NATIONAL RECONNAISSANCE OFFICE

Programmatic Estimating Tool (PET):
Conditional Estimates of Cost, Schedule & Phasing

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ICEAA International Conference and Symposium
May 2019

SUPRA ET ULTRA

Agenda

- NRO CAAG Overview
- PET and the ACP Process
- PET Methodology
- PET Example
- Conclusion
- Contact Information

The NRO CAAG

NRO: National Reconnaissance Office

- 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.

CAAG: Cost and Acquisition Assessment Group

- Independent Cost Estimates / Agency Cost Positions (ACPs)

  …“How much will it cost?”

- EVM Center of Excellence

  …“Is the baseline executable?”

PET & THE ACP PROCESS

PET Overview

- The Programmatic Estimating Tool (PET)
  - Integrates program cost, schedule, and budget phasing into a single tool in support of the CAAG ACP process for estimating Space Systems
  - Originally developed for NASA*
  - Significant modifications made to the inputs and outputs to align with NRO CAAG approach to program estimates
  - Underlying methodology remains unchanged
- Uses historical correlation between cost, schedule, and phasing estimate residuals to generate a tri-variate conditional distribution to estimate the impact of:
  - Schedule and/or phasing deviations (from CAAG models) on the cost estimate
  - Cost and/or phasing deviations (from CAAG models) on the schedule estimate
- Primary use:
  - Estimate the cost and/or schedule impact of a constrained budget profile

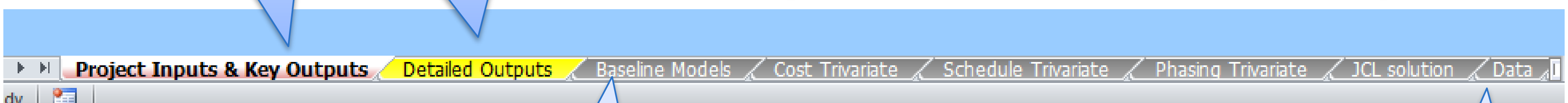
* Burgess, E., Elliott, D., and Hunt, C., "Programmatic Estimating Tool: Parametric-Based Cost, Schedule & Phasing Health Check," 2015 NASA Cost Symposium, Ames Research Center, Moffet Field, CA. 26 August 2015.

PET is 8 Linked Worksheets

Inputs and final results on Sheet 1

Details and intermediate results on Sheet 2

Math for evaluating the tri-variate distribution in various combinations of conditions



Baseline Cost, Schedule, and Phasing Models are implemented here

Implement new baseline models on these two sheets

Residuals from three baseline models are here.

CERs: Cost Estimating Relationships
SERs: Schedule Estimating Relationships
PERs: Phasing Estimating Relationships

NRO CAAG ACP Process

CAAG estimating approach remains unchanged

Cost Estimate

Schedule Estimate

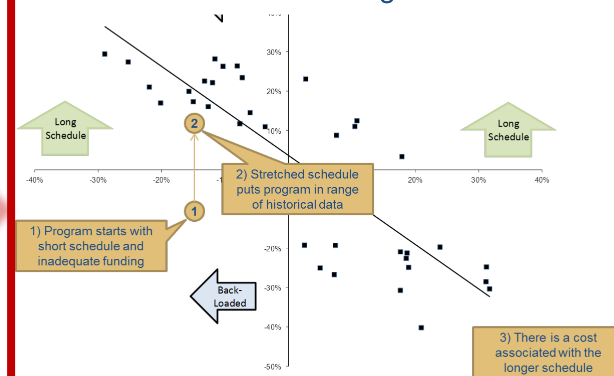
Phasing Profile

Schedule Adjustment

Budget Constraint

Have we stretched schedule so much* that cost should be added?

Quad chart: A visual guideline



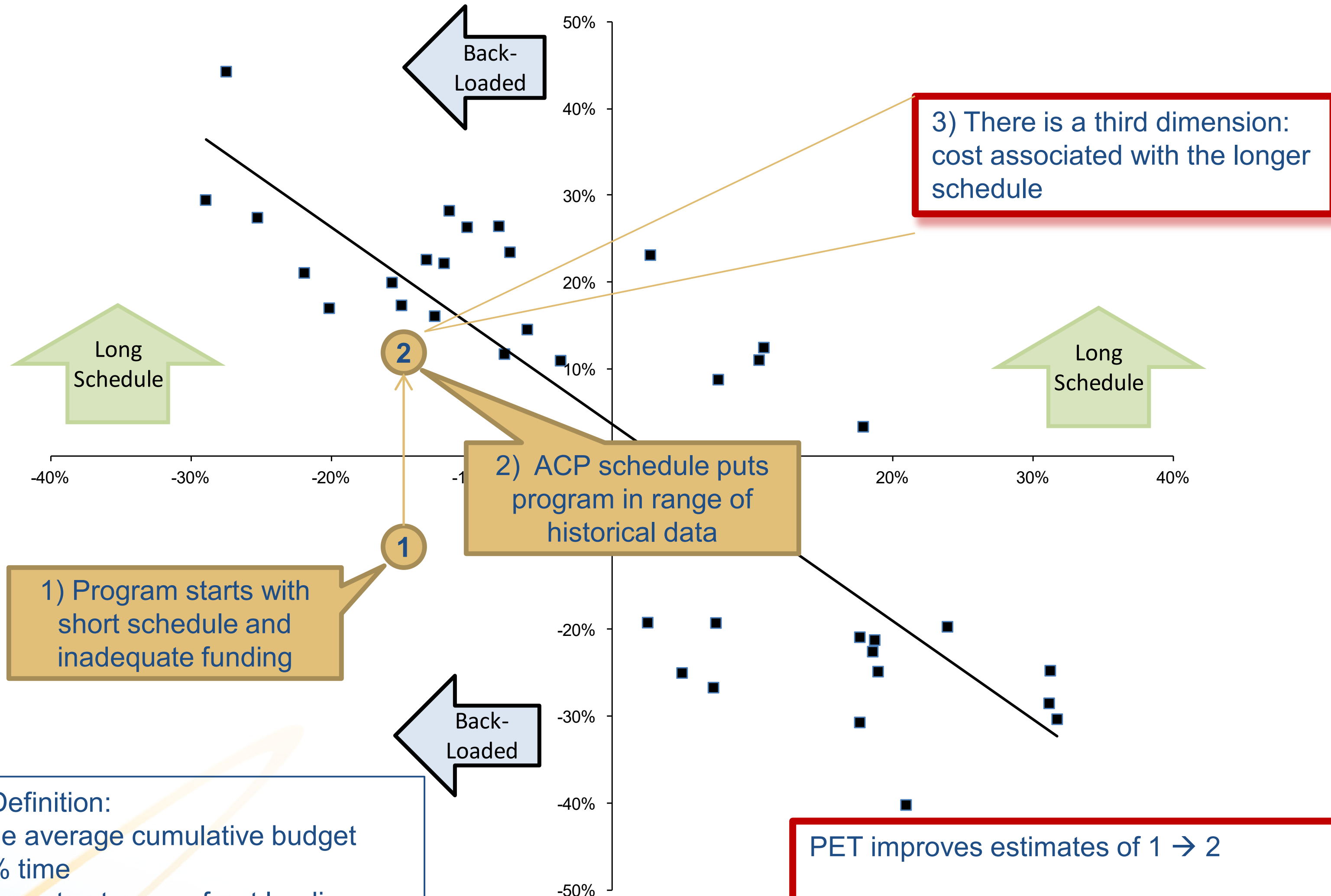
If no:
Develop ACP brief

If yes:
Add cost

Steps Integrated and Improved by PET

* has not been consistently defined

Example: ACP with Funding Constraint



Phasing Score Definition:
- Measure of the average cumulative budget over 20 – 60% time
- Higher value equates to more front loading

PET improves estimates of 1 → 2

PET adds the ability to quantify estimates of 2 → 3

NRO CAAG

PET METHODOLOGY

PET Methodology

- PET forms a trivariate probability distribution
  - Axis 1: Residual errors from CAAG cost model (CERs)
  - Axis 2: Residual errors from parametric schedule model (SER)
  - Axis 3: Residual errors from parametric phasing model (PER)

- Using matrix algebra (see next slide):
  - 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

- Key takeaways of the approach
  - Quantifies and ensures the interrelationship of cost, schedule, and phasing is modeled in the final CAAG ACP
  - Not a causal model of the impact of schedule changes on cost; treated as correlated random variables

Trivariate Conditional Distribution

- $X = (X_1, X_2, X_3)$ is a 3-dimensional random vector (e.g., SER, PER, CER)
  - The expected vector of **X** is μ
  - The variance-covariance matrix is $\Sigma = Cov(X_i, X_j)$, i, j = 1, ..., 3
- Partitioning:
  - Say $\mathbf{X_1}$ is a subvector of **X** with dimension 1 (e.g., SER)
  - Then $\mathbf{X_2}$ is the remainder of **X** with dimension 2 (e.g., PER, CER)

$$\mathbf{X} = \begin{bmatrix} \mathbf{X}_1 \\ \mathbf{X}_2 \end{bmatrix} \qquad \boldsymbol{\mu} = \begin{bmatrix} \boldsymbol{\mu}_1 \\ \boldsymbol{\mu}_2 \end{bmatrix} \qquad \boldsymbol{\Sigma} = \begin{bmatrix} \boldsymbol{\Sigma}_{11} & \boldsymbol{\Sigma}_{12} \\ \boldsymbol{\Sigma}_{21} & \boldsymbol{\Sigma}_{22} \end{bmatrix}$$

  - The conditional distribution of $\mathbf{X}_1$ given $\mathbf{X}_2$ is distributed as

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

- Conditional mean and variance are known exactly: Excel (NORMDIST) gives probabilities
- Similar solutions worked out for one or more lognormal distributions

Correlation Summary

- PET requires a best estimate of pairwise correlations among models
- More overlap = more accurate estimate of correlation
  - CER, SER residuals can be computed easily
  - Cost dataset is smallest (n=29), establishes minimum overlap

Maximized Sample Size

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

Resulting Correlations

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

- “back-loaded” phasing is associated with increased cost

- “back-loaded” phasing is associated with increased schedule

- Long schedules are associated with increased cost

PET EXAMPLE

Reminder: NRO CAAG ACP Process

CAAG estimating approach remains unchanged

Cost Estimate

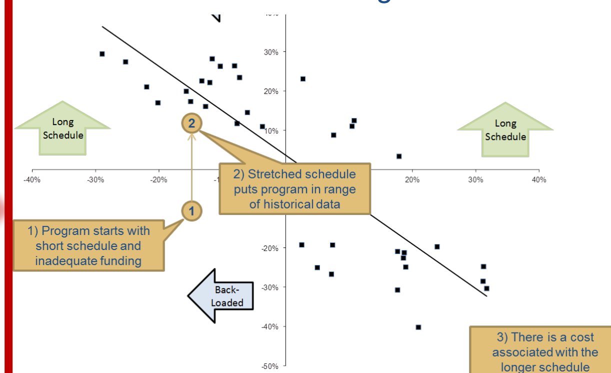
Schedule Estimate

Phasing Profile

Schedule Adjustment

Budget Constraint

Quad chart: A visual guideline



Have we stretched schedule so much* that cost should be added?

If no:
Develop ACP brief

If yes:
Add cost

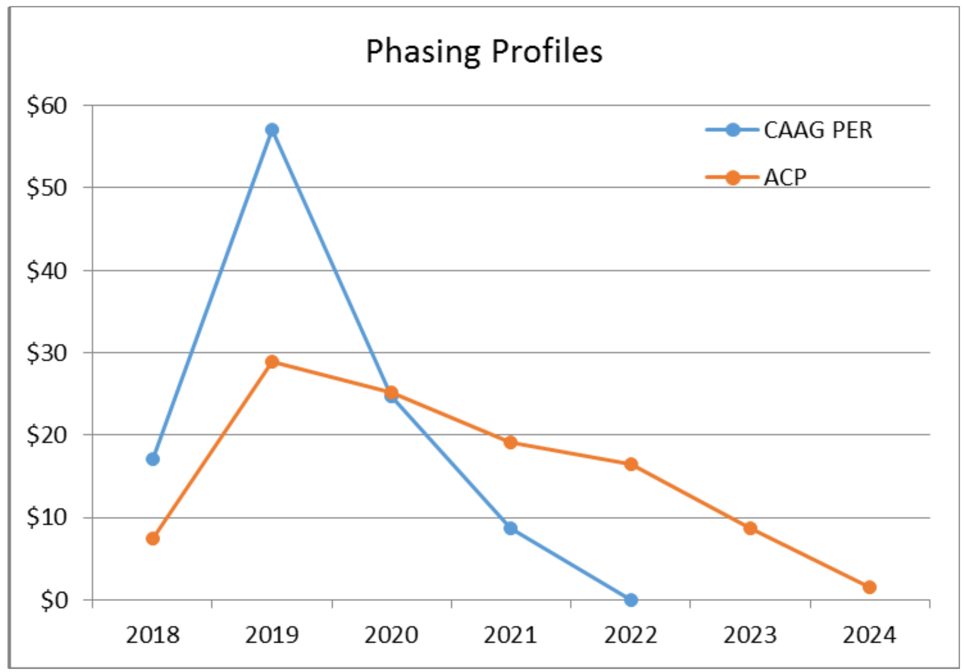
Steps Integrated and Improved by PET

* has not been consistently defined

Notional Program Example: ACP (Pre-PET)

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

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



Step 1: Evaluating the ACP

Inputs used to run baseline models and establish the trivariate distribution

NOTE: APPLICABLE ONLY TO SPACE SYSTEMS

Project Inputs

Program Name *Notional*

Yellow inputs cells

Green PET adjustments

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%

Expected cost, given the schedule and phasing inputs, is $8M higher than the ACP

Expected schedule, given the cost and phasing inputs, is 3 months shorter than the ACP

STEP 2: Adjusting the ACP

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

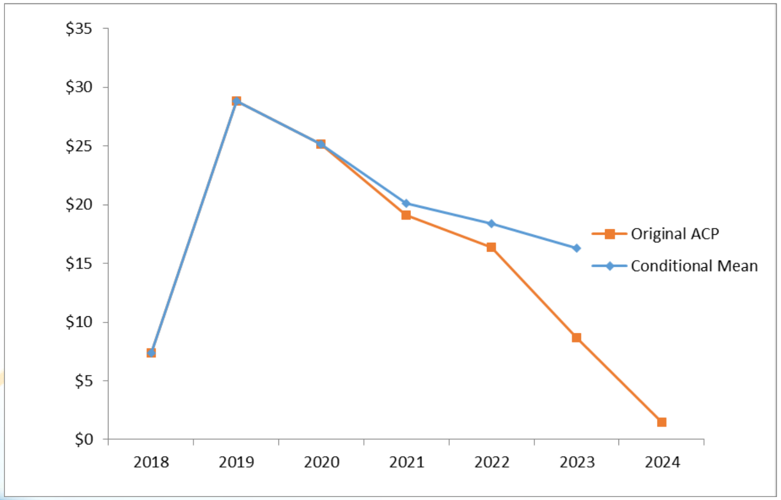
2018	Base Year
$100	Original ACP (BY18$M) for Space Segment
$107	Adjusted ACP (BY18$M) for Space Segment

Cost and schedule adjusted (manually) to bring both to their conditional means.

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%



Result:
- Expected (mean) cost and schedule conditioned on constrained funding
- Other confidence levels can be output

Other Uses of the Trivariate Distribution

Probability of meeting cost, given phasing and schedule constraints

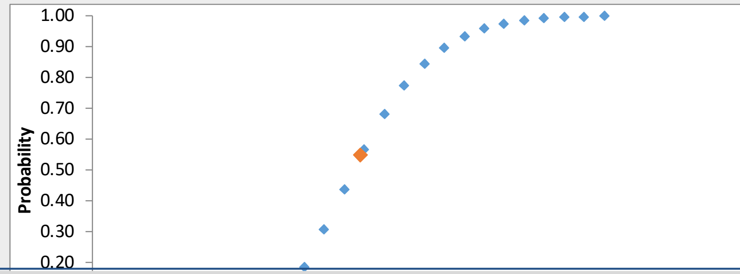
	Residual
X1, Cost	8%
X2, Phasing	-39%
X3, Schedule	43%

Probability of Cost under plan, given Phasing, Schedule

P(X1 < 0.08 | X2, X3) = 55%

Desired Probability Level: 80%

80th Percentile Cost: $ 127.42



Conditional probabilities of cost OR schedule

Probability of meeting schedule, given cost and phasing constraints

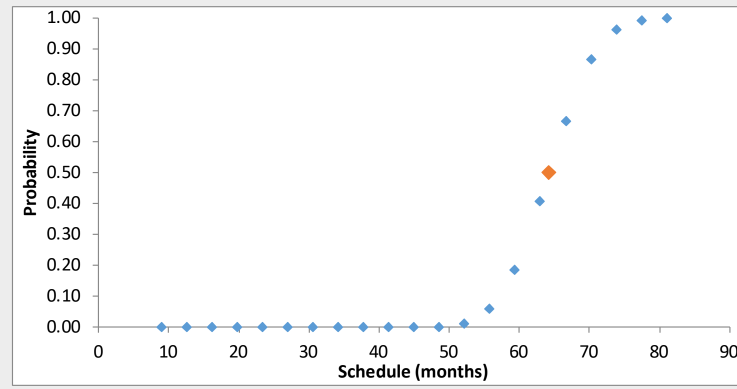
	Residual
X1, Cost	8%
X2, Phasing	-39%
X3, Schedule	43%

Probability of Schedule under plan, given Cost, Phasing

P(X3 < 0.43 | X1, X2) = 50%

Desired Probability Level: 80%

80th Percentile Schedule: 68.8



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

	Residual
X1, Cost	8%
X2, Phasing	-39%
X3, Schedule	43%

Joint probability of both Schedule and Cost under plan, given Phasing

P(X1 < 0.08, X3 < 0.43 | X2) = 28%

Conditional probability of cost AND schedule

Conclusion

- Cost, schedule and phasing estimates are often developed independently, but the interaction between them can be modelled

  - NRO CAAG has adapted NASA's PET project 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

- Version presented uses CAAG developed estimating relationships for space systems – but, the underlying methodology is not commodity (or agency) specific – can be easily updated with other estimating relationships

Contact Information

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