Determining the Value of On-Orbit Telescope Servicing

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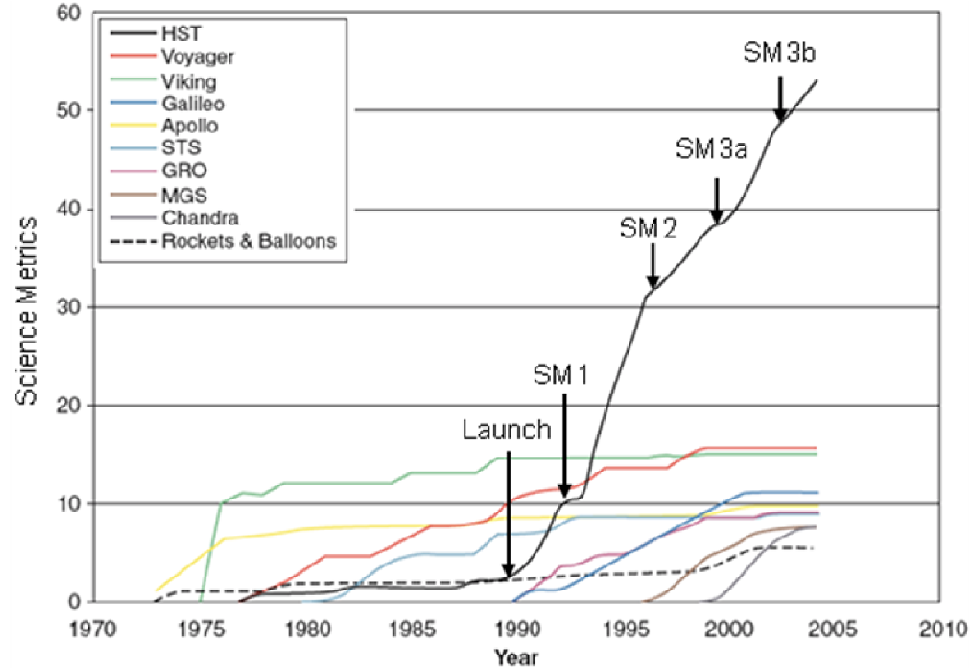
Motivation

- **Space Telescopes:** Excellent science opportunities outside atmosphere, high lifecycle costs (>$5B)
- **For a given budget, goal is to maximize science return**
- **Servicing can increase science capability & extend lifetime**
  - Instrument upgrade
  - Component replacement/upgrade
  - Tool for managing uncertainty

- **How can the value of serviceability be quantified?**

Servicing Hubble

- SM4 marks the third transformation of Hubble
- Each servicing mission has had large scientific impacts



Cumulative science contributions of the ten most productive NASA programs over time, based on citations in scientific literature [1]

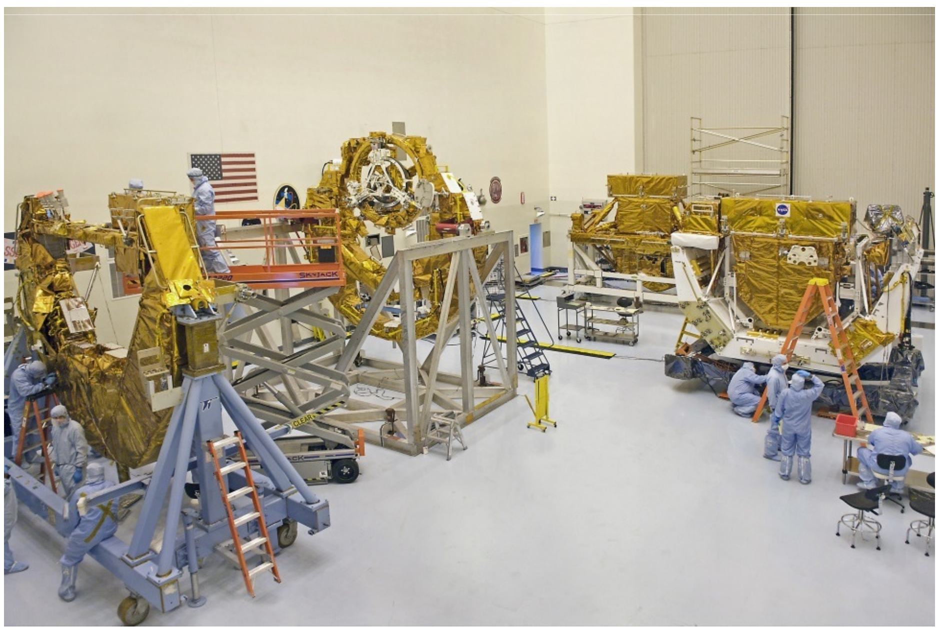
Mission	Date	Instruments				
		Radial	Axial 1	Axial 2	Axial 3	Axial 4
Launch	Apr, 1990	WFPC1	GHRS	FOS	FOC	HSP
SM1	Dec, 1993	WFPC2				COSTAR
SM2	Feb, 1997		STIS	NICMOS		
SM3A	Dec, 1999					
SM3B	Mar, 2002			NCS	ACS	
SM4	May, 2009	WFC3	Repair STIS		Repair ACS	COS

Source: http://hubble.nasa.gov/technology/instruments.php [2]

Removal of WFPC 2 (Source: NASA)

Serviceability: Costs and Uncertainty

- Impacts of serviceability on costs:
  - Modularity
  - Docking interface
  - Orbit selection
  - Offline time
  - Potential damage

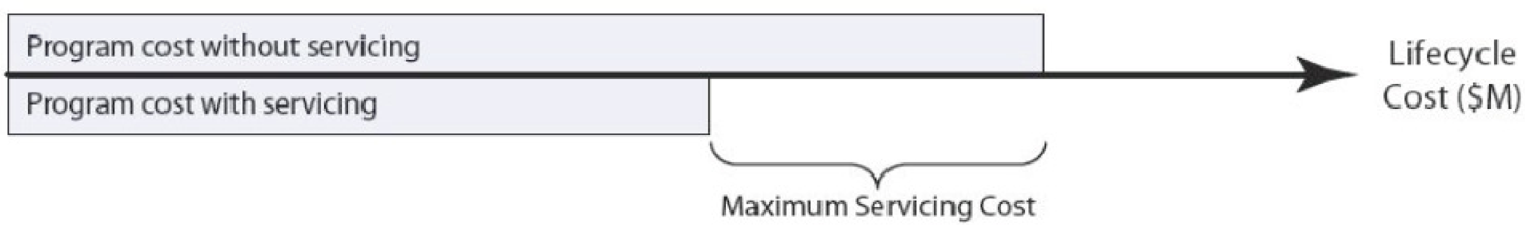


- Any telescope program faces uncertainty:
  - Technology Growth
    - Future instruments provide enhanced capabilities
  - Component Failure
    - Critical components fail over time
    - Currently dealt with by redundancy
  - Change Mission Requirements
    - More data in different wavelengths
    - Different types of measurements (spectroscopy vs. imaging)

- **Serviceability is insurance against uncertainty**

Value of Serviceability

- How can the value of serviceability be quantified?
- Instead of finding the cost of servicing missions, **find the break-even cost between a program with servicing and a program without servicing**
  - Baseline is a program where telescope is servicing is **replaced upon failure** (≥ 2 missions)
- **Value of serviceability is the difference between programs with and without servicing:**



- For a fixed budget, the difference in program costs is the maximum amount that should be spent on servicing

Servicing vs. Replacement

Replacement Case	Servicing Case
Upon failure… …construct and launch a replacement with newest science instruments	Upon failure… …repair the telescope and install upgraded science instruments

+

Replacement

Serviceable

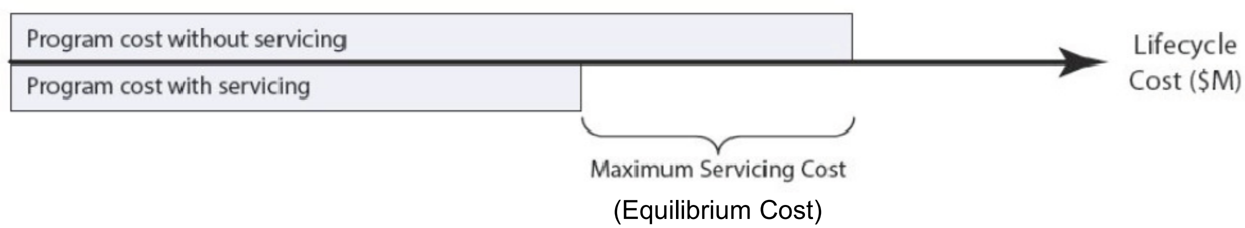
+

Fixed Schedule	Replace-on-Failure	Fixed Schedule	Service-on-Failure
Replace telescope at a pre-specified time	**Replace** telescope when the first one stops operations	**Service** telescope at pre-specified times	**Service** telescope when operations are suspended

Servicing vs. Replacement Costs

- Servicing Program Cost
  - Initial Telescope Cost
  - Initial Instrument Costs
  - Initial Launch Cost
  - Serviceability Cost Multiplier
  - Upgraded Instrument Costs
  - Replacement Component Costs
  - Operations Costs
- Replacement Program Cost
  - Initial Telescope Cost
  - Initial Instrument Costs
  - Initial Launch Cost
  - Replacement Telescope Costs
  - Replacement Instrument Costs
  - Replacement Launch Costs
  - Operations Costs

- **Equilibrium Cost:**
  - ***Training Costs***
  - ***Facility Costs***
  - ***Servicing Mission Costs***



Telescope Program Model

Inputs

- Program type (service/replace; fixed/as needed)
- Program length
- Failure rates
- Technology growth rate
- Cost data

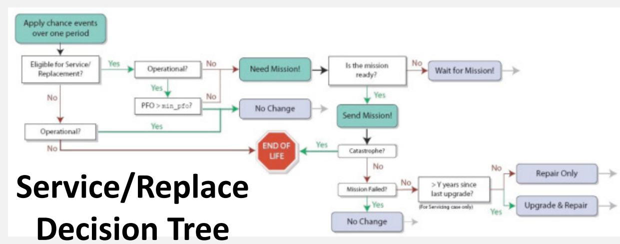
Monte Carlo Simulation
(1000 Runs)

Program Simulation Model

While time< Program Lifetime

Telescope Failure Model

Decision Model



Service/Replace Decision Tree

Increment Time

Service/Replace as Required

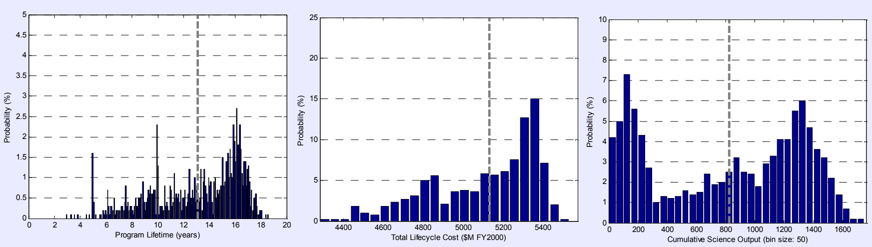
Cost Model

Science Utility Model

Outputs

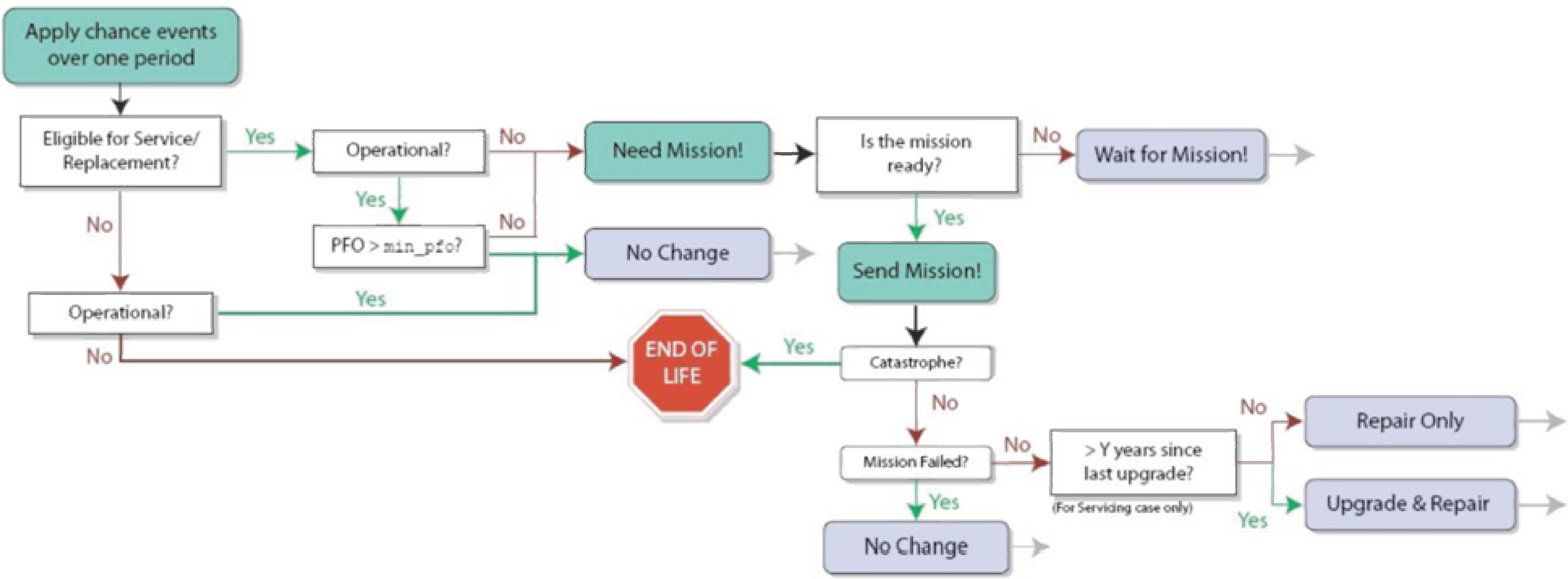
Distributions of the expected values of:

- End of Mission Time
- Total Cost
- Total Utility
- Number of Missions



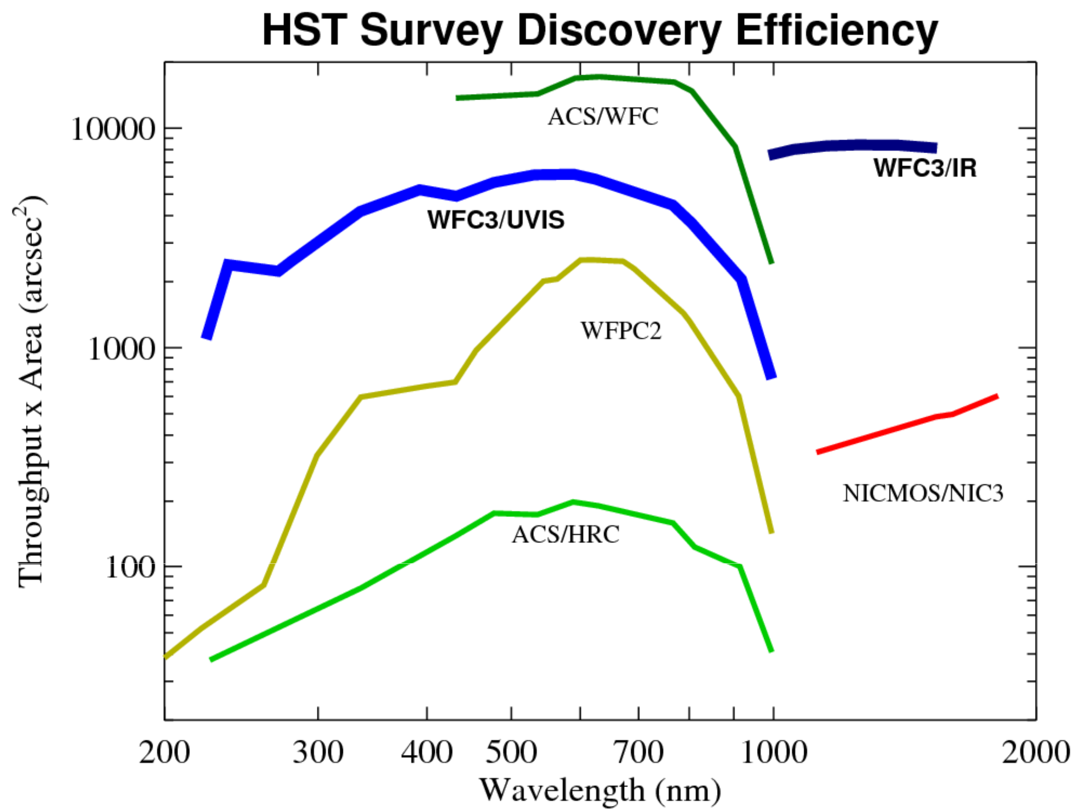
Decision Framework

- In each time step:
  - Apply random events
    - Failure of instruments & bus components
    - Servicing mission failure
  - Apply decision rules:
    - Send servicing/upgrade mission?
- Stochastic modeling captures uncertainty



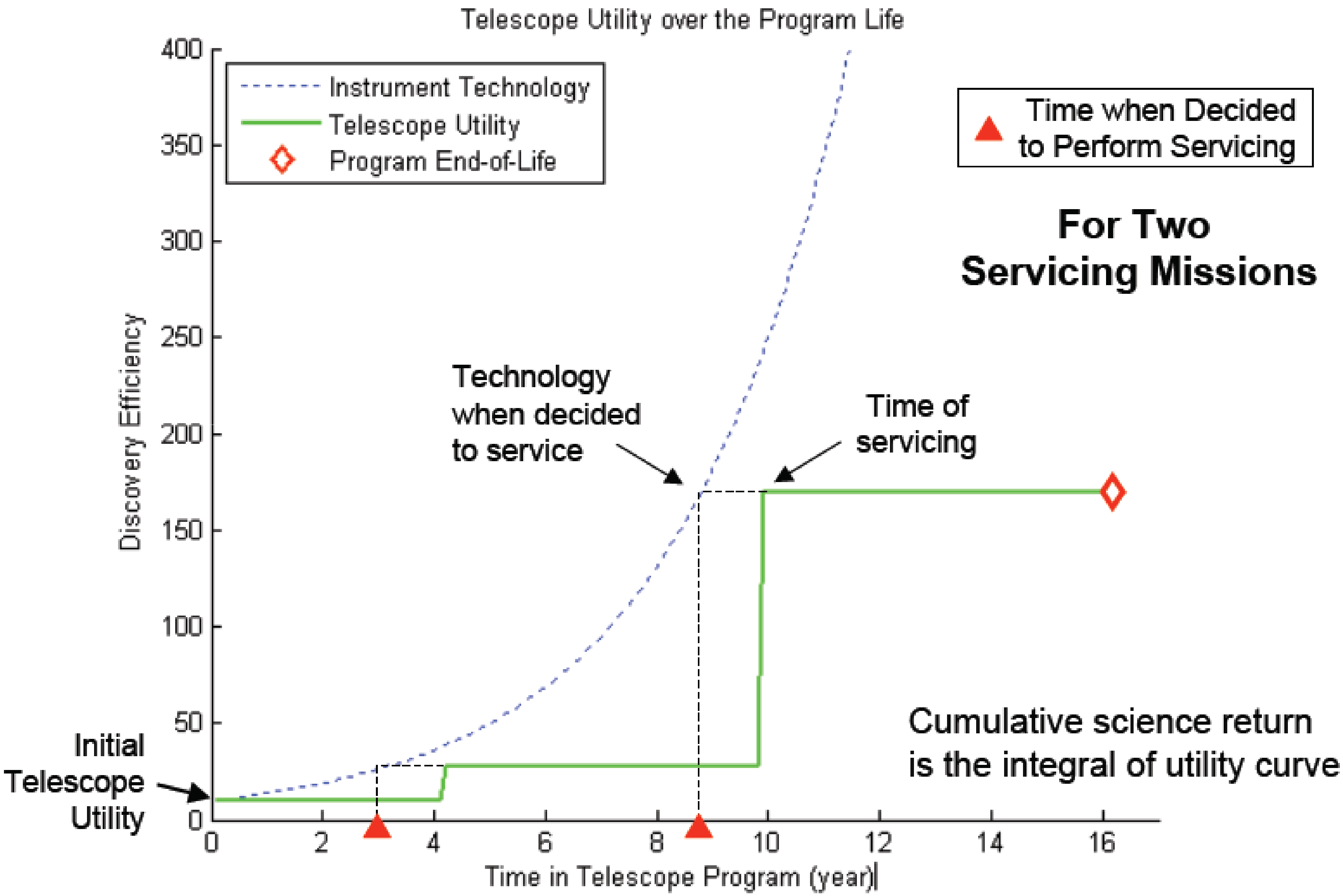
Discovery Efficiency

- **Discovery Efficiency (DE)** = (Instrument Throughput) x (Field of View)
  - Yearly science return of an instrument
  - Best used for imaging instruments
- **DE Growth**
  - CCD resolution (FOV/pixel) improves over time (Moore's Law)
  - CCD throughput does not necessarily improve over time
  - ACS -> WFC3 Improvements: Lower noise, Optimization for UV
- **Telescope Utility**
  - Integral of DE over program life
- **DE of telescope increases when upgraded with latest technology**
  - Cumulative science output increases with more servicing missions



Discovery Efficiency vs. Wavelength [3]

Utility vs. Time



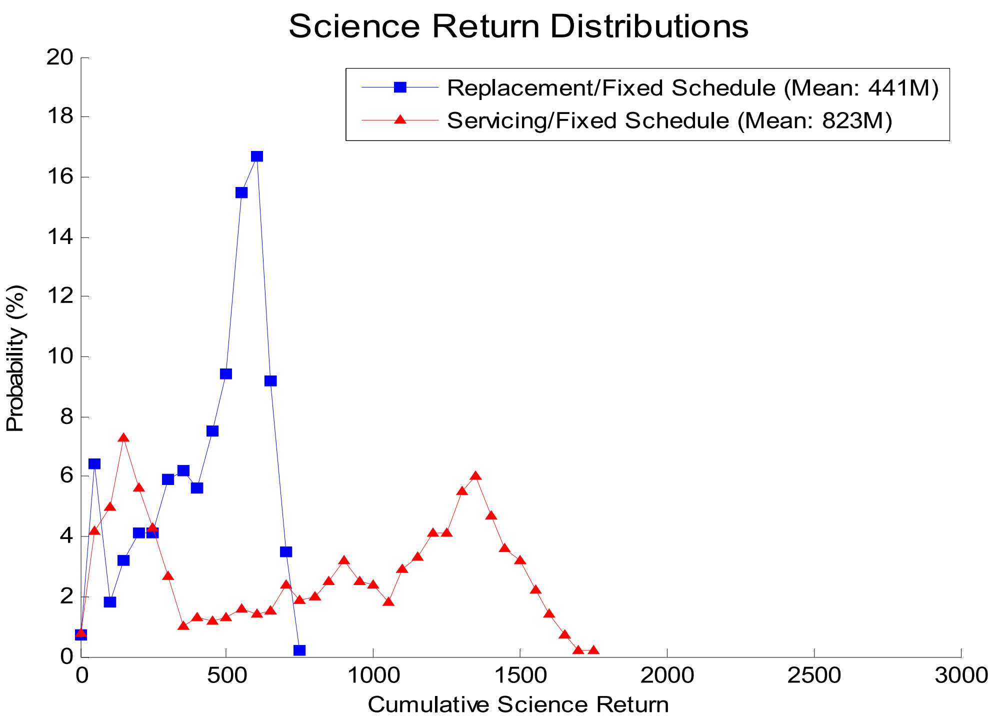
Sample Case Study

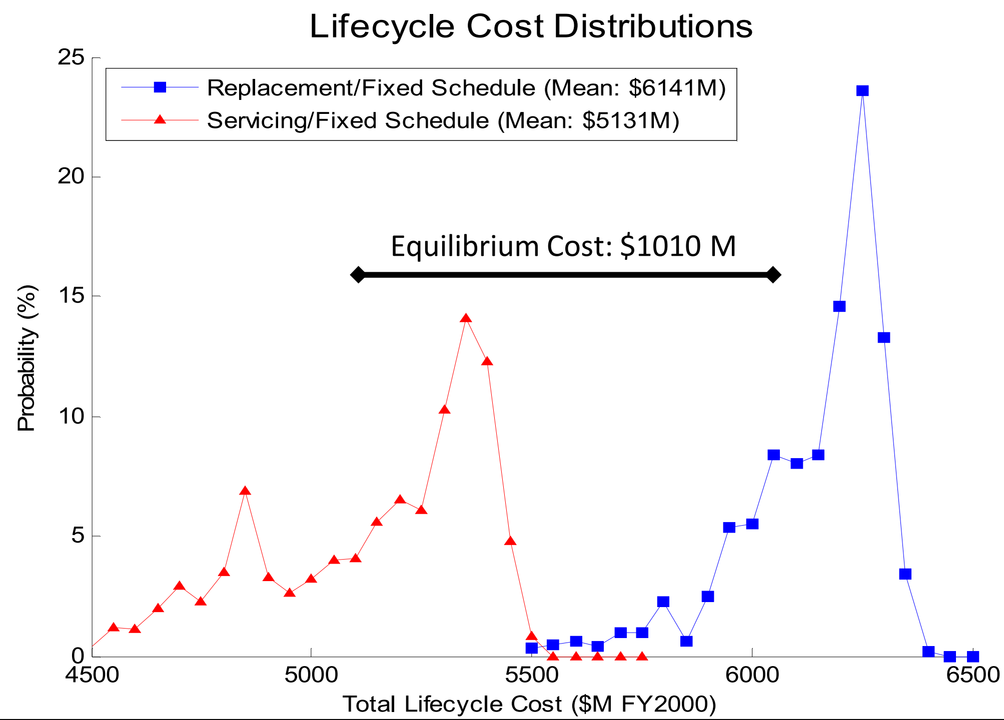
- Assumptions:
  - 11,000 kg telescope (Hubble-class)
  - 15 year program
  - Simplified telescope model. Four components modeled using failure data from Aerospace Corporation. [4]
  - Single instrument model. Technology growth from Moore's Law.
  - Risk parameters estimated from historical data.
- Two cases:
  - Fixed servicing (5 yrs – two servicing missions)
  - Fixed replacement (7.5 yrs – one replacement mission)

Sample Case Study

- Evaluate science return & lifecycle cost
- Science Return: Servicing **increases** probability of higher science return
- If servicing missions can be conducted for less than $505M, then increased science does not result in increased lifecycle cost

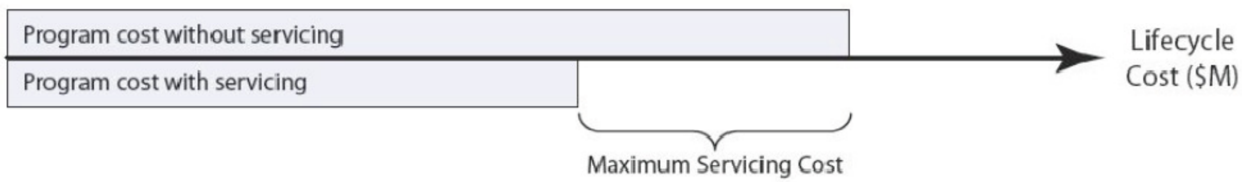
	Replacement (7.5 yr)	Servicing (5 yr)
Science Return [M]	441	823
Lifecycle Cost [$M]	6141	5131
Equilibrium Cost	-	1010
Servicing Cost per Mission [$M]		505





Conclusions

- The difference in cost between a replacement program and a program with servicing yields the upper bound for what a servicing program should cost



- Spacecraft servicing studies should be undertaken during conceptual design (Pre-Phase A/Phase A)

- This quantitative framework can be applied to all expensive, long-lifetime spacecraft (Space telescopes, Earth observatories, and GEO communications satellites)

References

[1] Christian, C. A. and Davidson, G. "The Science News Metrics." [ed.] A. Heck. *Organizations and Strategies in Astronomy.* Dordrecht, The Netherlands: Kluwer Academic Publishers, 2005, Vol. 6, pp. 145-156.

[2] *The Hubble Program: Scientific Instruments.* http://hubble.nasa.gov/technology/instruments.php

[3] Bond, H. E., and Kim Quijano, J., et al. 2007, "Wide Field Camera 3 Instrument Handbook, Version 1.0" (Baltimore: STScI)

[4] H. Wong, *Hubble Space Telescope Reliability Assessment, July 2002 Model.*, Aerospace Report No. TOR-2003(2154)-2352, The Aerospace Corporation, El Segundo, Calif., 2002.

[5] M. Baldesarra, *A Decision-Making Framework to Determine the Value of On-Orbit Servicing Compared to Replacement of Space Telescopes*, S.M. Thesis, MIT, June 2007

[6] Bailey, Z. J. and Baldesarra, M., "The Economic Value of Space Telescope Servicing," *Astro2010: The Astronomy and Astrophysics Decadal Survey, Position Papers*. March 2009. http://www8.nationalacademies.org/astro2010/DetailFileDisplay.aspx?id=429.