Integrated Analysis Framework for Space Propellant Logistics: Production, Storage, and Transportation

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Introduction: As the interest in large-scale human exploration increases, in situ resource utilization (ISRU) attracts more and more attention for its long-term benefits in space transportation. However, traditional ISRU trade study models tend to only focus on ISRU plant design and do not capture its interaction with other space transportation systems. Our research proposes an integrated ISRU evaluation framework through the network-based space logistics architecture. It analyzes the performance of ISRU by considering plant deployment, regular production operations, and storage of the produced resource. The proposed framework can help the community identify the necessary infrastructure and its impact on architectures, to maximize the value of ISRU and identify technology gaps that need to be addressed to achieve those missions.

Literature Review: Past ISRU studies mainly focused on the architecture designs and their productivities. Schreiner [1] and Meyen [2] from MIT performed thorough analyses of ISRU performance, respectively. Lockheed Martin [3] and NASA [4] built their testbeds to evaluate the performance of ISRU. However, these studies did not consider ISRU plant deployment and propellant storage as part of the trade space. On the other hand, there are studies that considered ISRU plant sizing and space mission planning concurrently. Ishimatsu [5], Ho [6], and Chen [7] proposed a series of space logistics optimization frameworks based on the generalized multi-commodity network flow model (GMCNF) to optimize space mission planning together with the architecture design. However, their work considered the ISRU system as an integrated system and did not consider the tradeoff among ISRU subsystem sizing (e.g., reactor, power system, and storage) and their logistics.

Mathematical Framework: This paper proposes an integrated ISRU analysis and design framework through the network-based space logistics optimization model, as shown in the figure. In the network model, nodes represent planets or orbits; arcs represent space flight trajectories. The space transportation and logistics are denoted as commodity flows along arcs. Each subsystem of the ISRU plant is considered as a separate commodity. A large-scale multi-mission lunar exploration campaign will be considered as a case study. Multiple types of ISRU system will be evaluated from the subsystem-level focusing on the propellant production, storage, and transportation from the perspective of the space logistics. Our method can not only evaluate the productivity performance of an ISRU system, but also provide an effective subsystem sizing and technology selection tool that takes into account the plant deployment, ISRU production storage, and power supply.

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