Benefits of a Proposed Process to Preserve Lunar Sites

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Assets in lunar orbit and on the surface, whether operational or defunct, have the ability to cause inadvertent interference with proximity operations. As missions to the Moon continue to proliferate, and as more actors become involved, a mechanism is needed to bring communities together to ensure ones' actions do not inhibit the mission objectives of another. A mechanism may also be needed to determine whether any locations on the Moon or in its orbit are of high value to various users, and, pending potential decreases in this value due to interference and other concerns, warrant mitigative actions to preserve these locations. Such a mechanism could provide benefits to all those involved, including governments, industry, academia, and other interested groups. We present a notional process to aggregate community interests for lunar sites and orbits. We then consider two user needs and explore how this process could be used to identify potential alignments and misalignments across communities.

I. Background and Purpose

A. Preservation of Lunar Activities – Related U.S. Policy

Over the past ten years, U.S. policy has encouraged lunar exploration, resource utilization, and prioritization of scientific interests. We outline several recent policies related to lunar activity below.

The April 6, 2020, Executive Order on Encouraging International Support for the Recovery and Use of Space Resources establishes commercial exploration, recover, and use of outer space resources as consistent with applicable law. The Executive Order additionally notes "Successful long-term exploration and scientific discovery of the Moon, Mars, and other celestial bodies will require partnership with commercial entities to recover and use resources, including water and certain minerals, in outer space." The Executive Order's accompanied fact sheet encourages the "establishment of stable international practices by which private citizens, companies and the economy will benefit from expanding the economic sphere of human activity beyond the Earth."

The 2020 National Space Policy of the United States elaborated on future lunar exploration plans, including enabling a sustained lunar presence. It sought to "extend human economic activity into deep space by establishing a permanent human presence on the Moon, and, in cooperation with private industry and international partners, develop infrastructure and services that will enable science driven exploration, space resource utilization, and human missions to Mars" It accordingly instructed the NASA Administrator, in collaboration with other appropriate agencies, Federal laboratories, and commercial partners, to "[m]aintain a sustained robotic presence in the solar system with international and commercial partners to: prepare for future human missions; conduct scientific investigations; map and characterize water, mineral, and elemental resources; and demonstrate new technologies."

The 2022 National Cislunar Science and Technology Strategy further instructs the U.S. government to "[m]aintain a Cislunar-focused science objectives summary to comprehensively identify the highest-priority scientific opportunities in Cislunar space."

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B. Preservation of Lunar Activities – Motivation

In order to develop a sustained robotic and human lunar presence, and achieve high priority lunar science objectives, NASA will need to determine the alignment of objectives of lunar missions and support best practices that enable long-term lunar activity. Enabling lunar in-situ resource utilization (ISRU), for example, may have objectives that are congruous with priority scientific investigations, such as mapping and sampling of lunar regions of interest. Lunar ISRU may also have objectives that are incongruous with lunar scientific priorities, such as thermal destruction of volatiles during operations. Incongruous objectives may also have mitigation or remediation options, or mutual future common benefits, such as an ISRU rover obtaining and storing cryogenic samples prior to beginning operations, or the ISRU rover eroding the surface, making future transit for other missions easier. Determining areas of congruence or incongruence of mission objectives, and potential to increase congruence or probability of success of mission objectives, requires a strategic process which takes into account not only mission objectives, but also a system that can identify and recommend mitigation/remediation options for incongruous objectives.

C. Preservation of Lunar Activities – Related Work Within NASA

Recent NASA studies have underscored the need to determine—as a community—what is of value on the lunar surface (and in lunar orbit), what actions could negatively impact this value, and what may warrant preservation. In 2022, NASA's Office of Technology, Policy, and Strategy (OTPS) published a report, "Lunar Landing and Operations Policy Analysis" [1] which highlighted seven major challenges to lunar landings and operations. These challenges represent issues that could interfere with operations or science objectives. The report discusses potential policy options for addressing these challenges as well as other measures for increasing the likelihood of success, including working transparently and in coordination with other actors. In 2024, OTPS published the "Policy Questions Framework for Missions" [2] which used the Moon to Mars Objectives to identify twelve broad policy questions applicable for any mission. Of these twelve policy questions, the following two relate to this study: 1) the protection[4] of valuable locations: how should the international community, and by extension NASA, equitably and sustainably identify and protect locations of high value and adjudicate their use by competing interests?; and 2) avoiding interference among actors: how should NASA's actions in pursuit of the Moon to Mars Objectives ensure compatibility with other actors and not impede the ability of others to achieve mission success, and vice versa?

To begin to address some of these questions, OTPS released a public questionnaire[5] in May 2023 to better understand what is of value to different communities, what interferences could inhibit science or operations, and what mitigative actions could be taken to limit these impacts. Using these data, OTPS presented a paper at the 2024 International Astronautical Congress in Milan, Italy [3] discussing the results, as well as history of the definitions of related terms (e.g., interference and contamination).

In this paper, we present a notional process by which the government, industry, academia, and others with an interest in lunar science and operations can consider in an approach to preserve lunar sites for mission objectives. The goals of this process are to proactively identify areas of alignment and misalignment as they relate to user needs; provide transparency into what other operations, either past or current, could interfere with mission objectives; and inform the prioritization of efforts to preserve sites.

To illustrate the benefits of this notional process, we consider user needs related to ISRU and geology. Although ISRU remains a long-term goal, demonstrating an ISRU related example through the proposed process will serve to highlight how differing user needs on the lunar surface could pose interference concerns to ISRU. Due to the interest in ISRU and geology from many stakeholders (domestic and international governments, industry, academia), this process can serve as a common language by which these stakeholders can discuss mission objectives, interference concerns as they relate to specific sites, and mitigative actions to limit the impact to mission objectives. This is a transparent means to aggregate communities in the interest of achieving mission objectives.

II. Overview of Notional Process to Preserve Sites

NASA is exploring the development of a process to connect user needs for lunar sites (on the surface and in orbit) with mitigative actions that could preserve these sites, and thus increase the probability of achieving mission

[4] Note that after NASA-internal and -external discussions, we moved from terminology related to "protection" to that of "preservation," as that is more closely representative of the nature and purpose of these efforts.

[5] "OTPS seeks input from the lunar community to inform a framework for further work on non-interference of lunar activities," https://www.nasa.gov/organizations/otps/otps-seeks-input-from-the-lunar-community-to-inform-a-framework-for-further-work-on-non-interference-of-lunar-activities/

objectives. The process under consideration is specific to NASA, however, can be expanded to include other domestic and international needs.

The notional process consists of three main segments: the Moon to Mars Architecture segment, which represents NASA's needs; a Catalog, which relates these needs to specific locations and associated concerns; and a preservation segment which highlights what actions could be taken to minimize concerns at these locations.

The Moon to Mars Architecture is a segment of the process which maps the Moon to Mars Objectives to the subsequent segments. The Moon to Mars Architecture Definition Document[6] includes a functional breakdown for each of the 63 Moon to Mars Objectives. That is, each objective is broken down into multiple functions, which represent the actions that are needed to accomplish that objective. These functions, as well as their connection to the relevant objective, are captured; this begins the lead-in to the Catalog. External communities also begin the process here; however, the specific need may deviate from these objectives.

The Catalog then takes these user needs and relates them to potential sites (locations on the lunar surface or in orbit). Each need and associated location can then be used to assess what specific concerns might be in effect. Concerns represent anything that could hinder the user need at a defined location, thus impacting mission objectives. Concerns can include contamination of the lunar environment by unwanted materials,[7] interferences that could impact the ability to carry out the mission objective,[8] and any other hindrance such as lack of demand, impact to historic sites, site accessibility, and others. If a concern already employs a mitigation mechanism to reduce its impact on mission objectives, that is captured in the Catalog. These user needs along with associated sites and concerns can be used to assess not only what is of value to users, but also how that value may change. This value determination is used to inform the next segment.

The preservation segment includes mitigations that could be implemented to address concerns at given sites. These future mitigations entail any technical, operational, or policy-driven action that could, in effect, work to preserve the site of interest for this specific user need.

The Catalog and preservation segments are meant to be cyclic, updating as concerns are understood and as mitigative actions are implemented.

Populating the Catalog and preservation segments for a given user need can help inform other user needs in multiple ways. For example, understanding NASA's needs with respect to full-scale ISRU operations can inform, 1) other NASA needs, such as what could positively or adversely impact science, 2) other domestic stakeholder needs, such as how industry could benefit from mitigative actions, or 3) the needs of international space agencies, which could potentially overlap with NASA's plans.

Ultimately, aggregating stakeholders will benefit all current and future stakeholder needs for lunar surface or orbital missions. At minimum, bringing communities together will build an understanding of what is of value for different users. Tracking what concerns are related to user needs and cataloging them in relation to different sites will ensure that a record is kept for any known changes to the lunar environment. This is of benefit to current and future generations, especially as operations at the lunar surface become more prolific. Finally, determining what sites may be in need of mitigative actions to preserve their value may help ensure the most scientific value from the Moon is obtained.

III. Demonstrating the Notional Process Through Example User Needs

Results to come.

D. References

[1] Swiney, G., and Hernandez, A., "Lunar Landing and Operations Policy Analysis," NASA, 2022.
[2] Swiney G., McBrayer, K., Beauchemin, A., "Policy Framework for Missions," NASA, 2024.
[3] Jones, T., et al., "Non-Interference of Lunar Activities," 75th International Astronautical Congress, Milan, Italy, 14-18 October 2024.

[6] 2023 Moon to Mars Architecture Definition Document, https://www.nasa.gov/wp-content/uploads/2024/01/rev-a-acr23-esdmd-001-m2madd.pdf?emrc=b2c9ef

[7] The definition of contamination, using NASA STD 8719.27 is "Unwanted material present on or in the spacecraft/spacecraft assembly environment introduced into the environment of a solar system body" https://standards.nasa.gov/standard/NASA/NASA-STD-871927

[8] As noted in the NASA OTPS paper presented at the 2024 IAC in Milan, Italy, we refer to interference as "an activity that may impact the activity of another actor to carry out a mission or objective."