Paper ID: 91285
student

IAF SPACE SYSTEMS SYMPOSIUM (D1)
Systems Engineering Approaches, Processes and Methods (6)

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MODELING AND SIMULATION FRAMEWORK TO ASSESS THE IMPACT OF PREDICTIVE MAINTENANCE ON SPARES LOGISTICS IN CISLUNAR SPACE

Abstract

There is an increased interest in lunar exploration missions and campaigns, including NASA's Artemis mission which aims to establish a sustained human presence on the lunar surface. Projects such as NASA's Gateway and ESA's Moon Village are aimed at developing new manned infrastructure for lunar missions and habitation. Logistics and spares management are vital for long-term cislunar operations. Traditional approaches used for International Space Station logistics may not be sustainable for future missions that are more complex and require a higher degree of reliability. Most network-based logistics studies have focused on the transportation of commodities to demand points by assuming deterministic demand. In practice, demand is stochastic, subject to uncertainties and variations. Data-driven solutions like Digital Twin and predictive analytics can analyze data for accurate demand forecasting.

This research investigates the optimization of spare parts provisioning and maintenance scheduling through a Modeling and Simulation framework. These are often managed in isolation, leading to inefficiencies in supply versus demand management. To analyze and evaluate the behavior of complex systems in cislunar space logistics, this study utilizes Discrete Event Simulation (DES) as the modeling technique. DES allows for the simulation of spare logistics as a series of discrete events occurring at specific points in time. A key novelty of this research is the integration of a degradation model into the logistics framework, which models the degradation state of the system and enables predictive maintenance strategies. This integration aims to improve the prediction of both supply and demand for spare parts, leading to more effective logistics planning. The framework is then evaluated using a case scenario involving the Environmental Control and Life Support System (ECLSS), a critical component of space habitats. The study assesses the effectiveness of the framework in optimizing spare parts provisioning and maintenance scheduling, considering factors such as Maintenance logistics mass, cost, and system reliability.