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Author: Ms. Julia Milton
Massachusetts Institute of Technology (MIT), United States, jmilton@mit.edu

ASSESSING “DEEP UNCERTAINTY” IN SPACE SYSTEMS DESIGN: A SCENARIO-BASED FRAMEWORK FOR IDENTIFYING AND QUANTIFYING POLICY-CRITICAL SOURCES OF UNCERTAINTY

Abstract

The design and development of space missions is highly complex, characterized by multiple epistemic and aleatoric uncertainties stemming from technological, political, and economic components. Complex and interacting objectives such as mass and power constraints, budget priorities, evolving technical requirements, and changing policy directives have immense potential to alter the solution space for the design of any mission. In this work, we define “deep uncertainty” in complex systems design to be uncertainty stemming from these technical and policy risks of unknown likelihood. We develop a scenario-based methodology and framework to identify and quantify these sources of deep uncertainty, and apply it to the analysis of a robotic on-orbit servicing system for a proliferated communications satellite constellation in low-Earth orbit.

The scenario-based framework developed in this work can be used to assess the performance of a system in a range of possible uncertain futures, so that decision makers can understand the sources of risk and design space missions using informed approaches that are robust to changes. Drawing from successful uses of scenario-based modeling to account for risk and uncertainty in highly complex and uncertain systems, our framework uses policy scenarios coupled with quantitative models that characterize the driving forces of deep uncertainty and the potential performance of the system and ability to meet mission objectives that may result in these alternate futures. These quantitative models include traditional uncertainty quantification techniques found in systems dynamics models and Monte Carlo methods, as well as a novel method for probabilitstic Epoch Era tradespace analysis. Compared to previous models for quantifying uncertainty in space system design, we seek to enable decisions with less information (no known likelihoods of many key driving forces), in a framework that is computationally tractable, and can be updated as new information becomes available.