# Launch and Production Schedule Modeling for Sustained Earth Observation Constellations

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## Abstract

Satellite missions are typically thought of singly or in the small blocks corresponding to a funded program. However, in many mission areas the need is to provide a continuous and sustained on-orbit capability far beyond the borders of a single mission or even a single program. For example, in weather and environmental remote sensing the U.S. geostationary program currently launching comprises four geostationary satellites (GOES-R through GOES-U) and five satellites in polar low-earth orbit (LEO) (SNPP launched and four JPSS yet to launch). In weather and environmental mission area we want decades-long remote sensing data records and there is a strong disutility to any gap in service. There is near certainty that the U.S. will continue its weather and environmental satellites beyond the current program, but there is not yet an official plan to do so. This presents both a problem and opportunity when designing constellations. In designing and analyzing launch and production policies we should consider not a single satellite mission or a single funded program but a whole sequence of production and launch programs (most of which are in the unplanned future). In considering the far "out-years", we might discover that decisions made today may have complex consequences in the future, and policies that seem logical in the context of a single program may not be effective when considered over the lifetime of several programs. As part of the NOAA Satellite Observing Systems Architecture (NSOSA) study we made a broad study of launch policies for long-term sustainment of diverse constellation types, concentrating on how to optimize trades between reliable service provision and cost efficient use of resources.

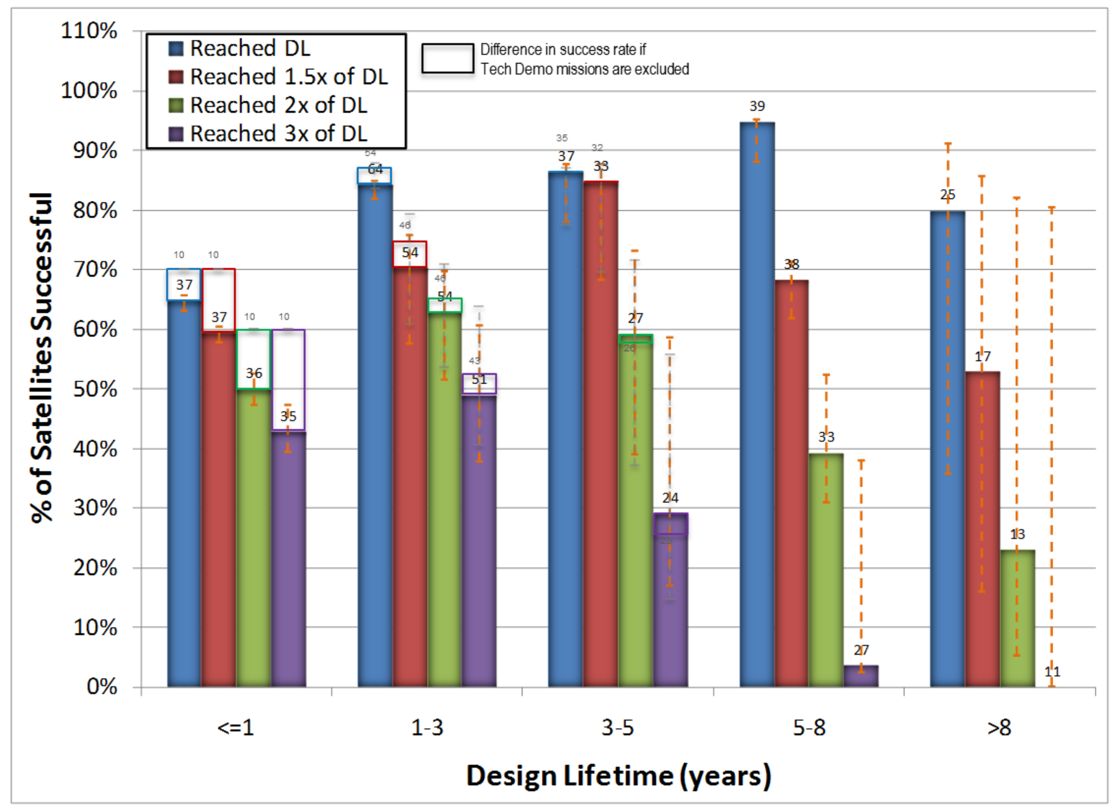
**NSOSA further details – see St. Germain et al. (2018)**

## Problem Description

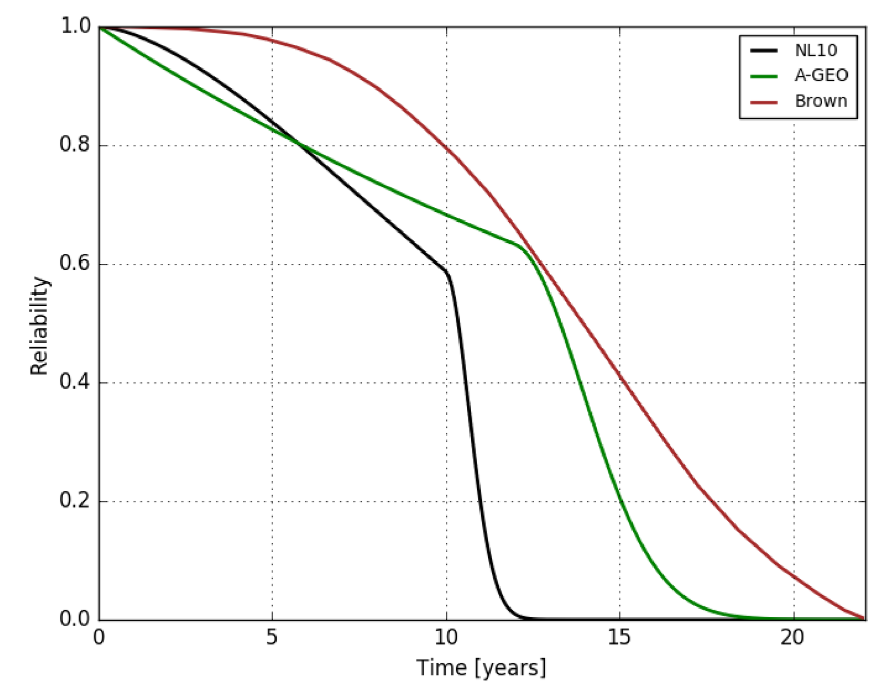
- How do we launch (and produce) satellites to maintain desired observation constellations?
- Example constellation types:
  - One satellite, one plane (e.g., JPSS)
  - Two satellites, one plane (e.g., GOES)
  - Three satellites, three planes (e.g., desired polar sounding)
  - Many others (GNSS-RO, space weather, etc.)
- Why is this a hard problem?
  - Sometimes launches fail
  - Satellite lifetimes are known only statistically, design lifetime is not even an average
  - Design predictions and empirical lifetimes don't match well

## Satellite Lifetime Issues

Satellites have design lifetimes, but actual lifetimes vary considerably. "Infant mortality" happens, but successful satellites often live >1.5*Design-Life. Actual life may be governed by replacement more than by failure.




Statistical lifetime performance for different design classes

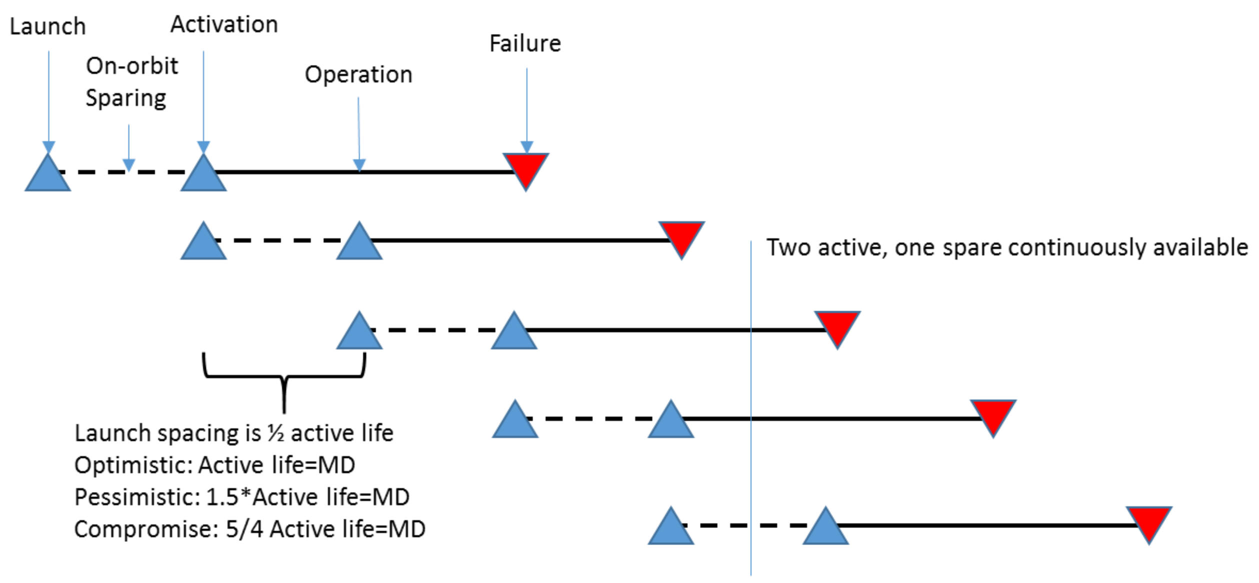



Typical design lifetime curve (NL-10) versus empirical curves for satellites like geostationary weather satellites. A-GEO is empirical with heuristics, Brown is unrestricted empirical.

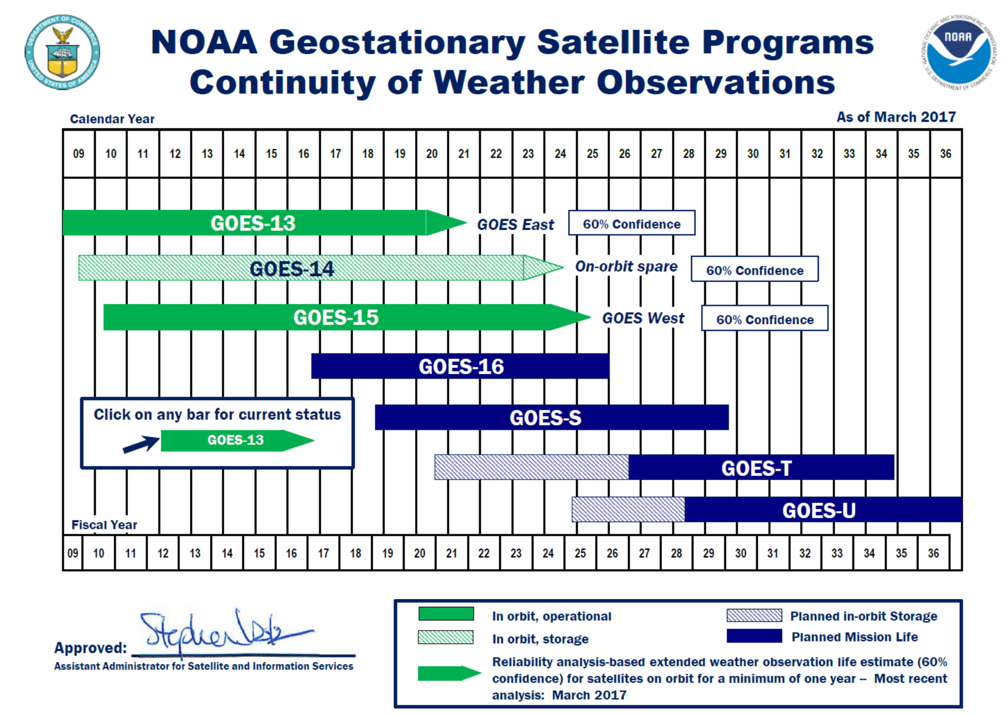
## Three Approaches to Scheduling

- Quasi-deterministic (flyout charts)
  - Assume a fixed lifetime and build to redundancy requirement
- Fixed cadence with availability metric
  - New flight when design life curve hits a threshold
- Windowed launch-on-need
  - Fly when redundancy condition is lost, using no-earlier-than and no-later-than bounds

## Flyout Chart Scheduling: Generic and Real




Generic flyout chart design, showing range of appropriate assumptions




Typical Real-Case: The GOES Flyout schedule

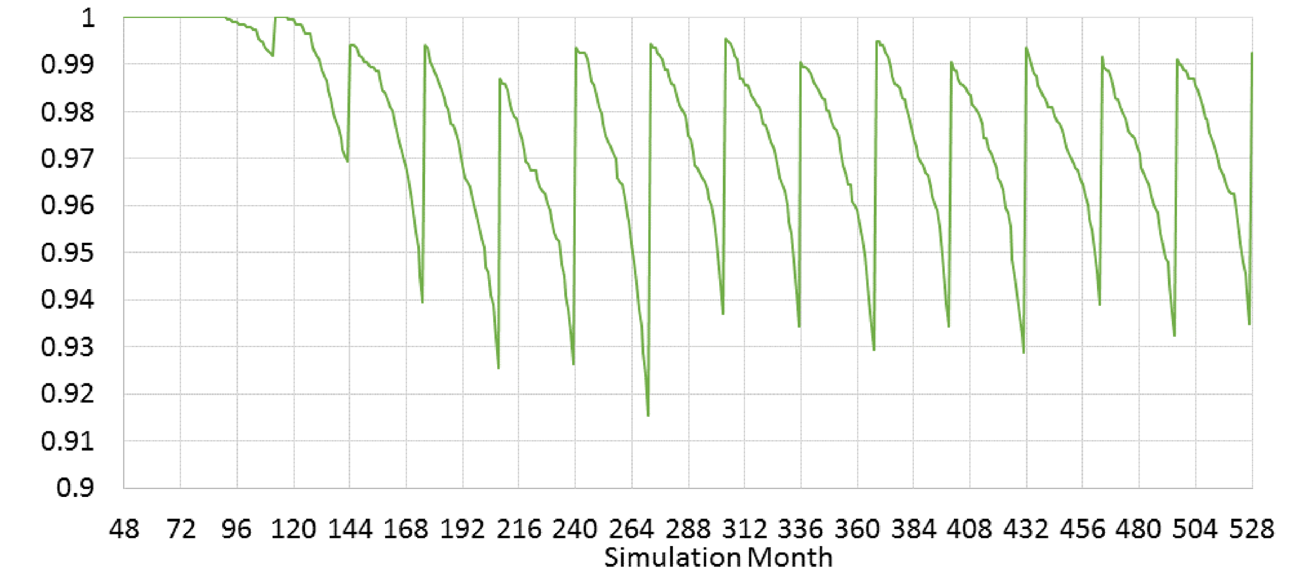
## Comparative Results

Required fixed launch cadences (months) by lifetime model and minimum availability

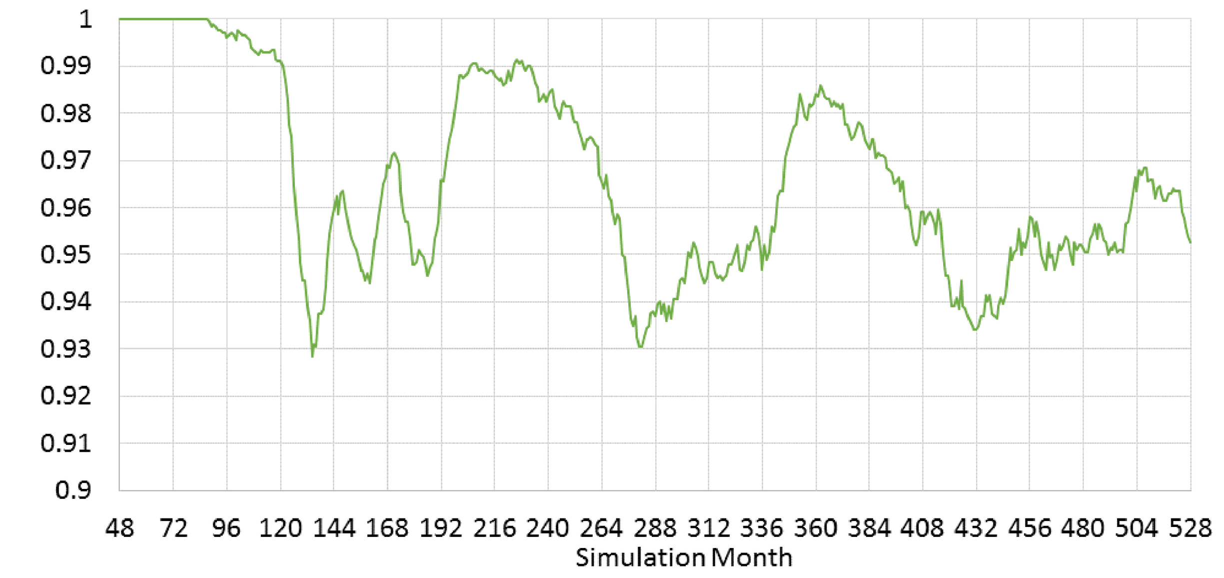
| | Required Availability | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 0.5 | 0.6 | 0.7 | 0.8 | 0.9 | 0.93 | 0.95 | 0.98 | 0.99 |
| NL10 | 56 | 46 | 43 | 40 | 33 | 31 | 30 | 25 | 23 |
| A-GEO | 68 | 60 | 55 | 49 | 41 | 38 | 36 | 30 | 27 |
| Brown | 80 | 75 | 69 | 62 | 55 | 51 | 49 | 43 | 39 |

Table 2: Results of Two Scenarios and Three Launch Policies

| Launch Policy | Min Avail | Prob HG | Prob SG | Worst HG | # Launch |
|---|---|---|---|---|---|
| **Scenario of Actual Lifetime Statistics: Pessimistic** | | | | | |
| Fixed 32 | 93% | 4.9% | 47% | 33 | 15 |
| Fixed 48 | 57% | 31% | 97% | 68 | 10 |
| LoN-12/72 | 93% | 29% | 91% | 12 | 17-21 |
| **Scenario of Actual Lifetime Statistics: Optimistic (empirically supported)** | | | | | |
| Fixed 32 | 99.5% | 0.05% | 2.6% | 3 | 15 |
| Fixed 48 | 98% | 0.45% | 7% | 36 | 10 |
| LoN-12/72 | 99+% | 0.1% | 16% | 9 | 5-9 |




Availability Curve (at least two in one plane) for Fixed-32 launch policy and pessimistic lifetime performance




Availability Curve (at least two in one plane) for LoN-12/72 launch policy and same pessimistic lifetime assumptions

| NET | NLT | P≥2 | %Runs1Sat | %Runs0Sat | 1SatAvgDur | 0SatAvgDur |
|---|---|---|---|---|---|---|
| 6 | 72 | 0.989 | 50.75 | 0.65 | 3.95 | 3.08 |
| 12 | 72 | 0.970 | 71.45 | 3.80 | 7.04 | 6.14 |
| 24 | 72 | 0.940 | 88.5 | 6.30 | 11.30 | 8.71 |
| | | | | | | |
| 6 | 60 | 0.992 | 46.85 | 0.75 | 3.97 | 3.56 |
| 12 | 60 | 0.975 | 69.05 | 2.55 | 6.45 | 4.69 |
| 24 | 60 | 0.940 | 88.35 | 6.60 | 11.43 | 8.83 |

NET has very strong effect, NLT has weak effect on statistics of importance

## Summary

- Quasi-deterministic with redundancy ("two failures from a gap") may yield unexpectedly poor gap statistics
- Fixed cadence availability schedules provide very regular launches and controlled availability, but no adaptation when lifetime performance is better (or worse) than anticipated
- Launch on need policies put difficult demands on production, but provide performance robust to actual lifetime characteristics
  - Minimum time between launches is key

### References

St. Germain, K., F. Gallagher, and M. Maier, 2018: The NOAA Satellites Observing System Architecture (NSOSA) study, 14th Annual Symposium on New Generation Operational Environmental Satellite Systems, Austin, TX, Amer. Meteor. Soc., 6.1, https://ams.confex.com/ams/98Annual/webprogram/Paper332552.html.

### Disclaimer

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