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Strategies & Architectures as the Framework for Future Building Blocks in Space Exploration and Development (1)

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INCENTIVE DESIGN FOR COMMERCIAL PARTICIPATION IN SPACE LOGISTICS INFRASTRUCTURE DEVELOPMENT AND DEPLOYMENT

Abstract

As rocket launch cost decreases and technology develops, more government and commercial entities exhibit their interest in participating in future large-scale space exploration with their own mission objective preferences and technology advantages. Different from previous space exploration eras when logistically independent mission planning strategies were mainly implemented, for future deep space explorations beyond Earth orbits, space logistics infrastructures play an important role in reducing space mission cost leveraging mission interdependencies. For example, in-situ resource utilization systems (i.e., oil fields in space) and propellant depots (i.e., gas stations in orbit) deployed in the early-stage of a space exploration campaign can support subsequent space missions by supplying propellant to transportation vehicles. The technology development and system deployment of these space public infrastructures are huge projects that rely on international collaborations and federations. However, even though successful federation can provide commercial players with higher rewards, they might still choose not to participate in the federation in fear of risk because of the unknowns of other players' decisions. Therefore, it requires the government/planner to offer incentives to pull the commercial players, who seek to maximize their own utilities, together. The problem is how to design an effective incentive mechanism to achieve this goal with minimum resources. To solve this problem, this paper proposes an incentive design framework based on game theory. We assume there is a planner/coordinator that performs system-level space logistics analysis to identify the desired logistics infrastructure designs and deployment strategies using network-based space logistics optimization method. According to current infrastructures deployed and their performances, the planner updates the desired infrastructure designs with deployment strategies and minimizes the incentives for each commercial player to shift its decision to a more desired direction for the next step from the planner's perspective. The commercial players' decisions with respect to their own goals and to the planner's incentives are identified as non-cooperative games through a multi-actor space logistics optimization model, which is a multi-layer commodity network flow problem. A case study of multi-mission cislunar exploration campaign with multiple players is performed to evaluate the performance of the proposed incentive design framework. A sensitivity analysis is also performed to analyze the impact of future space transaction activities among commercial players (e.g., propellant selling) on space infrastructure development. Our method provides an important step forward in incentive design for broader participation in future large-scale space exploration. It is particularly useful for future "building block" development and deployment.