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THE TECHNOLOGICAL AND OPERATIONAL TRADE-OFFS IN SPACE DEBRIS MITIGATION

Abstract

Space debris mitigation has become a priority for policymakers, with regulations emphasizing post mission disposal, active debris removal (ADR), and sustainable satellite designs. However, integrating these measures requires additional engineering effort, increased costs, and extended mission timelines, creating operational challenges for satellite developers. This study examines the technical and logistical tradeoffs of implementing debris mitigation and assesses its impact on mission feasibility.

Despite regulatory pressure, many satellite operators prioritize cost efficiency and rapid deployment over full compliance with sustainability measures. While policies highlight the long term risks of debris accumulation, they often overlook the immediate technical challenges, budget constraints, and design modifications required for compliance. Missions must balance sustainability goals with engineering complexity, software and hardware modifications, and human intervention levels, raising concerns about the practical feasibility of widespread adoption.

This research analyzes how compliance with debris mitigation policies affects spacecraft design, mission planning, and resource allocation. Using case studies of current missions, such as ESA's ClearSpace-1 and Astroscale's ADRAS-J (which prioritize debris removal) and commercial constellations like Starlink and OneWeb (which focus on operational efficiency), the study evaluates added mission costs, required technology upgrades, and manual oversight. Data from industry reports and expert insights will be used to quantify engineering workload and mission delays due to compliance.

Findings indicate that while policy driven missions incorporate sustainability measures, they often face increased complexity, higher costs, and longer development cycles. Missions that deprioritize debris mitigation operate more efficiently but contribute to long term sustainability concerns. The gap between policy expectations and operational realities suggests that current mitigation strategies may not be universally feasible without further technological advancements or regulatory incentives.

By providing an engineering focused assessment, this study helps mission planners, satellite manufacturers, and policymakers understand the real world impact of compliance measures. A practical, technology aware approach is needed, one that aligns sustainability policies with the technical and operational constraints of modern space missions.