Lunar Base Agent-Based Modeling - A Benchmark for Simulating Crewed Space Missions

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Abstract: Space exploration has progressed significantly since the mid-20th century, and recent technological advancements, along with the emergence of commercial space travel, have led to substantial leaps in planning for future space missions. The largest planned upcoming mission is the Artemis program, supported by NASA and the international Artemis Accords, which aims to create the first permanent human presence on the Moon and in deep space (the Moon to Mars architecture). Although human psychology and team science have been crucial for the success of past space missions, from the Apollo program and Skylab to the Space Shuttle (STS) and the International Space Station (ISS), human factors and social behavior will become even more ubiquitous and essential for space missions in the new era of commercial space. By simulating upcoming permanent space missions in an agent-based model (ABM), we can draw insights into the long-term effects of human factors and interactions in space. Drawing from the literature on proxy environments (extreme environments on Earth (i.e., Antarctica), space analogs, and past space missions), and on theories of small group complex systems and team science, we created a highly probable representation (simulation) of expected social interactions between astronauts, and astronauts with the lunar environment for the Artemis program (i.e., Artemis IV (Lunar Gateway) and Artemis V (lunar south pole base)). Our Lunar Base ABM explores the exogenous and endogenous factors that are more likely to lead to sustainable versus catastrophic scenarios on the Moon in the next couple of decades. The model represents astronauts as agents with cognitive skills, emotional states, and personality traits to capture how social and environmental factors interact to affect mission outcomes. Monte Carlo simulations consisting of tens of thousands of iterations show trade-offs in productivity and psychological well-being. This approach demonstrates how agent-based modeling can help mission planners evaluate operational resilience, team structures, and workload dynamics in support of future lunar exploration.

Bio: Dr. Berea is a double PhD (economics and computational social sciences) and an associate professor of computational and data sciences at George Mason University. She is also a research investigator with Blue Marble Space Institute of Science, an affiliate mentor with NASA/SETI Frontier Development Lab and a research affiliate with the SETI Institute. Her research has focused mostly on applying computational methods such as agent-based modeling, social network analysis, natural language processing and deep learning to astrobiology and other complex systems phenomena in space sciences, for which she received three awards of merit from NASA. Her current research is focused on modeling human factors for crewed space missions.