, CER)

Thus,

$$X = \begin{bmatrix} X_1 \\ X_2 \end{bmatrix} \qquad \mu = \begin{bmatrix} \mu_1 \\ \mu_2 \end{bmatrix} \qquad \Sigma = \begin{bmatrix} \Sigma_{11} & \Sigma_{12} \\ \Sigma_{21} & \Sigma_{22} \end{bmatrix}$$

The conditional distribution of X1 given X2 is distributed as:

$$X_1 | X_2 \sim N_m(\mu_1 + \Sigma_{12}{\Sigma_{22}}^{-1}(X_2 - \mu_2), \Sigma_{11} - \Sigma_{12}{\Sigma_{22}}^{-1}\Sigma_{12}')$$

Given this, the conditional mean and variance are known exactly. Microsoft Excel using the NORMDIST functions calculates the probabilities. Similar solutions are worked out in cases where one or more of our dimensions are modeled as lognormal distributions.

The foundation of PET is correlated residuals amongst our cost, schedule, and phasing models. This requires a best estimate of pairwise correlations among models (cost/schedule; cost/phasing; schedule/phasing). Our approach is to develop multiple estimates of program cost, schedule, and phasing, and compare them to the historical actual cost, schedule, and phasing for as many programs as possible. These are not typical early-program estimates, where many of the technical inputs are not well known. Instead, CAAG uses a “Retro-estimate” process whereby we estimate the cost, scheduled, and phasing of completed programs using our latest methodologies. This provides us with what our models would have predicted for cost, schedule, and phasing of a completed program to compare with the actual cost, schedule, and phasing.

Table 1 below provides an overview of the number of programs for which we have performed retroactive analysis and the resulting correlations. Performing retroactive cost analysis is relatively speaking a complex endeavor as compared with retroactive schedule and phasing analyses. As a result, this analysis has been performed the most for schedule (70 programs), second for phasing (46), and the least for cost (29). Figure 3 shows the overlap between the three models, where more overlap equals more accurate estimate of correlation.

Counts	Cost	Phasing	SER
Cost	29		
Phasing	24	46	
SER	25	44	70

Table 1: Maximized Sample Size

A sanity check of the results, as seen in Table 2, shows that the resulting correlations are logical.

Correlations	Cost	Phasing	SER
Cost	1		
Phasing	-0.18	1	
SER	0.25	-0.80	1

Table 2: Resulting Correlations

Remember that our measure for phasing is such that a higher value reflects more front-loading of program dollars. Thus, a negative correlation between cost and phasing (-0.18) means that “back-loaded” phasing profiles are associated with increased cost. Likewise, schedule and phasing are negatively correlated (-0.80), as indicated earlier in the “quad chart.” Thus, “back-loaded” phasing results in longer schedules. On the other hand, cost and schedule are positively correlated (0.25) meaning that longer programs tend to be associated with increased cost.

IV. Example

This section walks through an example of the implementation of PET. This example is notional, and not indicative of the parameters of any real program. Referring back to Section II and the description of the

NRO CAAG ACP process, PET does not influence the initial estimating process. Therefore, the ACP proceeds as any other would, with the development of cost, schedule, and phasing models. The cost estimate follows the typical CAAG process and is developed parametrically at a detailed WBS level. Schedule and phasing are estimated parametrically as well, but at the space system level. For the purposes of this example, the parameters used to estimate space system schedule and phasing are shown in Table 3 below.

Technical & Programmatic Parameters (Drive Schedule & Phasing)	
ATP Date	20 AUG 18
Vehicle Quantity	1
Design Life	24 Months
# Mission Types	1
Vehicle Weights	1,000 lbs
Option on Prior Contract	0
Primary PL is GFE	1
Storage > 1 yr	0
Competitive Award	0

Table 3: Technical & Programmatic Parameters

Table 4 shows the cost estimate that resulted from the detailed WBS build-up and the schedule estimate (to last launch).

Estimate Results	CAAG Model
Cost	$100M
Launch Date	01 JAN 22

Table 4: Cost & Schedule Estimate

Figure 3 shows the predicted phasing profile.

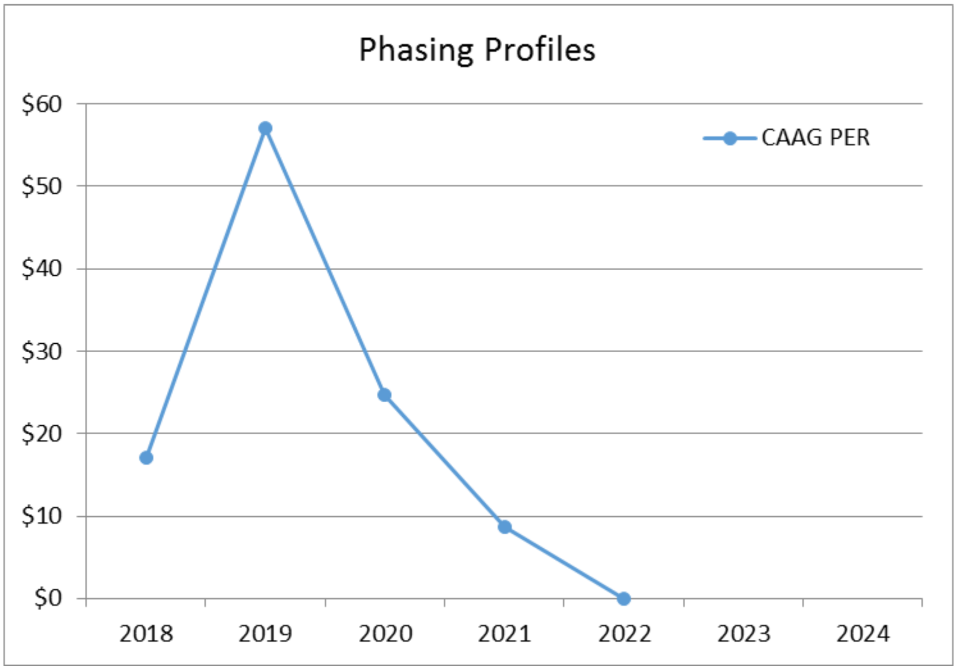

Figure 3: Predicted Phasing Profile

In an unconstrained environment where the ACP set not only the budget level, but also the schedule and the phasing profile, this would be the end of the analysis. However, there are many competing priorities and the budget is therefore constrained. In this case, the constraint on early year funding is significant. Figure 4 shows the constrained budget for the first three years of the program. It is clear from this that the budget profile predicted by the PER is not feasible and the profile will be far more back-loaded than the prediction.

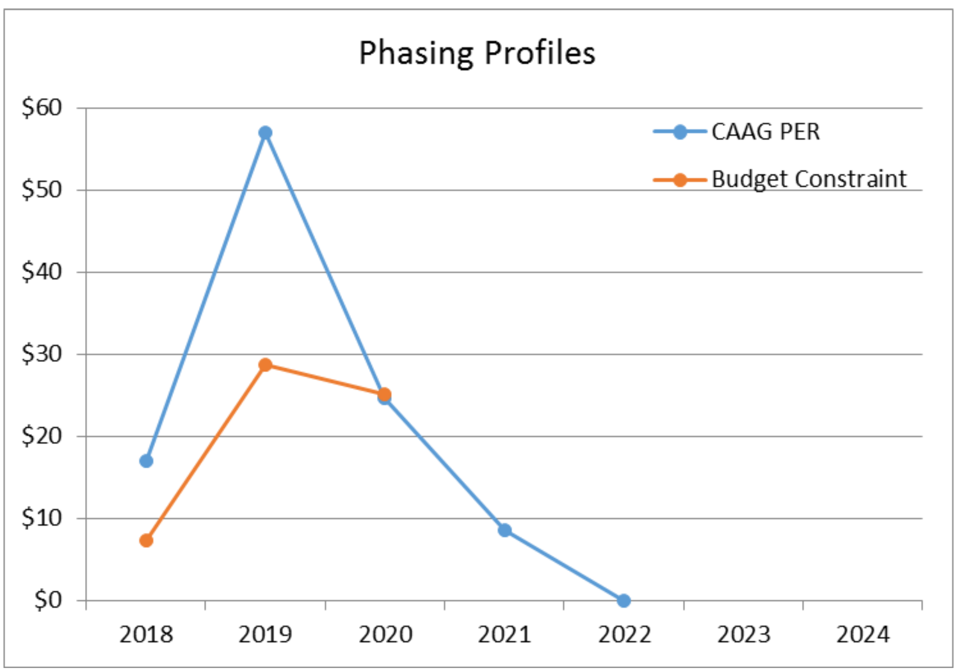

Figure 4: Constrained Phasing Profile

This is not an uncommon occurrence and the ACP process has a method for making schedule adjustments in the face of this sort of constraint. Using the Quad Chart as guidance, a judgment was made to extend the schedule by 16 months and the phasing profile was adjusted to reflect this. The results of this are shown in Table 5 and Figure 5.

Estimate Results	CAAG Model	ACP Adjustment
Cost	$100M	None
Launch Date	01 JAN 22	01 OCT 23

Table 5: ACP Adjustment

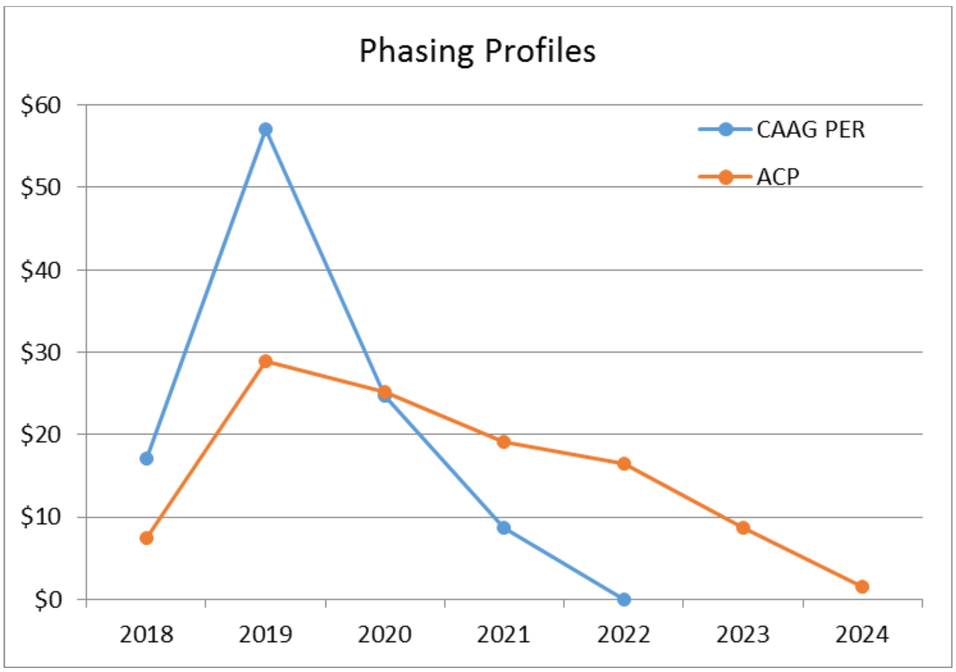

Figure 5: Adjusted Phasing Profile

It is at this point that PET enters the process. Step 1 is the evaluation of the ACP. Notice that the existing process did not make any adjustments to cost as a result of the change to the schedule and the phasing profile. However, as outlined in Section III, analysis of historical data indicates that stretched schedules that are relatively speaking back-loaded tend to have higher cost. PET allows us to evaluate the ACP cost in the context of the loner schedule and back-loaded phasing profile. Additionally, it allows us to evaluate the adjustment that was made to the schedule as part of the ACP process.

In order to proceed with the evaluation of the ACP, a few inputs are required. This is relatively straightforward, as all PET inputs are either inputs to the ACP or are outputs of the ACP. In other words, no new inputs are required. The required inputs include the following:

- Phased TY$M cost estimate
- All parameters required to run the CAAG Schedule model (SER)
- All parameters required to run the CAAG phasing model (PER)
- Adjusted ACP planned first and last launch dates (the same in the this example as there is a single launch)

These inputs combined establish the tri-variate distribution required to generate results from PET. Figure 6 shows the initial results from our example, which allow us to evaluate the ACP cost and schedule taking into account the interactions between cost, schedule, and phasing residuals.

NOTE: APPLICABLE ONLY TO SPACE SYSTEMS

Project Inputs

Yellow inputs cells | Green PET adjustments

Program Name *Notional*

Technical Parameters

24	Design Life (Months)
1	# Mission Types
1,000	Vehicle Weight

Schedule Parameters

4/1/2018	ATP or SRR Date
10/1/2023	Planned Last Launch
10/1/2023	Planned First Launch

Programmatic Parameters

1	Vehicle Quantity
0	Option on Prior Contract
1	Primary PL is GFE
0	Storage > 1 yr
0	Competitive Award

ACP By Year ($M) for Space Segment Scope

Fiscal Year	2018	2019	2020	2021	2022	2023	2024	2025	2026
Original ACP	$7	$29	$25	$19	$16	$9	$2	$0	$0
Adjustments									

2018	Base Year
$100	Original ACP (BY18$M) for Space Segment
$100	Adjusted ACP (BY18$M) for Space Segment

Key Outputs

	ACP	PET Conditional m	Delta $M	Delta %
Cost	$100	$108	$8	8.1%

	ACP	PET Conditional m	Delta Months	Delta %
Schedule	66	63	-3	-4.2%

Figure 6: Initial PET Results

All yellow cells are inputs that are required to run the initial model to be evaluated. The orange cells are outputs. If we focus on key putputs, we see that the extension of the schedule and the back-loaded nature of the phasiong profile have resulted in an ACP cost that is too low by 8.1%. We can compute this using the ACP cost value and the PET conditional mean cost value. The latter is the conditional mean cost based on the trivariuate distribution of cost, schedule, and phasing. The Delta cell reflects the adjsutment tjhat should be made in order to make cost consistent with the adjsuted schedule and constrained phasing of the ACP. Adfdiitonaly, when we look at the schedule outputs, we see that the PET Conditional mean schedule length differs from the adjsuetd ACP schedule. In this case though, ouradjusted schedule was 4.2% too long.

Next we move to Step 2, which is to adjust the ACP based on these findings. In PET, cells colored green are where changes to cost and schedule can be adjusted. (Cells colored red are used to highlight budget years that are viewed to be constrained and therefore should not be adjusted). Figure 7 below shows the adjustments that have been made in our example. Note that this is an iterative process, as any changes to cost or schedule will require further adjustment to the other two dimensions. Depending on the level of precision required, the model typically converges to a solution after a few iterations.

ACP By Year ($M) for Space Segment Scope

Fiscal Year	2018	2019	2020	2021	2022	2023	2024
Original ACP	$7	$29	$25	$19	$16	$9	$2
Adjustments				$1	$2	$8	-$2

2018	Base Year
$100	Original ACP (BY18$M) for Space Segment
$107	Adjusted ACP (BY18$M) for Space Segment

Key Outputs

Cost	ACP	PET Conditional m	Delta $M	Delta %
	$107	$107	$0	0.0%
Schedule	ACP	PET Conditional m	Delta Months	Delta %
	64	64	0	0.0%

Figure 7: PET Adjustments

The result in this example is about $7M additional cost (7.0%) and a schedule reduction of 2 months relative to the original ACP. So the ACP results before applying PET would have been too low with a schedule that was too long – a bad combination. The PET-adjusted phasing (our conditional mean) can be seen in Figure 7 above and Figure 8 below.

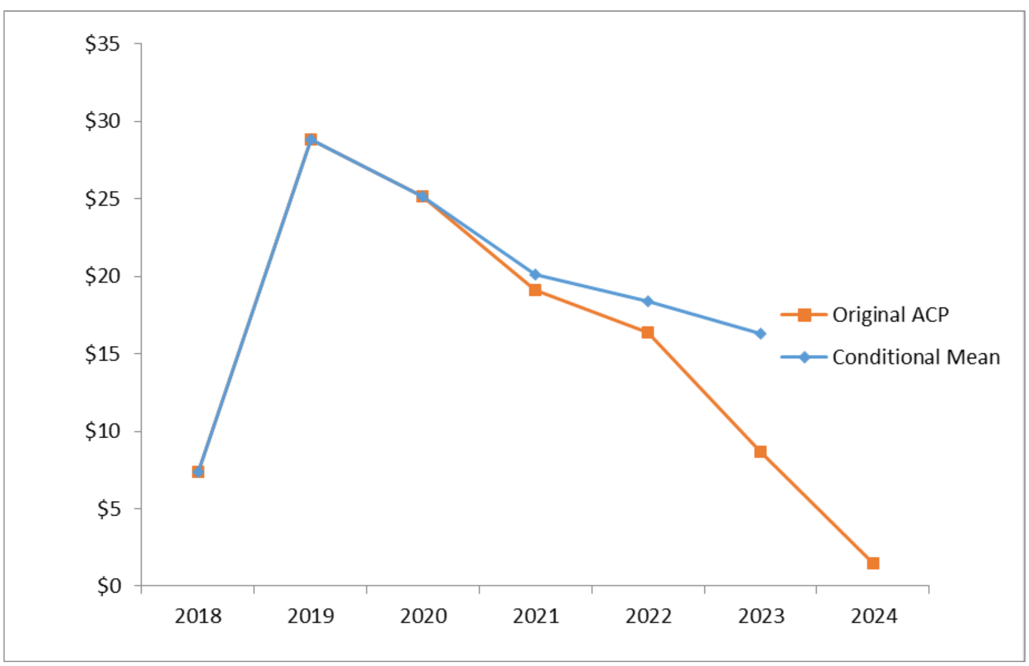

Figure 8: PET Adjusted Phasing Profile

V. Other Uses of the Tri-Variate Distribution

Section IV outlines the primary use of PET as part of the NRO ACP process. However, there are other useful outputs generated by PET that could provide value in other contexts. Specifically, PET can quantify

- the conditional probability of meeting a cost target given schedule and phasing constraints
- the conditional probability of meeting a schedule target given cost and phasing constraints
- the joint probability of hitting a cost and schedule target given a phasing constraint

Additionally, PET allows the user to input a desired probability level for both cost and schedule and will provide the cost and schedule required to meet that target. Figures 9 – 11 demonstrate these outputs in the context of the example in Section IV.

Figure 9 shows the output related to the probability of meeting cost, given phasing and schedule constraints. Given a back loaded schedule (reflected in the -37% phasing residual) and a long schedule (reflected in the 47% schedule residual) the probability of meeting the cost target (ACP cost) is 42%. This is consistent with the result in Section IV of a 7% increase in cost required to meet the conditional mean cost. If the goal is an 80% probability, cost would rise to $128M, an increase of 28% over the ACP of $100M.

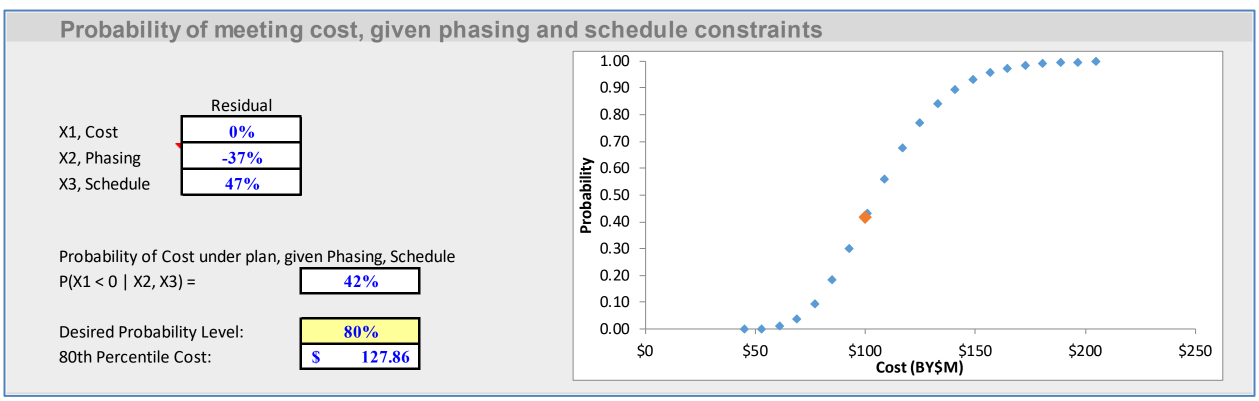

Figure 9: Probability of meeting cost, given schedule & phasing

Figure 10 shows the output related to the probability of meeting schedule, given phasing and cost constraints. Given a back loaded schedule (reflected in the -37% phasing residual) and the ACP cost (reflected in the 0% cost residual) the probability of meeting the schedule target (ACP schedule) is 70%. This is consistent with the result in Section IV of a 4.2% decrease in schedule required to meet the conditional mean schedule. If the goal is an 80% probability, schedule would rise to 68 months, an increase of 2 month over the ACP of 66 months.

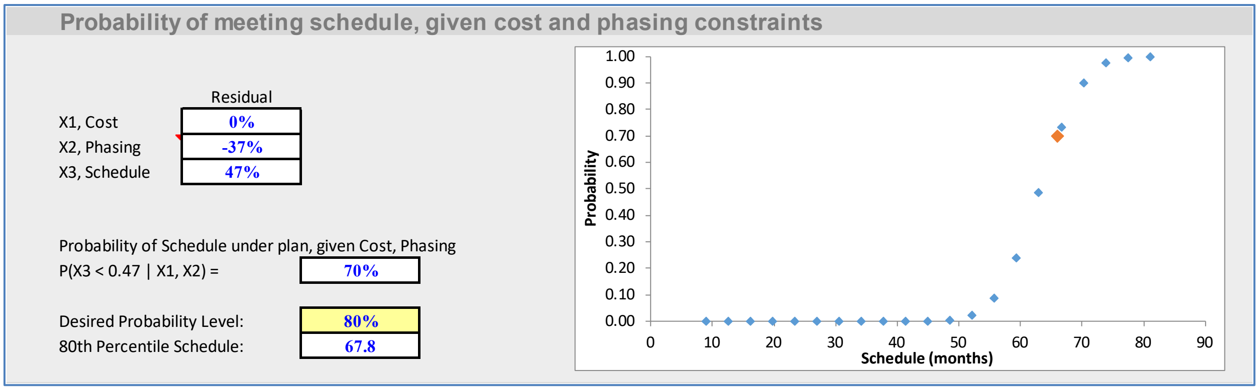

Figure 10: Probability of meeting schedule, given cost and phasing

Figure 11 shows the output related to the joint probability of meeting cost and schedule, given a phasing constraint. Given a back loaded schedule (reflected in the -37% phasing residual) the probability of meeting the cost and schedule target (ACP) is 30%.

Probability of meeting both cost and schedule, given a phasing constraint

	Residual
X1, Cost	0%
X2, Phasing	-37%
X3, Schedule	47%

Joint probability of both Schedule and Cost under plan, given Phasing
P(X1 < 0, X3 < 0.47 | X2) = 30%

Figure 11: Probability of meeting cost & schedule, given phasing

VI. Conclusion

The need for the capability provided by the Programmatic Estimating Tool (PET) arises because the normal estimating process misses key interactions between the estimates for cost, schedule and phasing. These estimates are usually related, but developed independently. Further, constraints on any one of these dimensions are often not fully (if at all) factored into the estimates for the others. However, using a tri-variate distribution of correlated residuals, these interactions can be modelled. PET provides a user-friendly, automated approach to that modeling.

Originally developed for NASA, the NRO CAAG has adapted PET to serve our needs in formulating Agency Cost Positions. PET provides a consistent method for evaluating the interactions between cost, schedule, and phasing based on historically derived correlation. Further, PET is a flexible tool that can be adapted to meet the needs of any agency. The cost, schedule, and phasing estimating relationships embedded in the NRO version of PET are specific to the NRO and are not portable. However, all that is required to operate PET is historical data on cost, schedule, and phasing estimates and actuals and agency-specific cost, schedule, and phasing methods. The PET tool itself can be updated to accommodate other models.

Bibliography

[1] Burgess, E. "Cost Associated with Acquisition Complexity and Differing Levels of Mission Assurance." Presented at the International Cost Estimating and Analysis Association symposium, Portland, OR, June 2017.

[2] Elliott, D., Burgess, E., Krause, C. "Programmatic Estimating Tools." Presented at the 2015 NASA Cost Analysis Symposium, August 2015.

[3] Garvey, P. "A Family of Joint Probability Models for Cost and Schedule Uncertainties." 27th Annual Department of Defense Cost Analysis Symposium, September 1993.

[4] Eaton, M. "Multivariate Statistics: a Vector Space Approach". John Wiley and Sons, 1983. pp. 116-117.

Biography – William Laing

William Laing is a Program Manager at Technomics, Inc. He has 19 years of experience performing cost analysis, economic analysis, portfolio analysis, and program assessments for intelligence, defense, and civil agency clients. He has developed cost estimates, performed cost research and methodology development, and constructed cost databases on a range of commodities, including satellites, aircraft, ships, ground vehicles, and automated information systems. Mr. Laing earned his M.A. and B.A. in Economics from George Mason University.

Biography - Erik Burgess

Erik Burgess has provided cost estimating and program support to the National Reconnaissance Office since 1995, and prior to that he supported space programs at the USAF Space and Missile Systems Center as an engineer and cost estimator. He is the president of Burgess Consulting Inc., and has also served with the Aerospace Corporation, PriceWaterhouseCoopers, and MCR, LLC. Mr. Burgess earned his M.S. and B.S. in Mechanical Engineering from the Massachusetts Institute of Technology.