Being Certain about Uncertainty
(Part 2)

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Outline

- Let's Begin at the End
- What is Extreme Cost Growth?
- The Past as an Imperfect Teacher
- A Simplistic View of the World
- Why Management likes Complexity and Why it Doesn't Work
- The Joint Cost Schedule Confidence Level – A Panacea?
- Predicting the Future
- Conclusions

The End

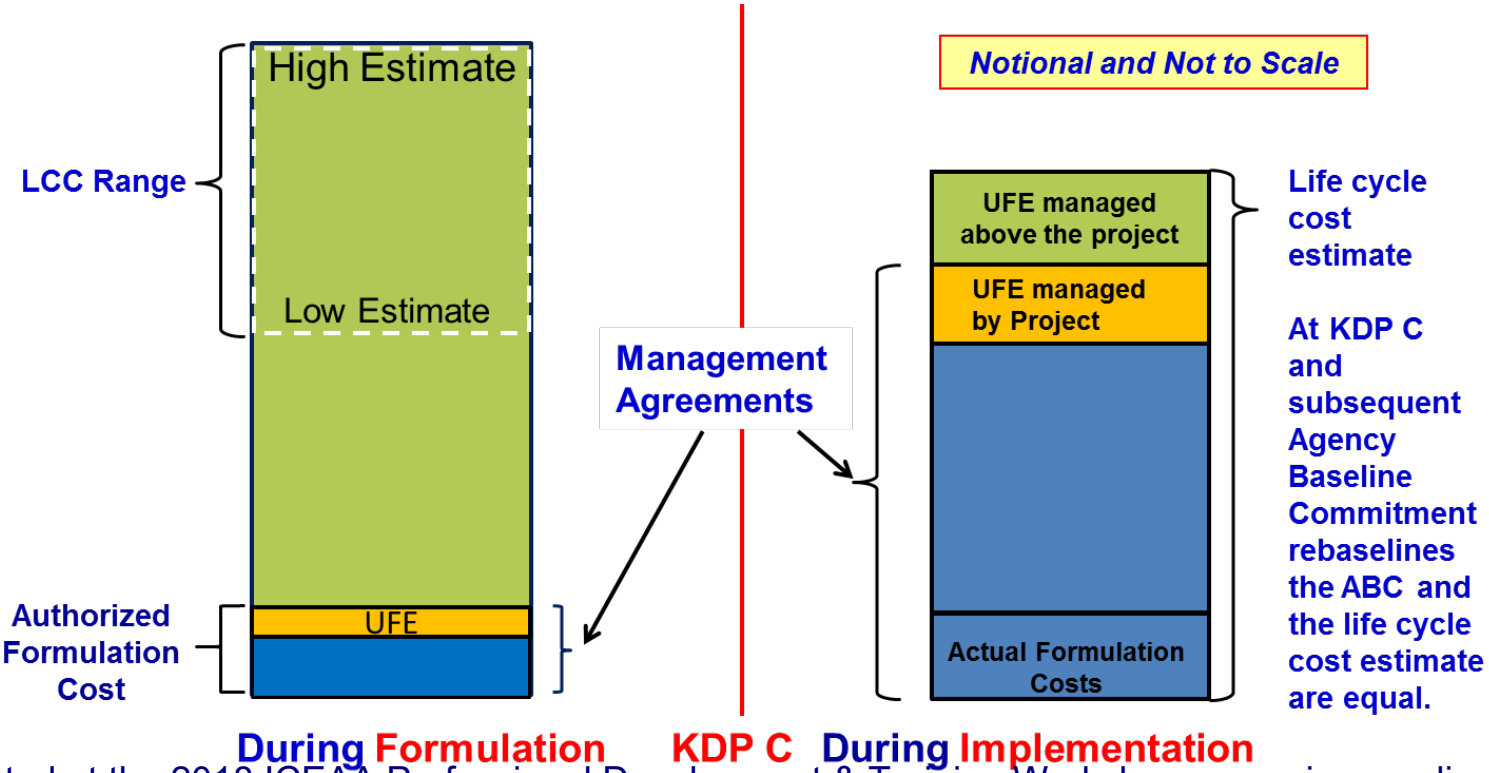
- **Government and Corporate Entities have Processes for Defining, Understanding, and Resourcing Programs and Projects**
- **These Processes, or Systems, Generally Provide Adequate Resources to Accomplish the Requirements**
- **DoD and NASA have Instituted Policies and Practices to Identify and Prevent Extreme Cost Growth**
- ***A Primary Cause of Extreme Cost Growth is a Failure in the System***

Nunn-McCurdy

- In order to combat cost growth Senator Nunn and Representative McCurdy established legislation in the early 1980s requiring programs to report on significant cost growth
- **A significant breach is 15% growth above the current baseline, or 30% above the original baseline**
- **A critical breach is 25% growth above the current baseline, or 50% above the original baseline**
- Critical breaches can result in program cancellation unless the program is restructured and root-cause analysis is conducted on the program's cost growth

NASA Policy

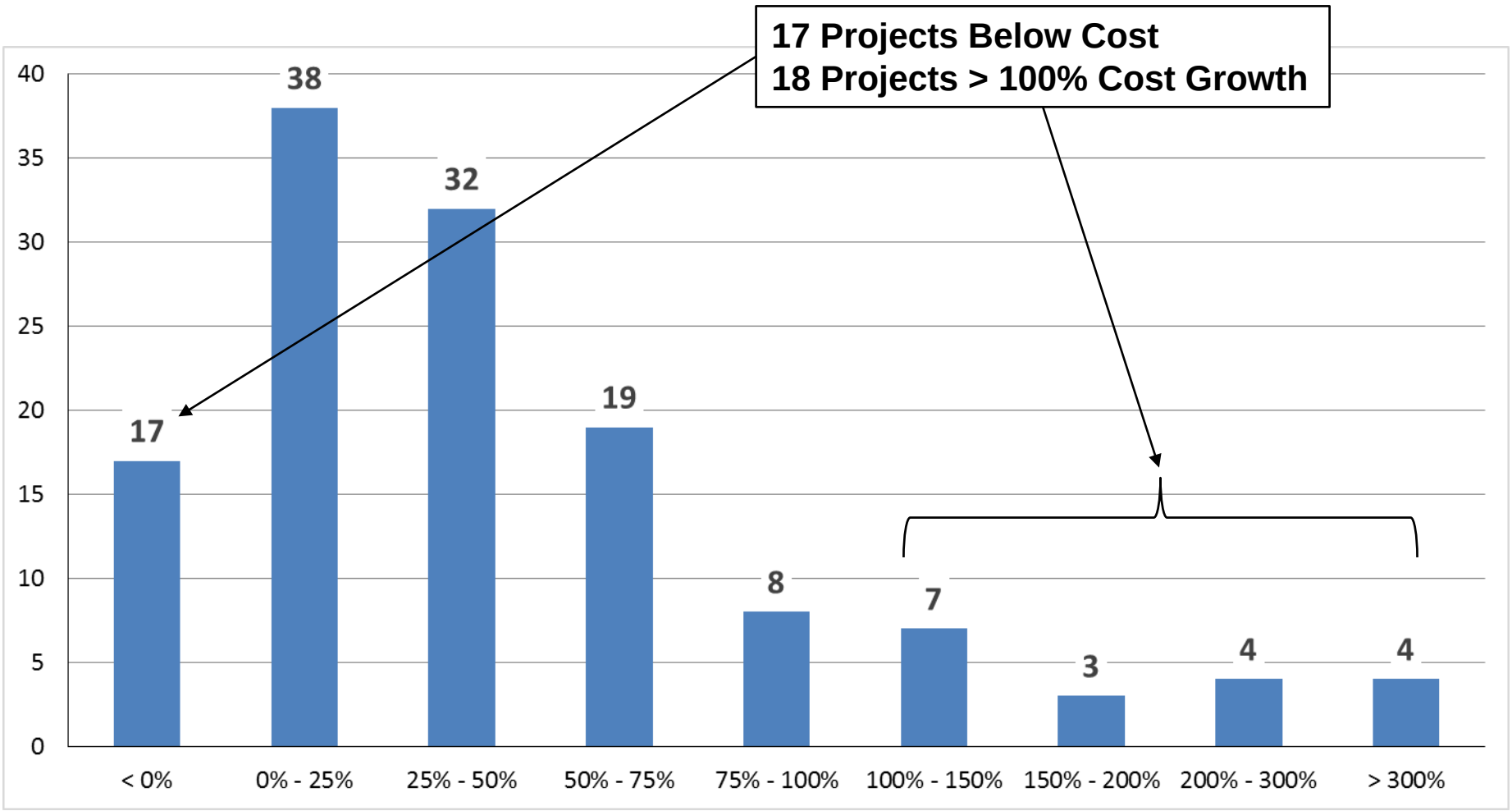
- **Rebaselined if cost exceeds 30% of Agency Baseline Commitment (ABC) – must report to OMB if growth exceeds 10%**
- **Joint Cost Schedule Confidence Level (JCL) analysis used to establish ABC**



Extreme Cost Growth

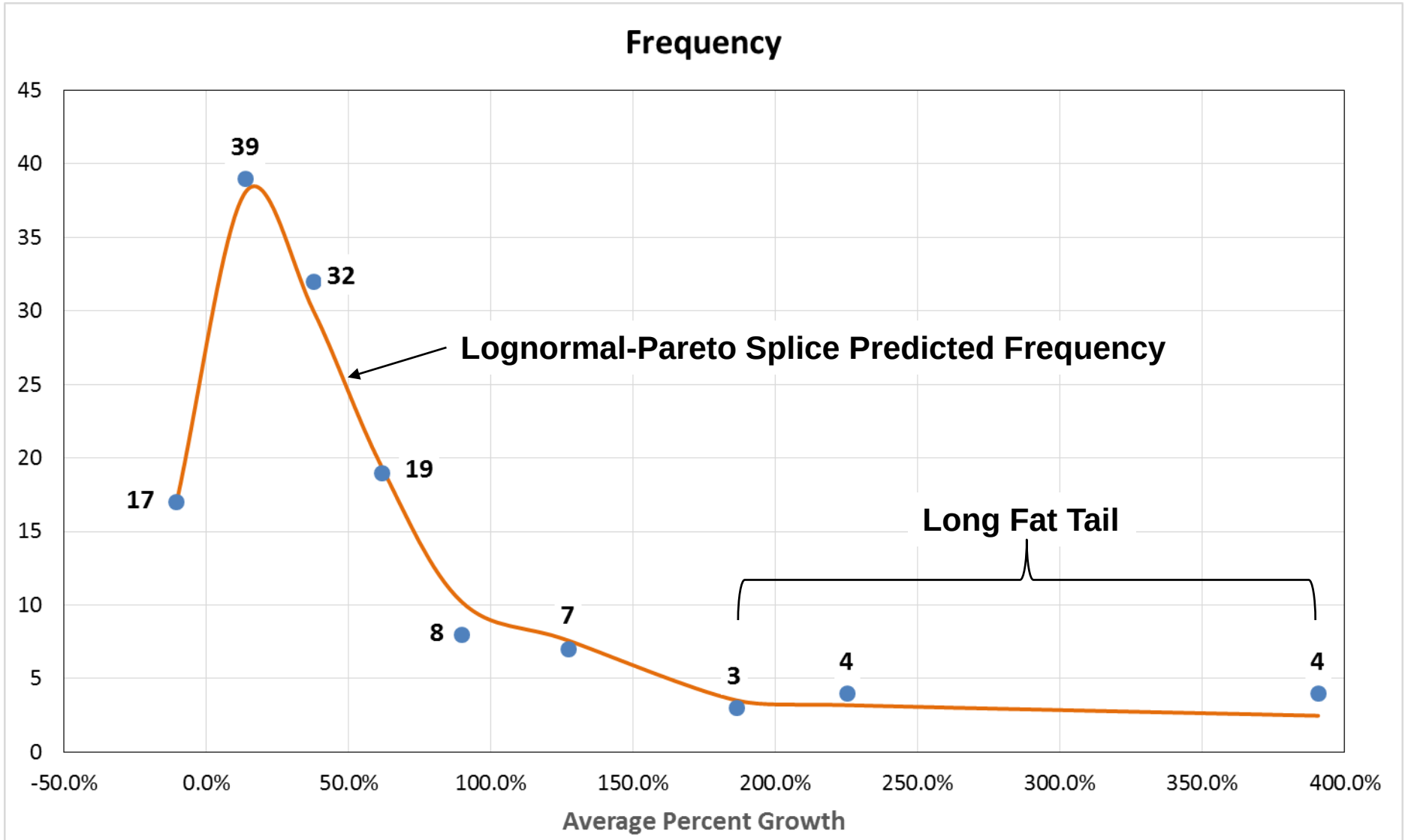
- For DoD Programs, Extreme Cost Growth is Well Defined (Nunn-McCurdy)
- For NASA Programs and Projects, the Definition of Extreme Cost Growth is Less Well Defined
- Tolerance of Cost Growth Appears to be Related to the Importance of the Program or Project to the Organization and the Politicians
  - Kept: F-35 JSF, JWST, Orion
  - Killed: Ares I, Future Combat Systems
- For the Purposes of this Study, Extreme Cost Growth is Exceeding the Baseline Estimate by 100% or more
  - Baseline for Study Data is System Requirements Review (SRR)
- No Correlation between Estimate and % Cost Growth or Actual Cost and % Cost Growth
- High Correlation between Estimate and Amount of Cost Growth, Actual Cost and Amount of Cost Growth

History for Cost Estimators

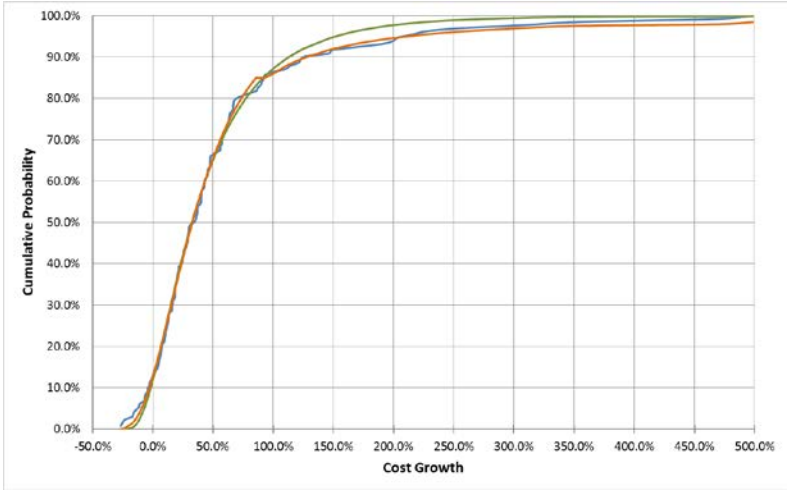


Mean: 56.2% **# of Projects: 132** **Minimum: -26.8%**
Median: 35.1% **Standard Deviation: 82.5%** **Maximum: 498.3%**

History has a Fat Tail

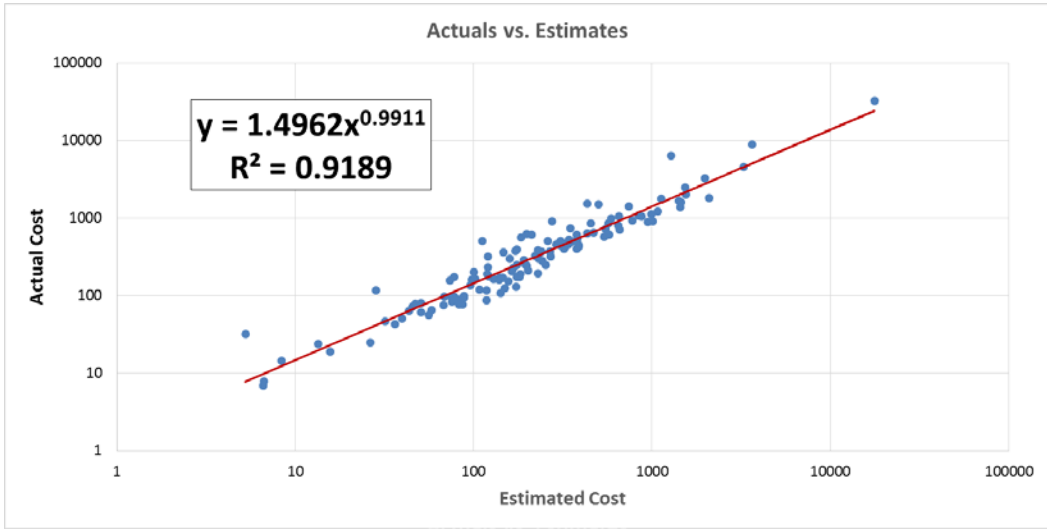


A Simplistic Approach



Use Cost Growth PDF to Develop Realistic Cost Risk Analyses (CV, Risk of Extreme Cost Growth, etc.)

Add 50% to any Estimate to Account for Expected Cost Growth



Two Views of the World

Cost Estimator/Analyst

- Data Driven
- Judgement and Experience
- Comfortable with Uncertainty
- Weighs all the Evidence
- Focused on Credibility, Supportability, Defendability

Project Manager

- Results Driven (Job to do)
- Sees the World Deterministically
- Consistent Message
- Builds/Maintains Relationships
- Focused on Success

Natural Tension

History for Managers

Engineering Cost Office

Cost Growth Reasons	1970s	1980s	1990s	2000s
Inadequate definitions prior to agency budget decision and to external commitments	X	X	X	X
Optimistic Cost Estimates/Estimating Errors	X	X	X	X
Inability to execute initial schedule baseline	X	X	X	X
Inadequate risk assessments	X	X	X	X
Higher technical complexity of projects than anticipated	X	X	X	X
Changes in Scope (Design/Content)	X	X	X	X
Inadequate assessment of impacts of schedule changes on cost		X	X	X
Annual Funding instability			X	X
Eroding in-house technical expertise			X	X
Poor tracking of contractor requirements against plans			X	X
Launch Vehicle			X	
Reserve Position adequacy		X		X
Lack of Probabilistic estimating		X		X
"Go as you can afford" Approach				X
Lack of formal document for recording key technical, schedule and programmatic assumptions (CARD)**				X

** CADRe has since been implemented as a requirement of NPR 7120.5

- **Top Four: Inadequate Project Definition; Optimistic Cost Estimates; Unexecutable Schedule; Inadequate Risk Assessments**
- **Number of reasons increasing over time <u>(failure to learn?)</u>**
- ***Specific, Explainable, Actionable***

The Illusion of History

- **Begin with a flawed understanding of cause and effect**
- **Use heuristics that are intuitive, simple, and easily understandable**
- **Minimize the impact of randomness or chance**

The illusion that one has understood the past feeds the further illusion that one can predict and control the future. These illusions are comforting. They reduce the anxiety we would experience if we allowed ourselves to fully acknowledge the uncertainties of existence.

Daniel Kahneman, "Thinking, Fast and Slow"

Over-specification

- **Our overly simplistic understanding of the past creates the illusion that the future is deterministic**
  - ***A flawed understanding of cause and effect***
- **We focus on the desired result, then back into the specific conditions needed to get us there**
  - ***"The cost is too high, your heritage assumption is too low."***
- **Providing more specificity to the initial conditions leads to the belief that we are reducing uncertainty**
  - ***Creates a false confidence in the estimate***

We confuse our ability to define the present with the ability to predict the future.

Random Stuff Happens

Engineering Cost Office

Complex systems are full of interdependencies – hard to detect – and nonlinear responses. … Man-made complex systems tend to develop cascades and runaway chains of reactions that decrease, even eliminate, predictability and cause outsized events.

Nassim Taleb, "Antifragile"

- **High technology projects are complex and fragile – small things can have large negative consequences**
- **We cannot foresee, with any reasonable reliability, what will cause cost growth or how extreme that growth will be**
- **14% probability of extreme cost growth per history, yet most cost risk analyses assume lower probability**

Case Study: HST

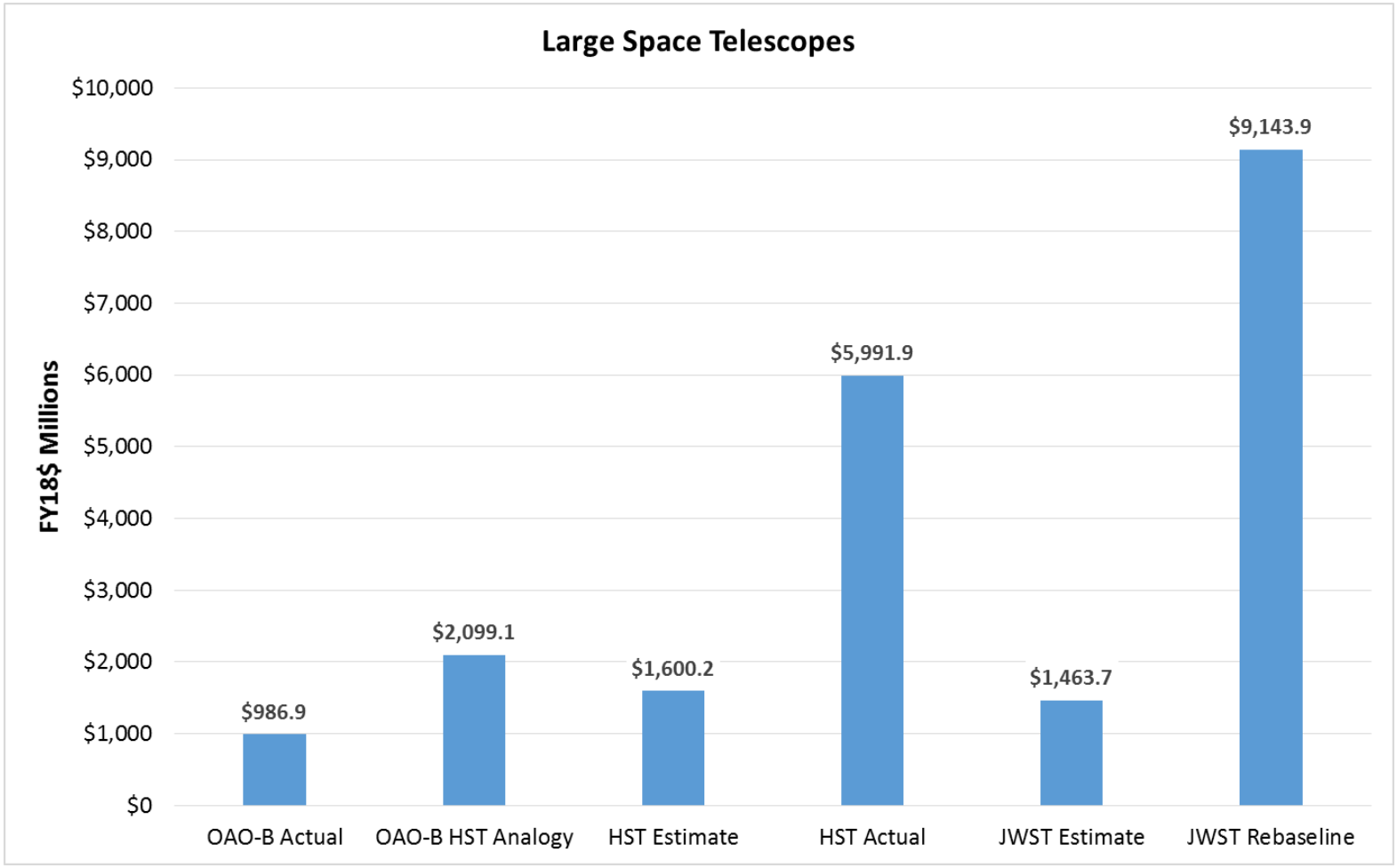
Cost Growth: 274% in Constant Year Dollars

- **Complex Management Interface**
  - **Two Primes: Lockheed & Perkin-Elmer**
  - **Two NASA Centers: MSFC (Spacecraft, Telescope, Integration); GSFC (Science Instruments, Ground System)**
- **Assumed Use of Existing/Standard Hardware did not Materialize**
- **Original Estimate did not Include Sufficient Spares**
- **Large Weight Margin led to Assumed Cost Savings – Weight Growth Consumed Margin and Design had to be Light Weighted**
- **Telescope was Sold as Design-to-Cost with Performance as the Variable – However Performance was held Constant**
- **Telescope Contamination Requirements Increased**
- **Historical Data indicating High Cost for Optics, Fine Guidance Sensors, and Optical Structures Removed from CERs**

Did we Learn from HST?

Engineering Cost Office

A History of Large Space Telescope Cost Estimates and Actuals



Why the System Breaks

- **The management system designed to prevent programmatic failure breaks when *independent cost analysis is not included in the decision process***
  - **No healthy tension between the project management and programmatic analysis community**
  - **No consideration of alternative points of view**
  - **Often goes hand-in-hand with a lack of independent technical analysis**
  - ***Selling the project is more important that knowing the truth***
- **Failure to perform an independent cost analysis does not guaranty that the project will fail to perform, *but it does increase the likelihood***

Observations from DoD

- **Learned Helplessness**
  - While a program manager is responsible for the success of a program, he or she is not the ultimate authority
  - Program managers often have to endure changes imposed upon them by their bosses, as well as Congress
  - This loss of control is a psychic stress that results in a sense of learned helplessness that can cause a program manager to lose their sense of responsibility
  - Results in a denigration of program performance
- **Program Management Durability**
  - DoD program managers are often military officers
  - These officers are on a continual rotation cycle that takes place every few years
  - These program managers thus do not have to "eat their own dinner" – thus they have *no skin in the game*

JCL: A NASA Success Story?

Engineering Cost Office

Mission	Data				Cost Growth		
	SRR	ABC	Actuals		SRR to ABC	SRR to Actuals	ABC to Actuals
NuSTAR	$96.2	$109.9	$104.0		14.2%	8.1%	-5.4%
Landsat 8	$382.1	$587.6	$395.7		53.8%	3.6%	-32.7%
IRIS	$86.2	$140.7	$156.0		63.3%	81.1%	10.9%
LADEE	$117.9	$168.2	$188.3		42.6%	59.6%	11.9%
MAVEN	$488.7	$567.2	$467.9		16.1%	-4.2%	-17.5%
GPM	$660.2	$555.2	$470.5		-15.9%	-28.7%	-15.3%
OCO-2	$225.2	$249.0	$304.6		10.6%	35.3%	22.3%
SMAP	$412.0	$485.7	$469.9		17.9%	14.0%	-3.2%
MMS	$741.0	$857.3	$962.3		15.7%	29.9%	12.2%
Astro-H	$30.0	$44.9	$51.0		49.9%	70.1%	13.5%
OSIRIS-Rex	$515.7	$778.6	$648.7		51.0%	25.8%	-16.7%
CYGNSS	$125.0	$152.8	$90.1		22.2%	-27.9%	-41.0%
SAGE-III	$56.8	$64.6	$81.6		13.7%	43.7%	26.3%
Average					**27.3%**	**23.9%**	**-2.7%**

- **Data from CADRe and the ONCE Database**
- **Average cost growth from SRR to Actuals not statistically different from large data set (Chart 7)**
- **Lack of overall cost growth from ABC to Actuals indicates that JCL might be working (more data needed to confirm)**

A Predictive Model

- **Can Extreme Cost Growth be Predicted Analytically?**
  - The hypothesis is that cost growth is often due to a misalignment of cost, schedule, and performance baselines early in the program
  - If we could provide decision makers with a tool that could alert them to this fact, we could potentially avoid extreme cost growth
- **Tool of Choice: Logistic Regression**
- **Logistic regression is a classification technique**
  - Algebraically, the logistic regression model has the form

$$\pi(x) = \frac{e^{g(x)}}{1 + e^{g(x)}}$$

where $g(x) = b0 + b1*x$

  - Logistic regression arose in epidemiological research, and is now commonly employed in business and finance, ecology, engineering, health policy, and linguistics

Early Results

- **Used the NASA cost growth study and version 5.0 of Joe Hamaker's Quick Cost database (69 data points)**
- **Independent variables include:**
  - Initial cost
  - Initial schedule
  - Spacecraft complexity
  - Instrument complexity
  - Planetary vs. Earth-Orbiting
  - Was the budget capped?
  - Was it mostly design and built in-house by the government?

- **Results:**

		Predicted	
		Extreme Growth	Not Extreme Growth
Actual	Extreme Growth	7	10
	Not Extreme Growth	11	41

- **There are 17 instances of extreme cost growth in the data set. The model predicts 7 of these (misses 10)**
- **The model also predicts 11 missions to have extreme cost growth that did not**

Bottom Line: More Work to be Done.

General Observations

- **A system that is larger and more complex than previous, similar systems *should cost more* than the predecessor systems**
- **The greater the number of cost saving assumptions the *greater the likelihood* of cost growth**
- **In general, technology advances *will not* reduce cost**
- **The *more important* the system is to the organization the more it will cost**
- **Being *told up front what it will cost* is a really, really bad sign**

Conclusions

- Extreme Cost Growth is primarily a failure in management that results from overselling and under controlling
- It is possibly easier to prevent Extreme Cost Growth than it is to foresee it due to randomness
- No independent cost estimates or analyses by an independent organization are a bad sign
- JCL combined with independent assessment might be a forcing function for good program planning and management

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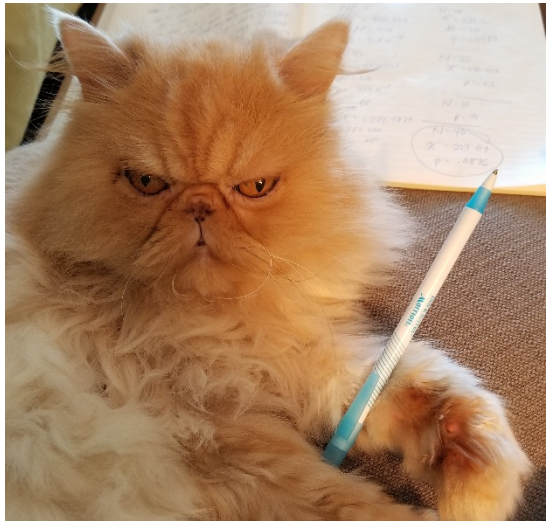

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