Validation of a Scenario-Based Approach to Assess Gaps in Earth Observations

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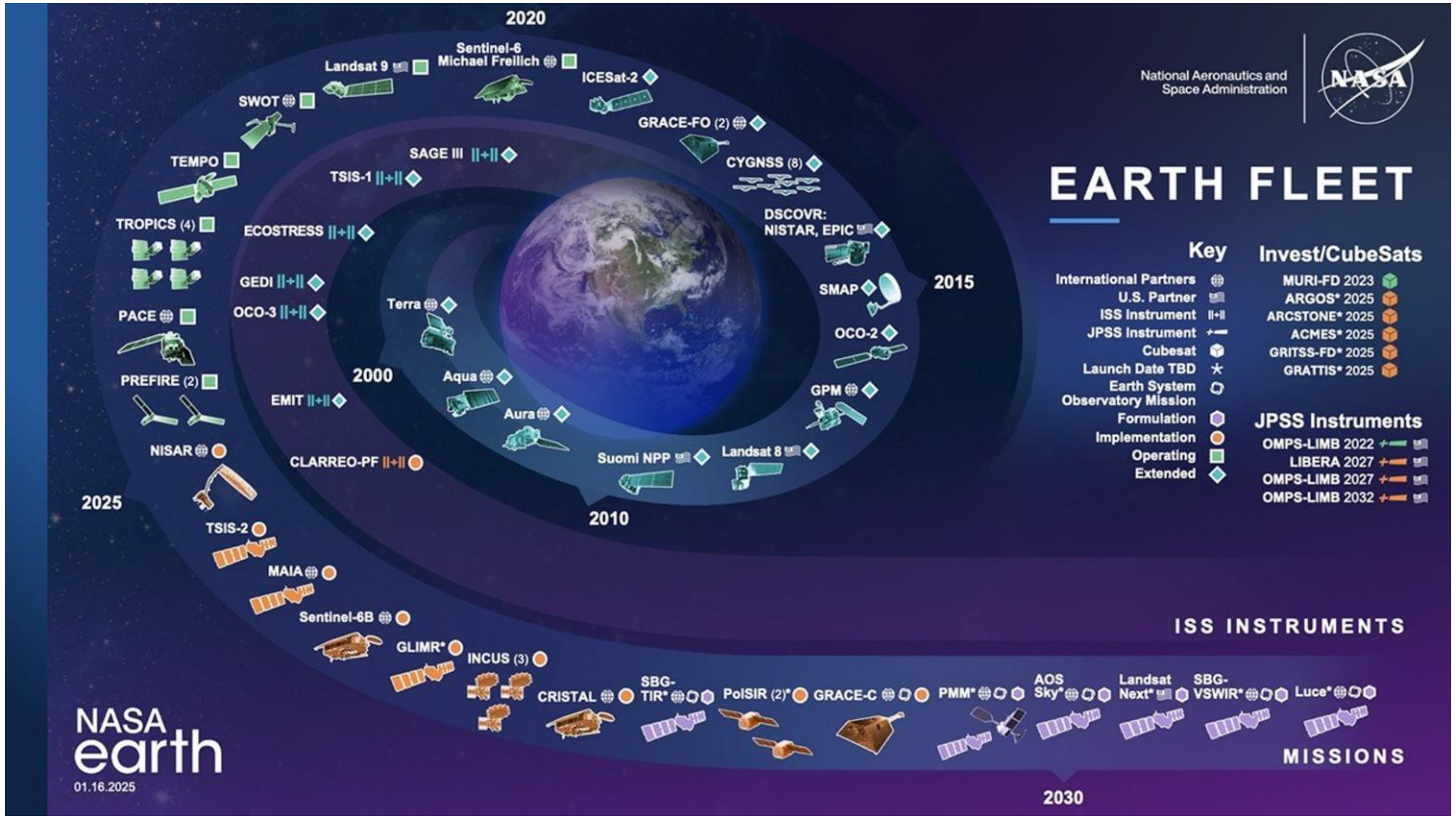
Motivation

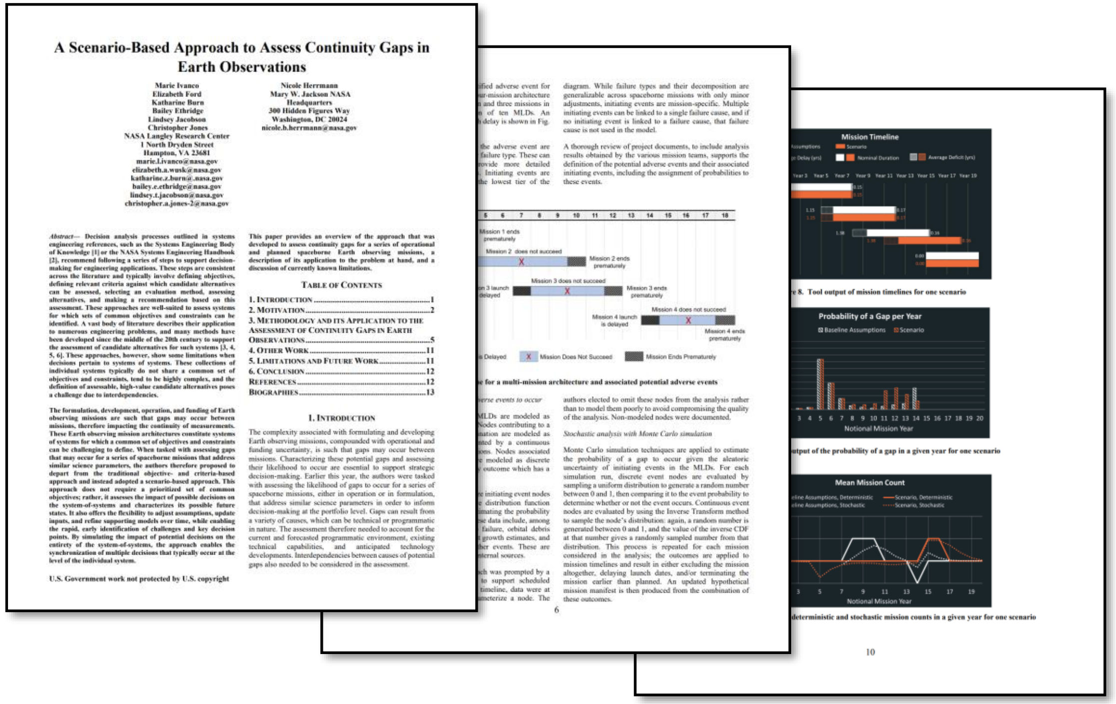


- Continuous Earth observation measurement records contribute to the accuracy of predictions and analysis of the Earth system

- The probability of gaps between Earth observation missions should be assessed well before their occurrence to support strategic decision making

- Factors contributing to the uncertainty of decision making:
  - Funding
  - Technology maturation
  - Shifting mission schedules

Previous Work



A Scenario-Based Approach to Assess Continuity Gaps in Earth Observations

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Abstract— Decision analysis processes outlined in systems engineering references, such as the Systems Engineering Body of Knowledge [1] or the NASA Systems Engineering Handbook [2], recommend following a series of steps to support decision-making for engineering applications. These steps are consistent across the literature and typically involve defining objectives, defining relevant criteria against which candidate alternatives can be assessed, selecting an evaluation method, assessing alternatives, and making a recommendation based on this assessment. These approaches are well-suited to assess systems for which sets of common objectives and constraints can be identified. A vast body of literature describes their application to numerous engineering problems, and many methods have been developed since the middle of the 20th century to support the assessment of candidate alternatives for such systems [3, 4, 5, 6]. These approaches, however, show some limitations when decisions pertain to systems of systems. These collections of individual systems typically do not share a common set of objectives and constraints, tend to be highly complex, and the definition of assessable, high-value candidate alternatives poses a challenge due to interdependencies.

The formulation, development, operation, and funding of Earth observing missions are such that gaps may occur between missions, therefore impacting the continuity of measurements. These Earth observing mission architectures constitute systems of systems for which a common set of objectives and constraints can be challenging to define. When tasked with assessing gaps that may occur for a series of spaceborne missions that address similar science parameters, the authors therefore proposed to depart from the traditional objective- and criteria-based approach and instead adopted a scenario-based approach. This approach does not require a prioritized set of common objectives; rather, it assesses the impact of possible decisions on the system-of-systems and characterizes its possible future states. It also offers the flexibility to adjust assumptions, update inputs, and refine supporting models over time, while enabling the rapid, early identification of challenges and key decision points. By simulating the impact of potential decisions on the entirety of the system-of-systems, the approach enables the synchronization of multiple decisions that typically occur at the level of the individual system.

This paper provides an overview of the approach that was developed to assess continuity gaps for a series of operational and planned spaceborne Earth observing missions, a description of its application to the problem at hand, and a discussion of currently known limitations.

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1. INTRODUCTION

The complexity associated with formulating and developing Earth observing missions, compounded with operational and funding uncertainty, is such that gaps may occur between missions. Characterizing these potential gaps and assessing their likelihood to occur are essential to support strategic decision-making. Earlier this year, the authors were tasked with assessing the likelihood of gaps to occur for a series of spaceborne missions, either in operation or in formulation, that address similar science parameters in order to inform decision-making at the portfolio level. Gaps can result from a variety of causes, which can be technical or programmatic in nature. The assessment therefore needed to account for the current and forecasted programmatic environment, existing technical capabilities, and anticipated technology developments. Interdependencies between causes of potential gaps also needed to be considered in the assessment.

- A scenario-based approach was developed by M. Ivanco et al.[1] to:
  1) Estimate the probability of potential continuity gaps in a multi-mission architecture
  2) Assess the probability in the context of multiple possible future states of the architecture

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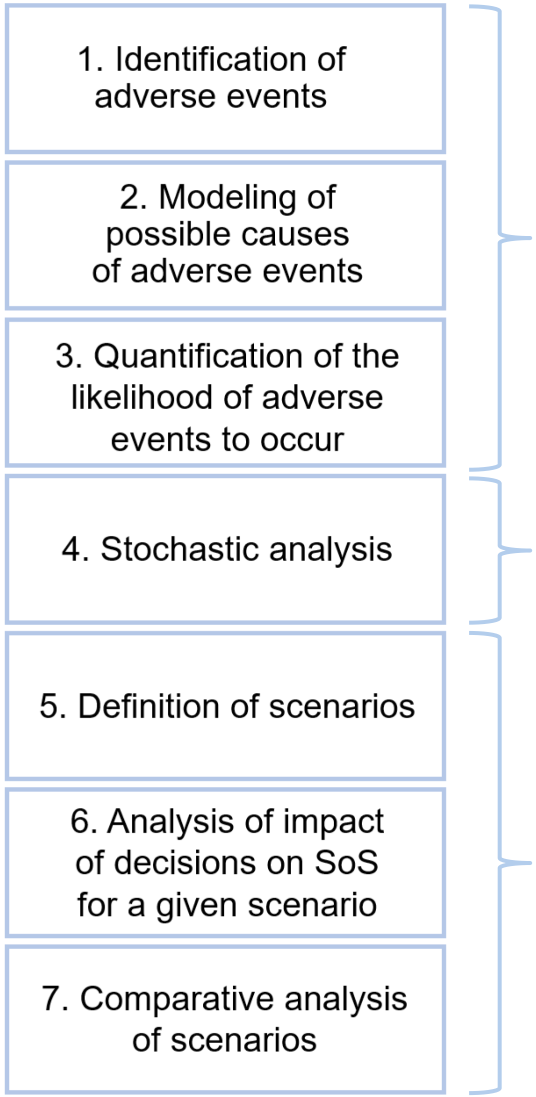
[1] M. Ivanco et al., “A Scenario-Based Approach to Assess Continuity Gaps in Earth Observations,” IEEE Aerospace Conference, Mar. 2024.

Previous Work

- Traditional NASA systems engineering decision analysis processes show limitations when decisions pertain to systems of systems (SoS)
- Ideas from the Military Decision-Making Process (MDMP) are incorporated
- A 7-step process defines the Scenario-Based Approach

1. Identification of adverse events
2. Modeling of possible causes of adverse events
3. Quantification of the likelihood of adverse events to occur
4. Stochastic analysis
5. Definition of scenarios
6. Analysis of impact of decisions on SoS for a given scenario
7. Comparative analysis of scenarios

Previous Work



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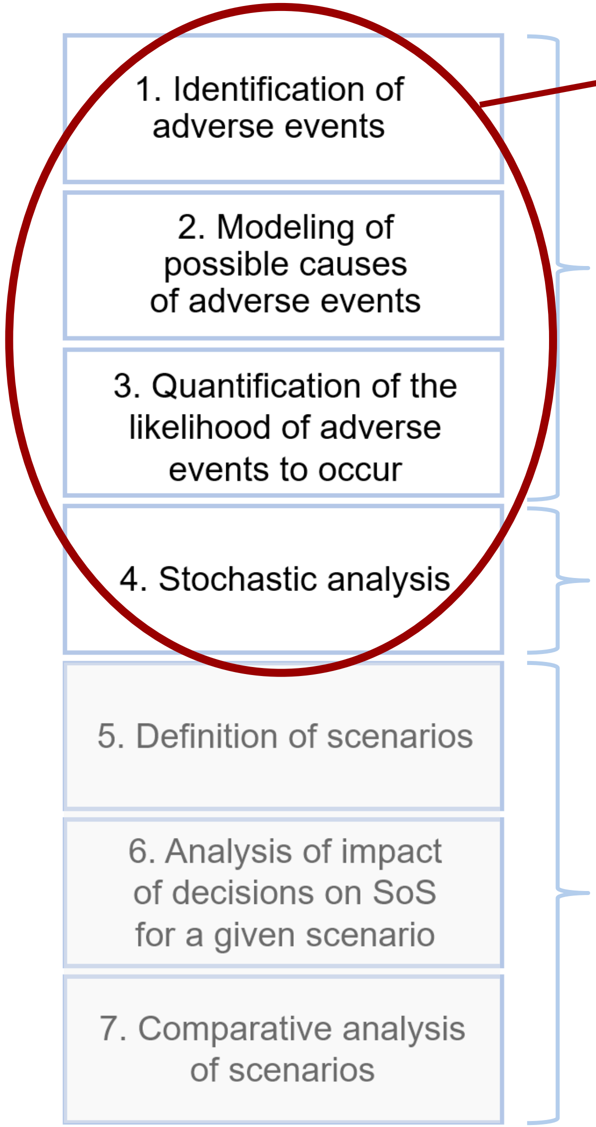
Identification and probabilistic modeling of possible events that would impact the likelihood of a continuity gap

Monte Carlo simulation to assess of the probability of a gap occurring in a given year for a set of baseline assumptions across the multi-mission architecture

Simulation of the effects of potential decisions on the overall architecture by use of scenarios

Previous Work



Today's discussion focuses here, on the stochastic portion of the method

Identification and probabilistic modeling of possible events that would impact the likelihood of a continuity gap

Monte Carlo simulation to assess of the probability of a gap occurring in a given year for a set of baseline assumptions across the multi-mission architecture

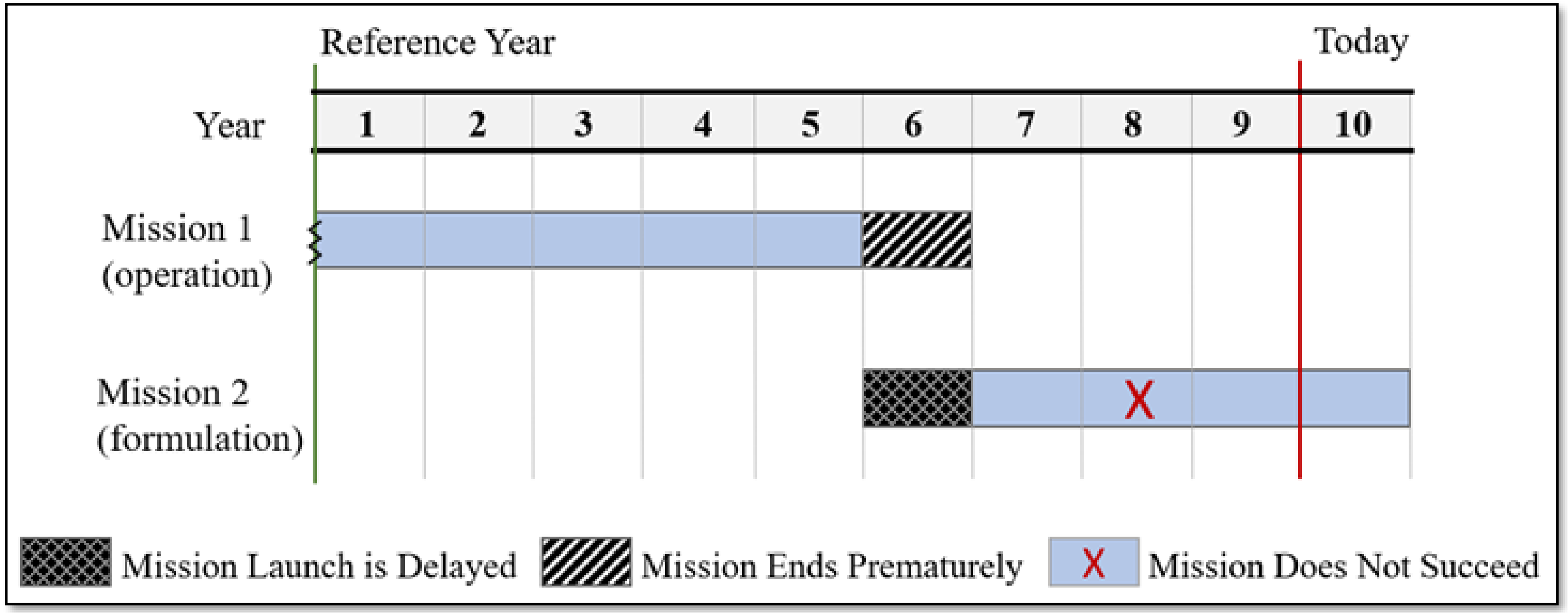
Simulation of the effects of potential decisions on the overall architecture by use of scenarios

Intent of Validation

- The stochastic method was applied retroactively to an existing multi-mission architecture, and the results were compared with actual outcomes of the missions
- Intent:
    - Initial effort investigating the validity and adequacy of the method
    - Provide insight into the effectiveness of the distributions and models used to assess the probability of gaps
    - Identify model improvements
- Not Intended:
    - An exhaustive validation of all use cases of the method

Validation Approach

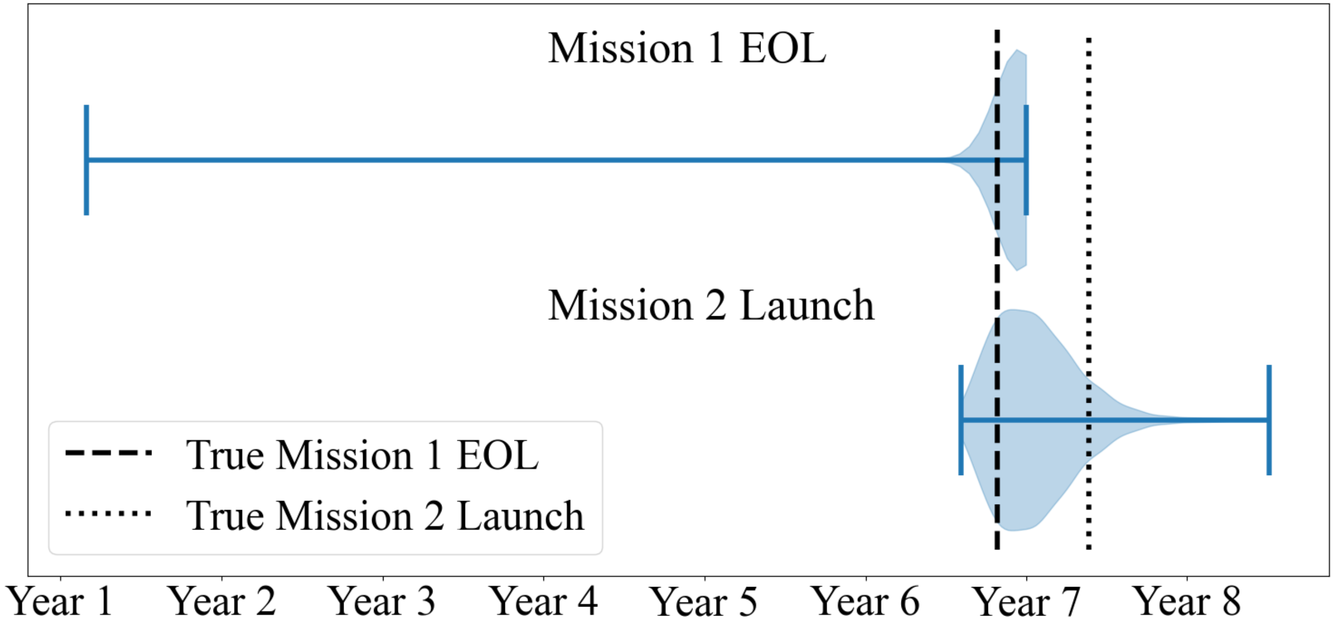
- Mission formulation documents, used to inform model distributions, were gathered from the development phase of a mission that is in operation today
- Analysis was conducted using information that was available 5 years prior to the start of Mission 2



Comparison of Model Results to True Dates

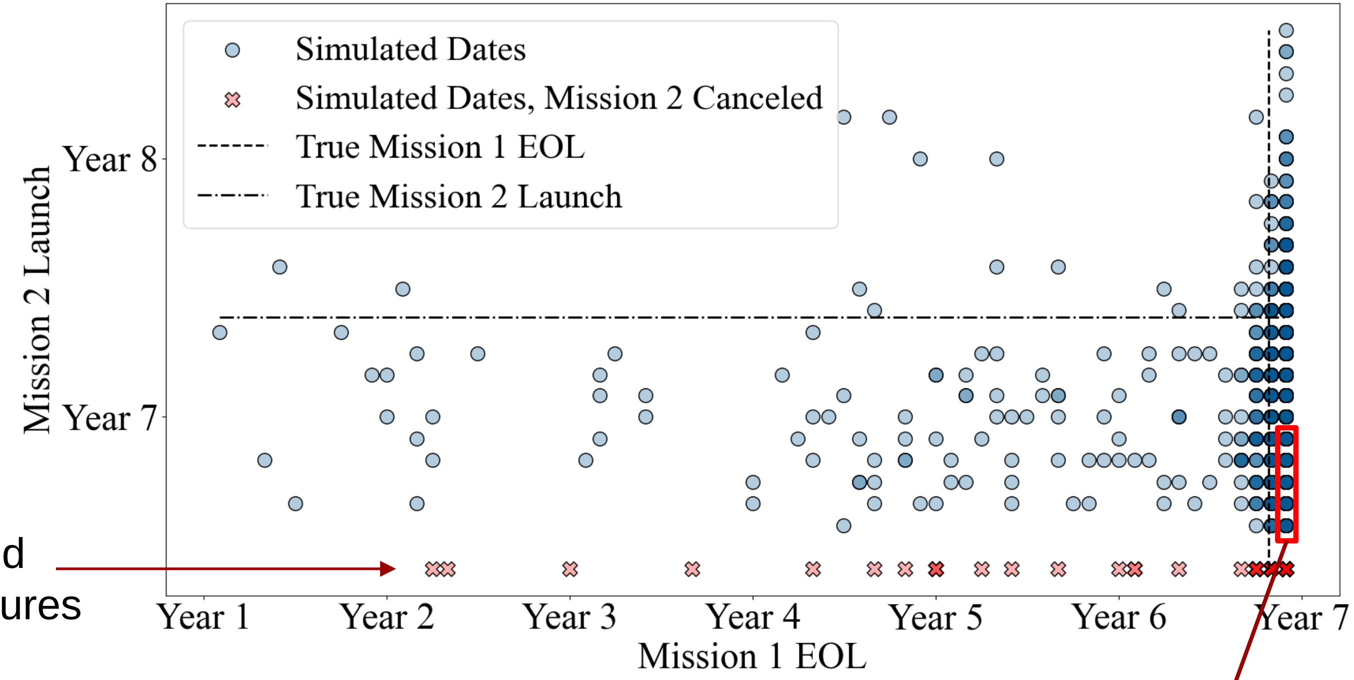
The simulation predicts the likelihood of a continuity gap by probabilistically estimating Mission 1 end of life (EOL) and Mission 2 launch dates

- ➢ Mean EOL estimate is within 2 days of the true EOL date
- ➢ Mean launch estimate predicts a 177-day launch delay
  - Actual launch delay = 294 days



Comparison of Model Results to True Dates

- Simulation tended to overestimate Mission 1 EOL and underestimate Mission 2 delay
  - 67% of points fall into bottom-right quadrant
- Mission 1 EOL estimates span Years 1-7, while Mission 2 Launch estimates appear after Year 6



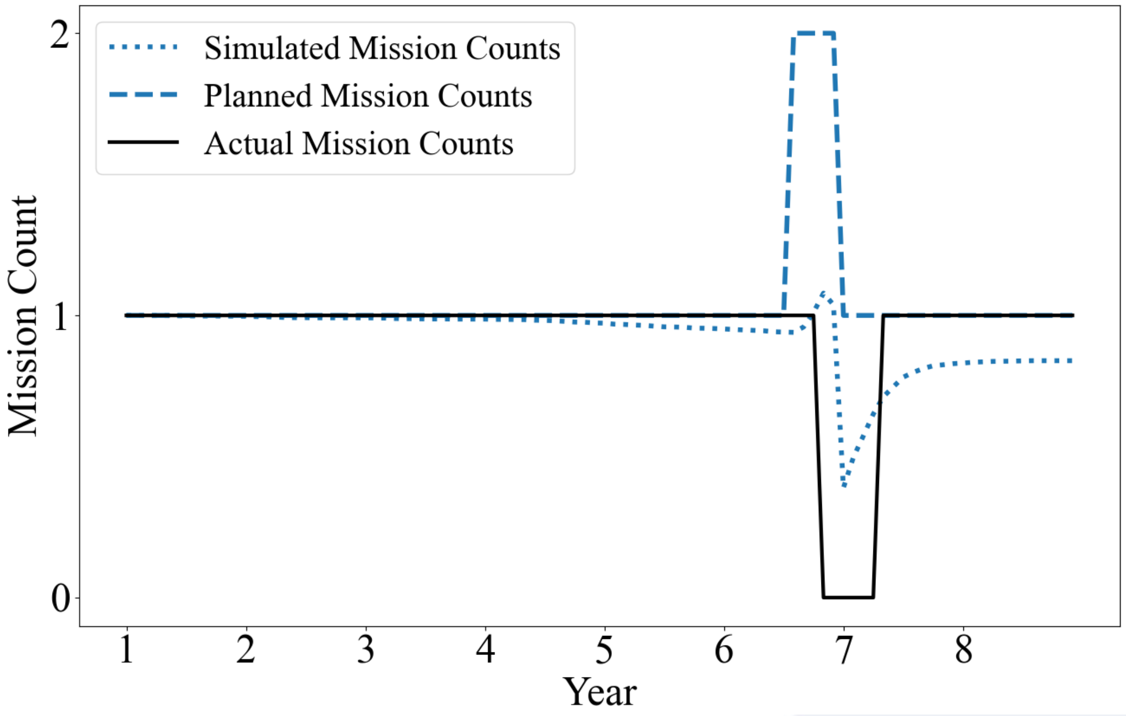
Simulated Launch Failures

Simulated Overlap

Comparison of Mission Counts

- Gaps between missions are identified by estimating the count of operational missions
  - Mission Count of 0 = Gap
- Simulated mission count represents the mean number of operational missions across all simulation runs for each time step

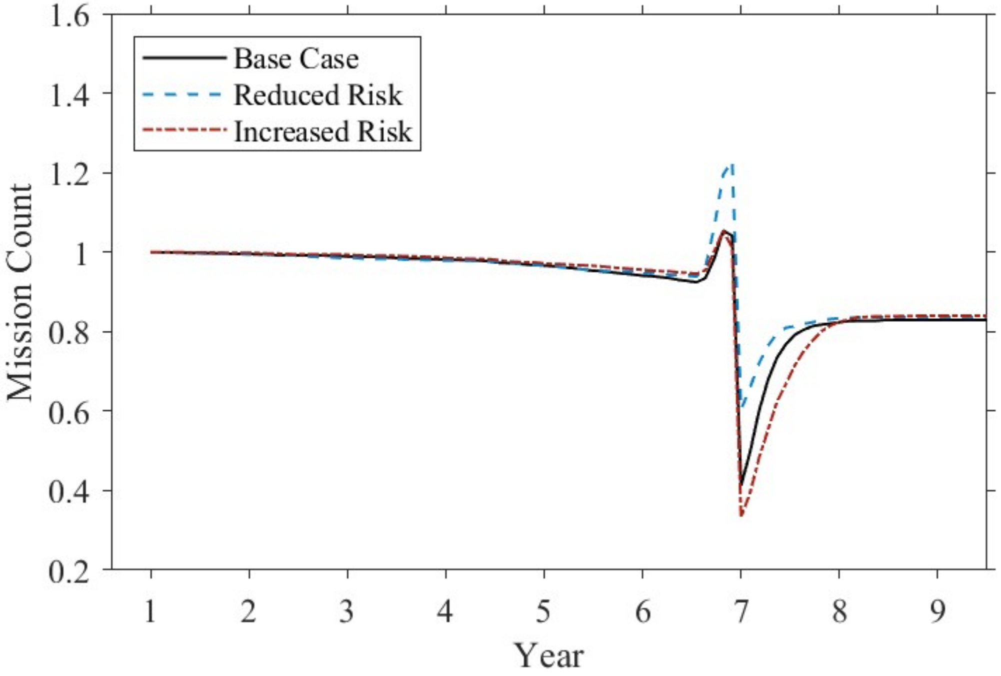
The stochastic model more closely predicts the true outcomes of the missions than what was planned during mission formulation



Sensitivity Analysis

How do adjustments to subjective input parameters affect model results?

- Should schedule risk be characterized as “Low,” “Low+,” or “Medium”?

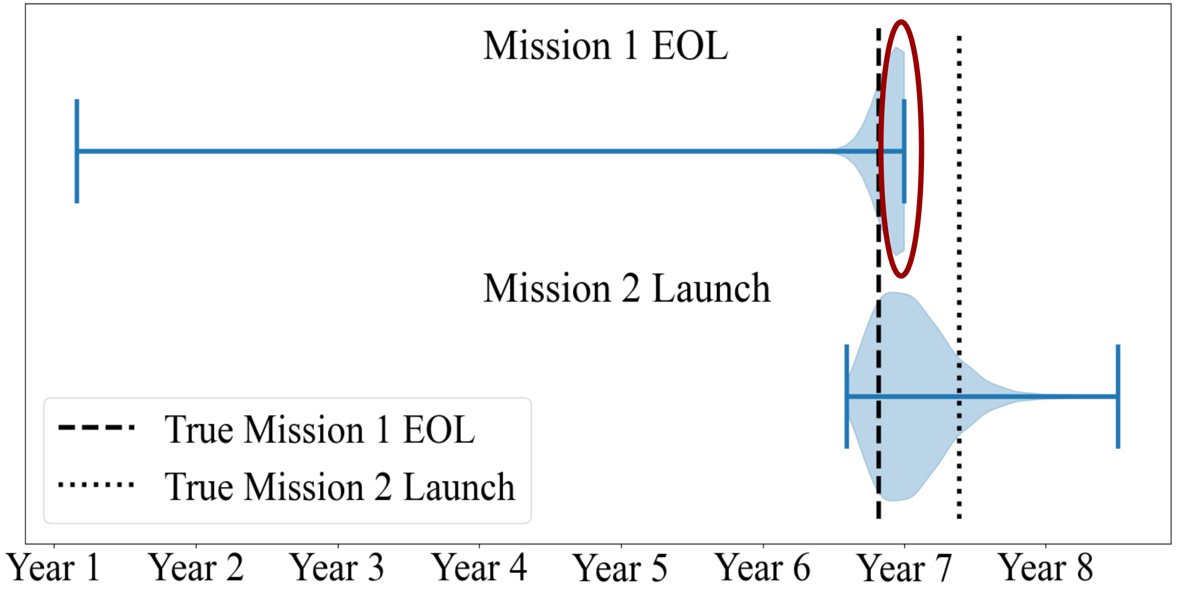


Underestimating risk could have a larger impact on the model results than adding additional risk margin to the inputs

Model Improvements

- **Planned model improvements:**
  1) Modeling extended mission lifetimes
     - Addresses truncation of right side of probability density plot for Mission 1
  2) Assess the relative ability of a mission to address a given science parameter, rather than using a binary mission count

- **Proposed model improvements:**
  3) Include the capability to simulate the effects of redundant systems or other non-mission ending failures



Concluding Remarks

Simulation estimates are adequate in predicting mission timelines and likelihood of gaps for the selected mission architecture

- The model more closely predicted the true outcomes of the missions than what was planned during formulation
  - Mean EOL estimate for Mission 1 was within 2 days of the true EOL date
  - 177-day predicted delay of Mission 2 launch is indicative of the 294-day true delay
- The sensitivity analysis suggests that underestimating the risk of a system could have a larger impact on the model results than adding additional risk margin to the inputs

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