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Planning pLEO Constellations

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Presentation Outline

- Problem Statement
- Methodology
- Data Analysis
- Conclusions and Next Steps

Problem Statement

- Many satellite operators, including DoD, are shifting the way they acquire and field space systems.
  - From: small numbers of expensive, long-lived satellites at GEO.
  - To: large numbers of inexpensive, short-lived satellites at LEO.
- Because the DoD builds budgets for its space programs years before they are fielded, the Department needs a predictive model for the launch and lifespan of pLEO constellations *as a system*.

This work will use publicly-available satellite and launch data to develop a mathematical model in support of budgeting for future DoD pLEO constellations

DoD: Department of Defense GEO: Geostationary Orbit LEO: Low Earth Orbit pLEO: Proliferated Low Earth Orbit

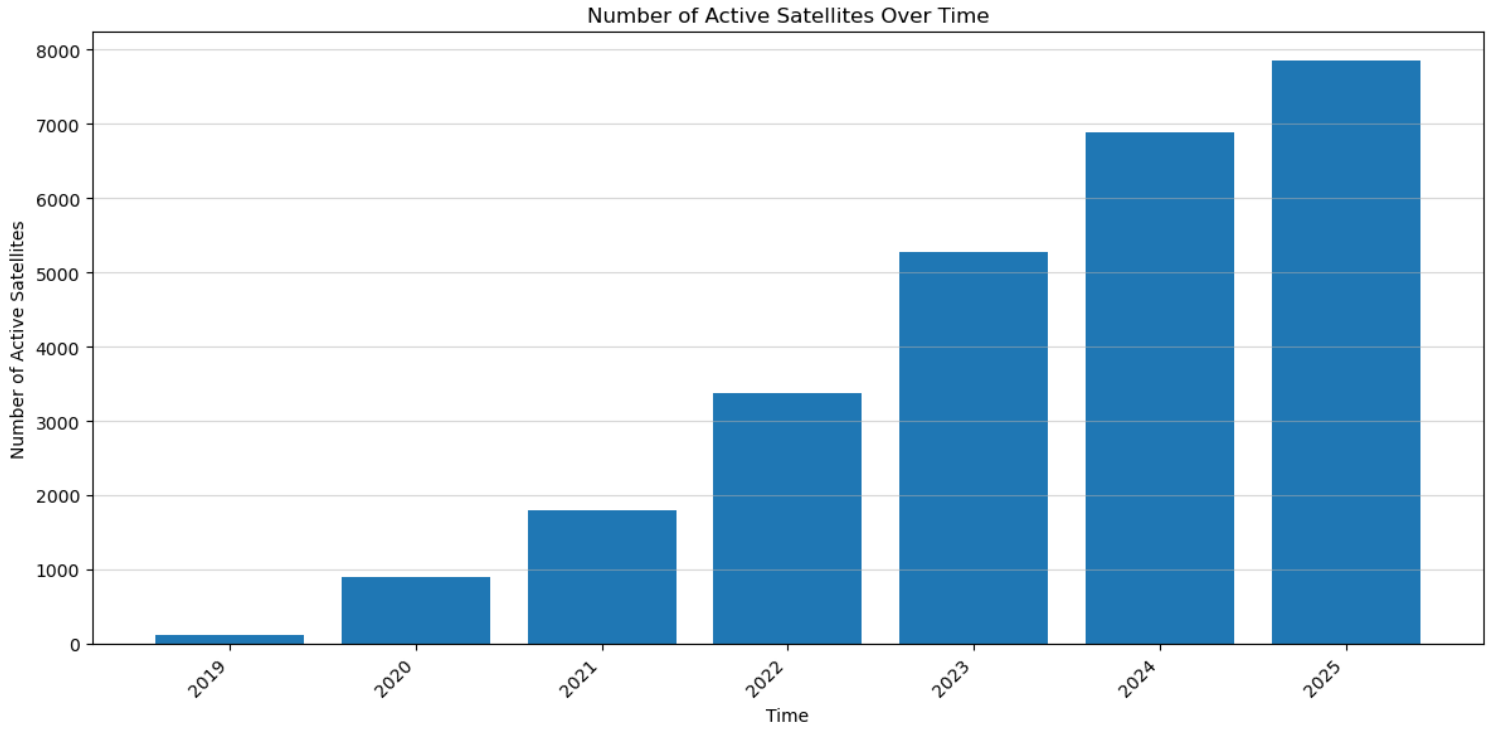
Methodology

1. Assemble historic dataset of publicly-available launch and decay dates for the largest pLEO constellation to date (SpaceX's Starlink).
2. Derive a decay rate from the historic dataset.
3. Use queuing theory to build a mathematical model of the launch and decay of a pLEO constellation.

Methodology

1. Assemble historic dataset of publicly-available launch and decay dates for the largest pLEO constellation to date (SpaceX's Starlink).

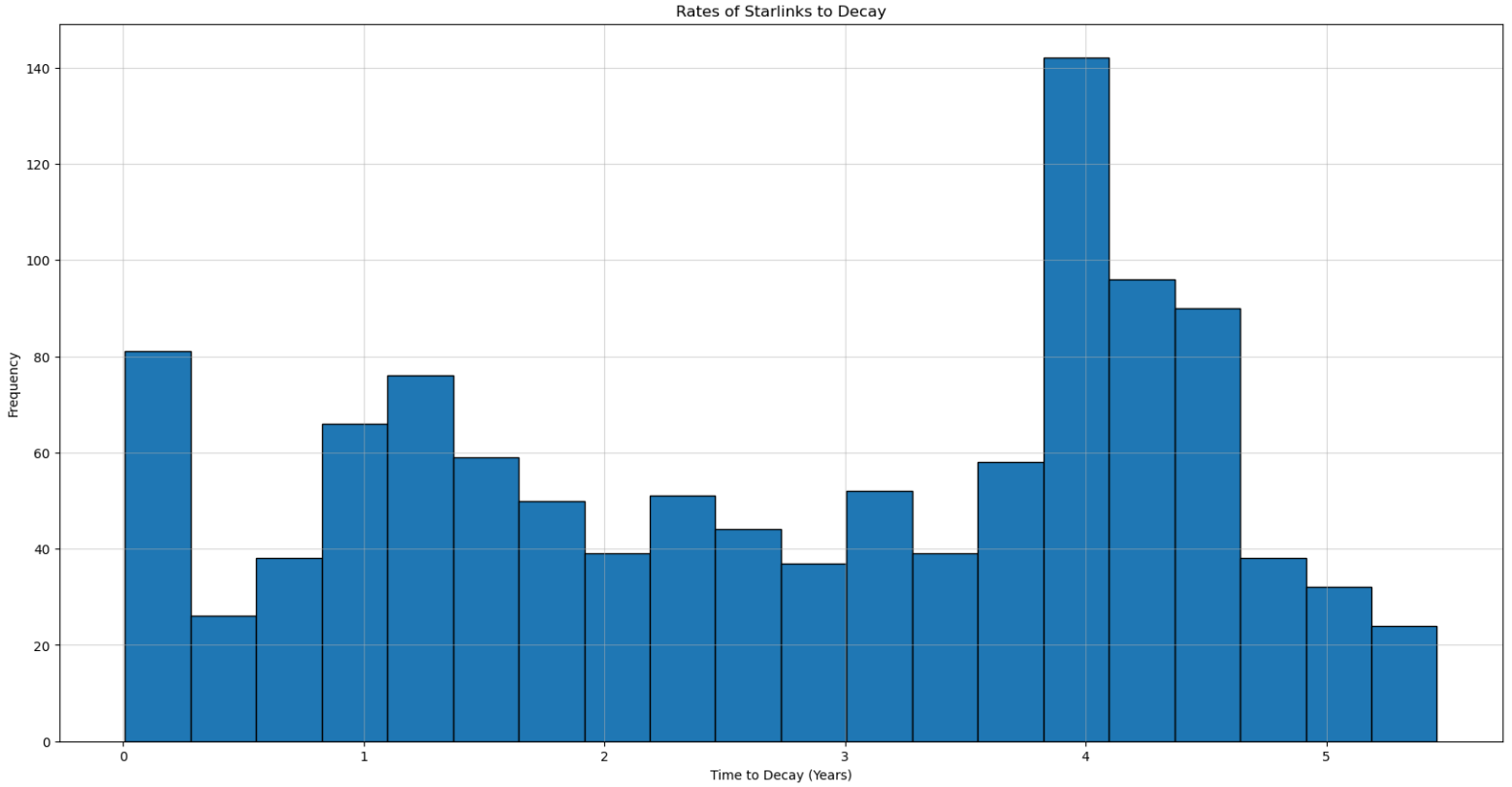
- Starlink has a robust data set
- We can use their data to model expected lifetimes
- We can create a system of anticipating when to launch satellites to maximize use time



Methodology

1. Assemble historic dataset of publicly-available launch and decay dates for the largest pLEO constellation to date (SpaceX's Starlink).

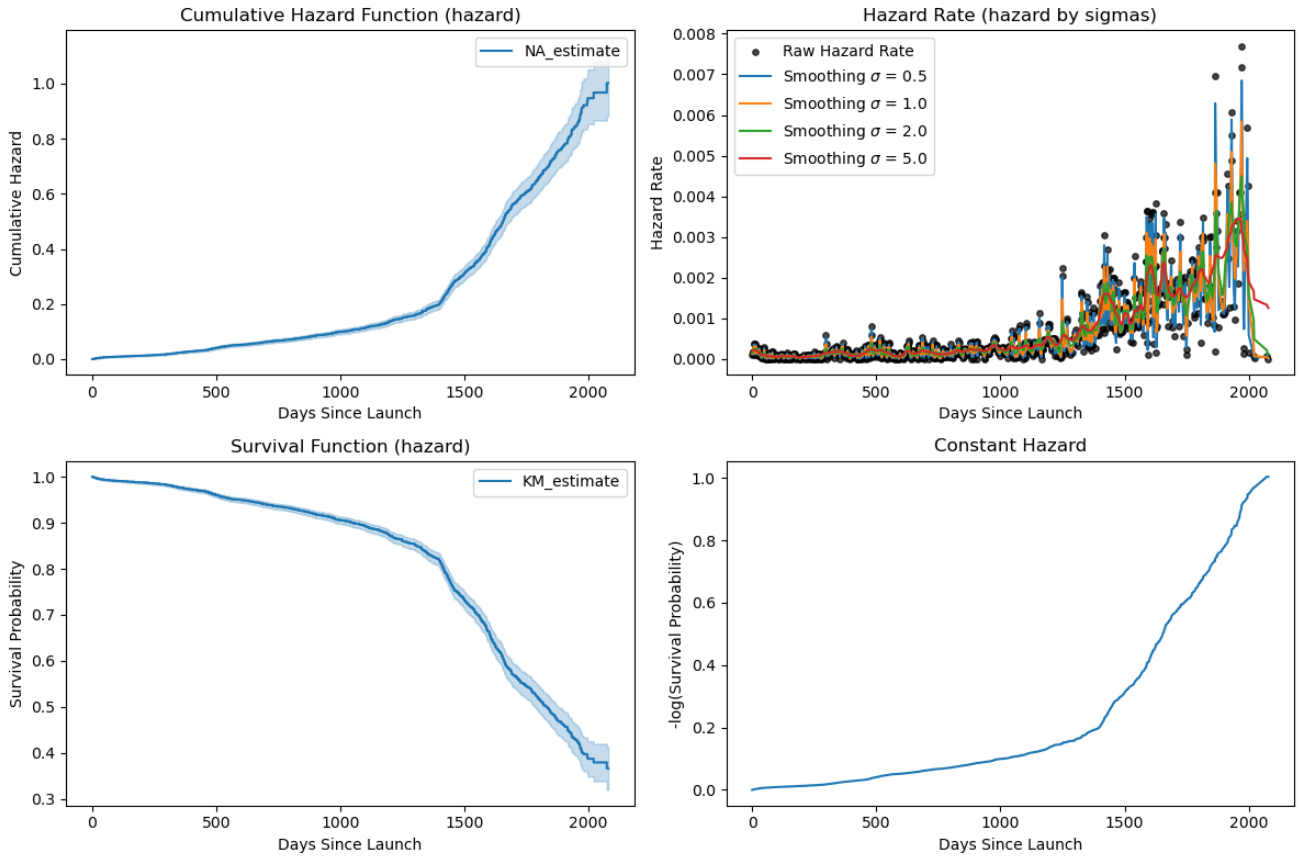
- Because they are in LEO, they decay fairly quicky
- Note the 4 year mark, where many tend to decay
- Their decay time gives us data on their expected lifetimes



Methodology

2. Derive a decay rate from the historic dataset.

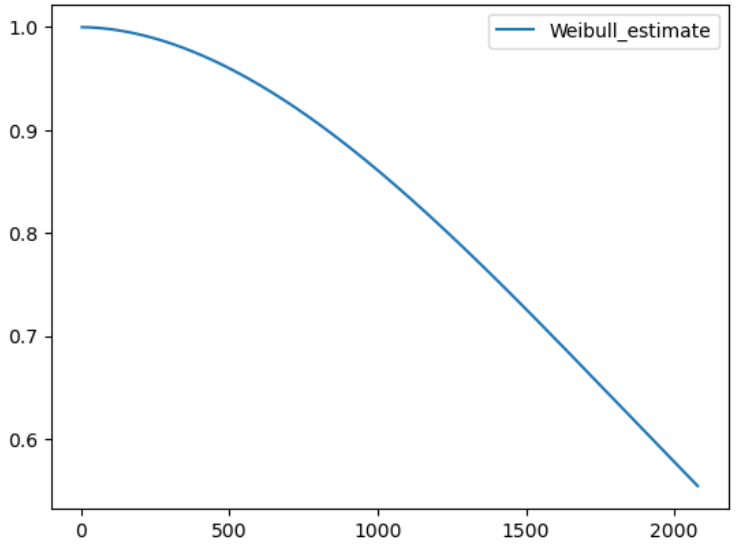
- Their expected lifetimes can be used to create a Hazard Function and derive a Hazard Rate
- Hazard Functions are models used to predict decays
- This model allowed us to do fitting

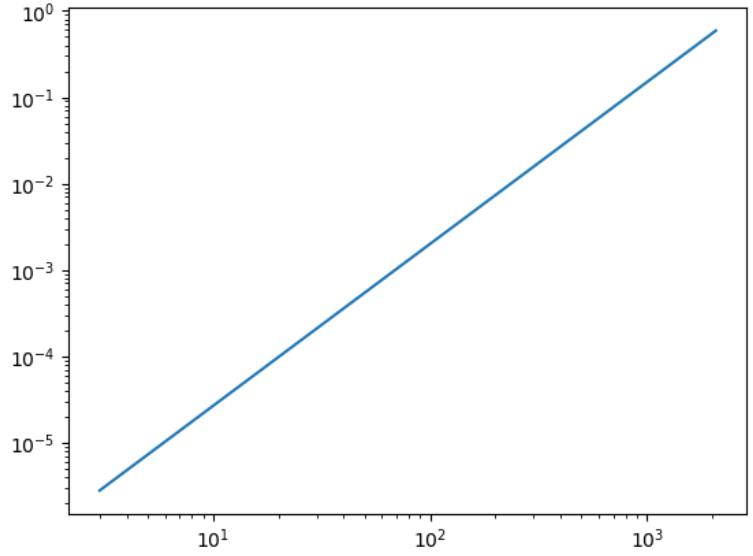


Methodology

2. Derive a decay rate from the historic dataset.

- The Hazard Function let us use a fitting tool called the Weibull distribution
- Doing this fit gave us a convex shape and a value of k>1
- Since we got a value of k = 1.87, we know that failure rate increases with time. This means that there is an aging process of the machinery that leads to decay, rather than random decay or a ‘high infancy mortality rate.’

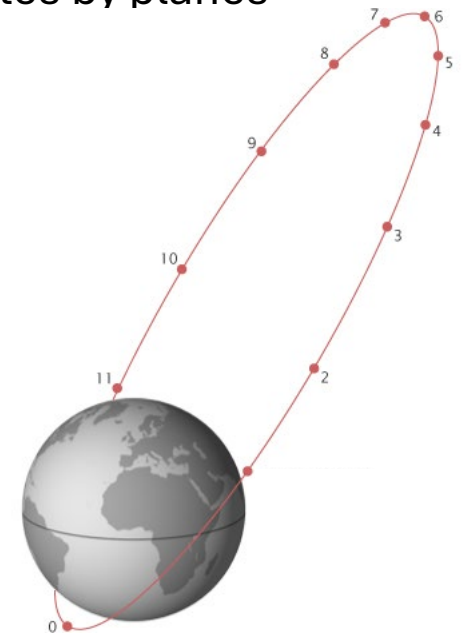




Methodology

3. Use queuing theory to build a mathematical model of the launch and decay of a pLEO constellation.

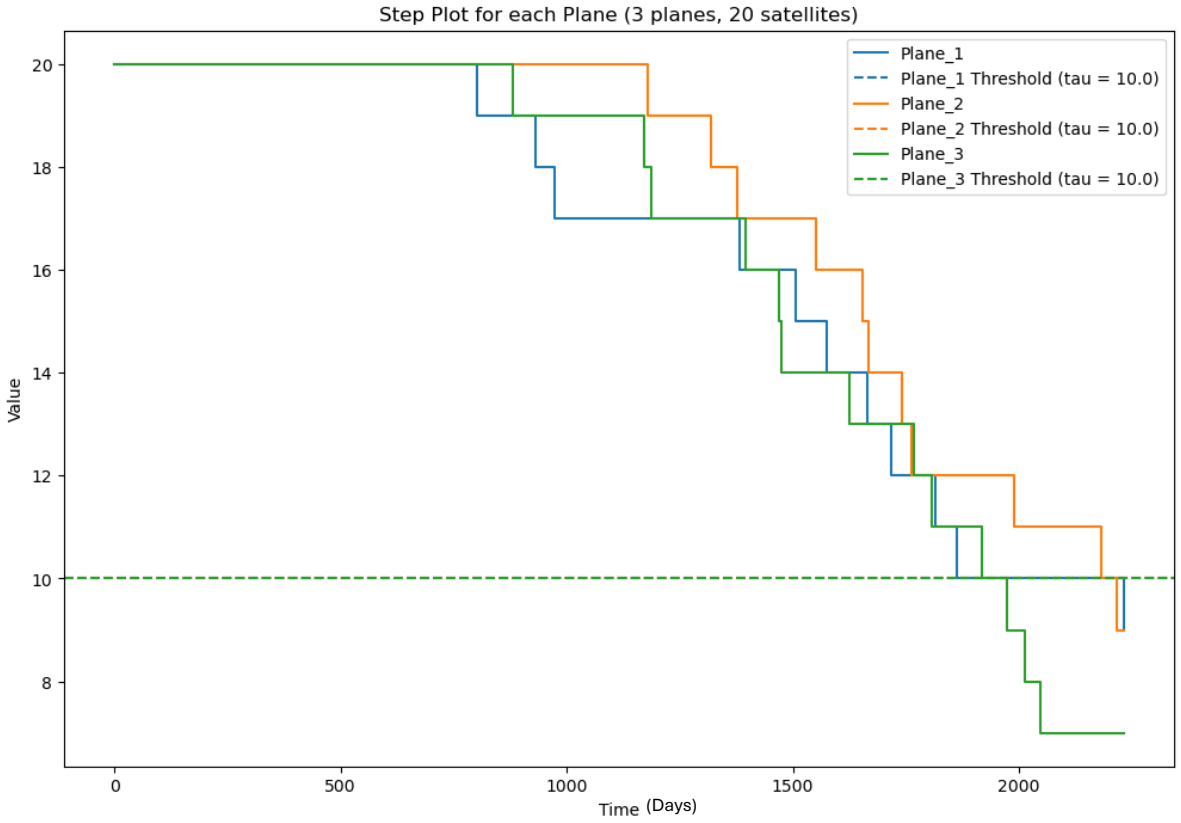
- Now that we know that satellites decay from machine failure, we can build a model that does not rely on the historical data
- We found the best way to think about replenishing satellites is to group satellites by planes
  (see figure that models 11 satellites in a plane at HEO)
- We built a model - using a Monte Carlo simulation - where one can parameterize the number of satellites and number of planes, to create constellations of various sizes
- This model can be used to optimize when to send up satellites and how many to send up, for constellation sustainment



Data Analysis

Use the model to evaluate different strategies for the initial launch and replenishment of different constellation sizes.

- I ran the model, changing the number of planes and number of satellites that make up a constellation, using different combinations of realistic number of planes and number of satellites
- Different iterates gave time until the first plane is rendered useless and time until all planes are rendered useless
- I found that the difference between well planned and poorly planned constellations is a span of 6 years. This is consistent with current lifetimes of Starlink lifetimes reaching up to 6 years



Note that we defined the time of a plane being rendered useless as Tau = half of the satellites have decayed from the original number

Predictive Analysis: Replenishing a pLEO constellation

- There is a significant difference in constellation life depending on the structure of number of planes and number of satellites
  - If tau is always half of the number of satellites per plane, for a fixed number of satellites in a constellation, it is generally better to have more planes than satellites per plane

- This model can thus inform how the DoD can save money by planning pLEO satellite constellations in an optimized way

Conclusions and next steps

- There is enough publicly-available data to model decay rate of certain types of pLEO constellations as a certain type of queuing problem
- These models can inform how satellite operators, including DoD, plan for the budgets and launch schedules of their space systems
- To improve the model further, future work can:
  - Vary assumptions on the number of satellites per launch vehicle and per plane
  - Investigate the impact of orbital altitude and inclination on modeled launch cadences
  - Add fidelity to the representation of launch and decay of specific planes of satellites within the overall constellation