Prototyping a Lunar Registry of Missions, Objects, and Activities

OPEN LUNAR FOUNDATION

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Summary

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The Lunar Registry aims to create a comprehensive database of Lunar objects and activities. As Lunar activities intensify, the need for such a registry is becoming increasingly crucial for a variety of stakeholders. This report expands on Open Lunar's foundational analysis of the historical and political context for the development of a Lunar Registry by providing detailed, actionable recommendations in several key areas: technical infrastructure, functional prototyping, design and legal considerations, institutional structure, and phased development work plan.

Key Recommendations and Outcomes

1. The identification and definition of important elements and attributes for building The Lunar Registry, such as objects, activities, missions, and owner/operators.
2. The exploration of the technical infrastructure required for an effective and scalable system for Lunar data management.
3. The exploration and learnings of creating a prototype sample Registry populated with historical information.
4. Detailed Registry development plan covering four critical phases: Alpha (current phase), Beta, Public Launch, and Expansion/Development.
5. Institutional design and legal considerations.

Introduction to the Lunar Registry

The current absence of reliable, detailed Lunar activity information presents a hazardous communications gap for cislunar operations. This information gap becomes increasingly pertinent given the anticipated surge in Lunar activities and operators in the coming decade.

A Global Registry of Lunar Objects and Activities will allow governments, private commercial operators, scientific and academic institutions, civil society, and financial institutions to set a baseline for information sharing, promote a clear understanding of activities, and enable appropriate coordination to reduce operating risks. The Registry intends to promote operator transparency as a key component of Lunar exploration and empower the public to engage with the development of the Lunar economy and environment.
This effort builds upon previous Open Lunar's foundational work in assessing the historical and political aspects of establishing a Lunar registry (1) , advancing this research, and bridging the theoretical concepts with practical feasibility.

(1) https://www.openlunar.org/projects/lunar-registry

Defining Factors and Attributes

Defining Objects and Activities

Defining objects and activities in the Lunar Registry is essential for maintaining order, consistency, and accountability in Lunar operations. Clearly defining objects and activities scopes the Registry and provides a framework for deciding what data should be collected, maintained, analyzed, and stored. For the purposes of this Registry, Space Object, and Space Activity are defined as follows.

Space Object: Any manufactured device, vessel, machine, satellite, their parts, or material item onboard such vessel or machine whether tethered or detached, or substance launched or intended to be launched into or from outer space including the Moon and other celestial bodies.

Space Activity: Defined as any or a combination of any of the following:

- Launching or attempting to launch space objects into outer space.
- The movement, operation, and control of space objects in outer space.
- Measures to return a space object, recovery to Earth, whether planned or unplanned.
- The exploration and use of outer space, including navigation, remote sensing, satellite operations, and resource exploration and extraction.
- Crewed spaceflights and the establishment of short-term or long-term settlements.
- The construction or use of facilities in space or on the surface of celestial bodies, whether temporarily or permanently.
- The manufacturing, assembly, completion, development, testing, transportation, storage, trade, and disposal of any space objects.

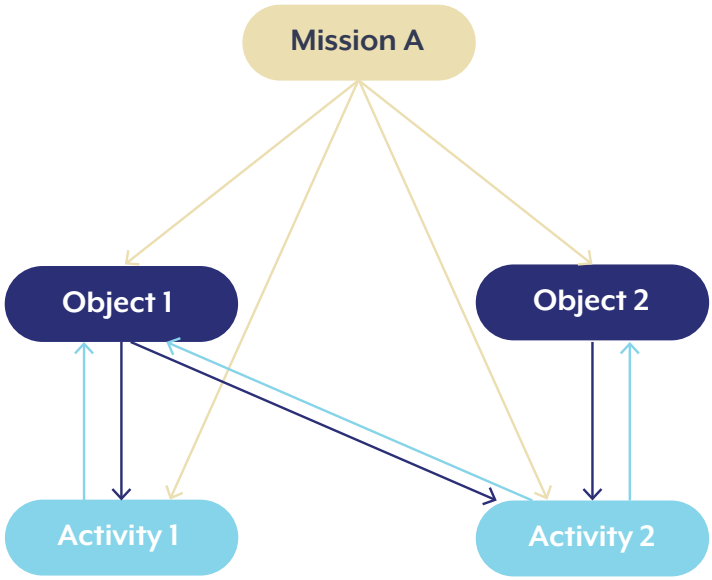
Delineating Between Objects and Activities

The distinction is evident by definition as noted above; an object is not an activity, thus an object has different attributes than an activity. These attributes constitute the data within the Registry; if an object has fundamentally different attributes than an activity, it cannot be catalogued in the same data table. Objects and activities are also created independently; new activities may be undertaken with pre-existing objects, and new objects may be introduced to accomplish existing activities. As Lunar activity scales, it will be prudent to track the introduction of objects and activities separately, as their growth may not be linear in ratio; this principle led to the decision to house objects and activities in individual data tables.

Scientific and commercial endeavours alike are constituted by activities undertaken in their pursuit, the objects that enable these activities, and the entities who own and administer them. Objects and activities in this context

are inherently dependent on each other. As the Moon and Lunar space are not naturally habitable, any human or human-made presence relies upon artificial objects. Space operations and those on the Lunar surface come at great cost and risk, leading any presence of humans and/or artificial objects to be associated with specific activities deemed valuable enough to substantiate this expenditure. This relationship underscores the afore-mentioned distinction between objects and activities, yet also defines an interdependency that is catered to in the Registry by way of associations; objects have associated missions and activities, activities have associated missions and objects, and missions possess both objects and activities.

Figure 1 demonstrates the relationships between a mission and its objects and activities



Example: A mission which is constituted by 2 activities performed by 2 objects

- Mission A log entry shows associations to object 1, object 2, activity 1 and activity 2.
- Object 1 entry is associated with Mission A, Activity 1, and Activity 2.
- Object 2 entry is associated with Mission A and Activity 2.
- Activity 1 entry is associated with Mission A, and Object 1.
- Activity 2 entry is associated with Mission A, Object 1 and Object 2.

Tracking Owners and Operators

The use of the term 'mission' typically implies a scientific and/or commercial intent to take action in a location different from that of its origin. Missions provide the context for Lunar objects and activities, while the operators of these missions offer the meaning and purpose for this context. Objects are utilized to undertake activities in real-time, with regular alterations to mission profiles as conditions change. The owner or operator of a mission is responsible for the usage of their mission's objects and the selection of their activities; their choices in this regard provide much of the data that populates an object or activity's attribution in the Registry. In other words, objects and activities are defined by the intent of the operator as much as they are by their spatial and physical characteristics.

Mission profiles and operator intent are variable; the Registry will not and cannot know what will change, though it must be able to accommodate change and capture this information as it pertains to the definition of objects and activities. However, while the intent of an operator may wholly define the purpose of a mission, it serves only as context for the objects and activities therein. Thus, it becomes necessary to track the owners and operators of objects, and their associated activities, over time and across missions. An object wielded by 'Operator A' performing 'Activity A' in the name of 'Mission A' may have substantially different implications than the same object wielded by 'Operator B' performing 'Activity B' in the name of 'Mission B'. Further, an object wielded by a different operator or in a different mission may carry with it unique safety, communications, and operations concerns from its previous use case. This implies that as operators and their intentions change over time, so too can the very definition of an object used in the fulfillment of those missions. A unique material item may be defined as multiple different objects within the Lunar Registry throughout its existence, necessitating the capture and specification of owners and operators for objects and activities across such time.

Lunar Registry Design

The Registry will be tasked with accommodating a unique set of operating constraints. Functionally, the Registry will need to accept highly variable, sensitive inputs from a variety of sources. This input data is made valuable through its accuracy, thus the Registry will require a verification schema to underwrite this data when published. Given the sensitive, often proprietary nature of the published information in the Registry, access may need to be tiered to ensure broad stakeholder participation and bolster the commitment to sharing valuable information.

The Registry's technical stack also must efficiently facilitate the development of a utility capable of achieving these functional objectives. Its database must be scalable, its information accessible, and its infrastructure fundable within a reasonable value proposition. In service to these objectives, considerations were made in each of the

aforementioned domains.

Stakeholder Involvement

Principally, the Registry is a public utility whose purpose is to collect data from Lunar operators, curate it, and present it as actionable information to end users. As Lunar activity scales, so must the Registry, thus it is necessary to establish a data process flow that can accommodate a rapid expansion in both the number and variety of inputs. The detailed nature of Lunar Registry input data, coupled with the variability of this data as mission profiles change, requires a data input and upkeep regimen supported by active stakeholder involvement. This also serves as a value proposition to operators and a liability mitigation measure for the Registry; the Registry will be most accurate if mission data is editable in real-time by those who own the mission, and if those who own the mission are responsible for this upkeep then the Registry itself need not be exclusively liable for the currency or accuracy of the data. There are multiple components to this process flow, as outlined in the following sections.

Initial Inputs

In the near term, working partnerships will need to be established with select industry stakeholders and potential end users as a part of the public launch/startup phase. These partnerships will help to guide the refinement of a more scalable data input process and will begin with a fillable form for each of the mission logs, objects, and activity tables. As neither objects nor activities exist in Lunar space outside the context of a mission, new stakeholders will be required to fill out and submit a mission profile before creating those for that mission's respective objects and activities. Once a stakeholder has established at least one mission profile in the Registry, and as such established themselves as a verified owner/operator, their submittal of additional objects and activities will denote this stakeholder verification.

In the mid to long term, as the Registry project enters the development/expansion phase, these fillable forms will need to be standardized and the input process at least partially automated. This may take the form of either verification markers to denote new submittals that have or have not been reviewed by the Registry curator(s), API integrations with partner stakeholders to auto-generate new line items, a combination of both, or another automated system entirely. Importantly, both new and established industry stakeholders intending to use the Registry must be able to freely submit operations data to populate the Registry; the level of human attention and curation on behalf of the Registry will need to be appropriate for the scale of this stakeholder interaction to ensure the consistency of inputs and validity of declared operators.

Entry Modification

In addition to handling the submittal of new data, the Registry must also accommodate adjustments and modifications made to existing data. These modifications may be made with little or no notice and may have immediate ramifications for other users of the Registry. Because of this, the owner of a line item in any Registry table must be able to make such modifications independently, with a simultaneous notification of the modification sent to the Registry curator. Before the public launch of the Registry, these modifications may be made ad hoc and without standardization; as a public-facing utility modifications to existing Registry entries may require adherence to a standardized language or set of characteristics outlining acceptable forms of data in each attribute field until such time that the curator can review the information. In addition, each entry will compile a log of its modifications accessible via a link so that the history of these changes, as well as the user making the change, may be viewed publicly. A verification marker may also be used for such modifications to indicate whether the Registry curator has reviewed the information for validity and accuracy.

Data Verification

While alpha and beta testing will occur with a comparatively small, known user base, the public launch phase of Registry operations will see a wide range of data entries from a large and international group of users. To scale feasibly to meet this demand, the Registry will likely have to accept data inputs without a curator visually screening all the information. Two paths exist at this juncture: either new inputs and existing entry modifications must wait in a queue to be manually reviewed and entered by the curator, or "unverified" data must be allowed to populate in the Registry. Unverified data threatens the value proposition of the Registry; if the object, activity, and mission data is not subject to any standard of accuracy or validity, then it cannot be reasonably acted upon. Conversely, a manual review process would become either cost-prohibitive from a staffing perspective or a throughput bottleneck delaying the posting of new information by days or weeks, equally devaluing the Registry and its contents.

A solution to this is layered data and user verification. The cisLunar operations' future state will see new space operators, missions, objects, and activities arise daily and at scale. New owners/operators need to be able to submit entries to the Registry and may not have any publicly available information about them. Existing operators may have new mission, object, or activity information that is also unable to be publicly verified. Thus, unverified data will be published in the Registry and should be noted as such. However, the ability to verify data critically distinguishes a registry from a database in that it offers context to the information therein. The Registry curator will seek to verify the identity and information of new users; in doing so, they will be marked as verified users when posting other Registry entries or modifying existing entries. Operators may also submit "verification information" about missions, objects, and activities that can be standardized via fillable forms for each data table. The submittal of this information, in conjunction with the creation or modification of a Registry entry, will allow for the ve-

rification of that entry pending review of the submitted form by the curator. In this way, the Registry's data tables will feature both "verified" and "unverified" entries, as well as both "verified" and "unverified" owners/operators.

Third-Party Verification

Additionally, there exists the unique prospect of third-party verification. Especially in the case of object positioning and movement of activities in public, third-party observers may be capable of verifying information submitted to the Registry by operators as a form of outsourcing at minimal cost. To accommodate this, an additional "class" of Registry users may need to be created, with a separate fillable form for registration as such. These users, once registered, may verify certain object and activity entry types depending on their declared user type (for example, a user registered as an amateur astronomer on Earth may be allowed to post a verification of a Lunar surface implement repositioning activity but not a transference of ownership or new mission of a satellite). The inclusion of this third-party verification method would feature its verification mark distinguishable from that of the Registry curator's verification, and could serve to generate interest and engagement in the Registry's maturation from the public.

Tiered Access

These verification methods also enable a "tiered access" system that may offer an increased value to certain users and a potential source of revenue for the Registry. If operators are submitting verification information within standardized fillable forms, this information will likely both complement and expand upon the existing attributes featured in the Registry. This additional information may improve upon the value of what is already featured in the Registry. However, care will need to be taken to select the right information to accomplish the verification without jeopardizing operator participation. This additional information may be published in the Registry only for those who pay, or have earned, access to it; a more comprehensive "tier" that offers more detailed information above and beyond that of the publicly facing Registry. While payment is an obvious method, this access need not be monetary, and could even be offered in exchange for participation in the verification process itself. As the Registry intends to operate as a nonprofit, careful consideration will be required to instantiate any tiered access without disenfranchising those who depend on the free and public use of this utility.

Technical Stack

Given the nature of its proposed datasets and potential for broad public adoption, the Lunar Registry's technical architecture must offer both a high degree of rationality and a suitable foundation for scalability. A test environment was constructed to simulate the front and back-end product without developing a full technical stack;

the details of this construction will be outlined in the next section. This sample Registry architecture was utilized for alpha testing within Open Lunar and will continue to serve as a development platform for beta testing with select stakeholders to hone operational principles and components. As the project evolves through the working beta phase, user adoption will grow, eventually leading to an inflection point at which the test environment's limitations will impede scalability, requiring a more sustainable technical stack.

From a hardware infrastructure perspective, the Lunar Registry will be cloud-based; configuring local hardware resources, maintaining them, and scaling them to accommodate variable data loads far exceed feasible staffing and budgetary limits for such a project. A cloud-native database infrastructure will provide the most efficient, scalable foundation for the Registry's data warehousing. In addition, cloud hosting services may also offer database-as-a-service utilities (DBaaS) which can allow for a more tailored, affordable database hosting experience at the expense of access to a full virtual machine on which a separate database server is run. In the near-to midterm, a DBaaS platform would be the most appropriate given the anticipated scale and complexity of the Lunar Registry.

The Registry's logical schema must also inform software and programming-language design decisions. Specifically, the choice of whether to utilize a SQL or NoSQL system will have broad impacts on the selection of tools within the technical stack and flexibility in database structure. On this topic, it is important to note that the Registry exists in part to define the relationships between missions, objects, activities, and their owner/operators. Through these relationships, the international space-faring community can make informed operational decisions, assign risk, and collaborate successfully at scale. Thus, there are somewhat rigid dependencies between objects, activities, and missions that serve to define the Registry and its contents. SQL databases are relational databases; data is stored in tables of rows and columns, fixed relationships are established between these tables, and specific commands are utilized to interact with the database. NoSQL databases are non-relational; data is stored in either key-value data stores retrieved with a unique key, document formats such as JSON, or in nodes graphically. The Registry is most easily visualized as a SQL database consisting of tables, line items, and their respective attribute values. The relationships between these tables and the values therein are rigid, with specific dependencies defined by the nature of Lunar operations. SQL databases employ atomicity, consistency, isolation, and durability (ACID) properties which help to ensure data reliability and integrity within the relational schema; this level of control over data integrity may help address long-term issues such as input validation and stakeholder verification. However, the fluidity and support of non-structured data offered by NoSQL database systems present a compelling case for long-term registry interfaces. The ability to store data in JSON documents or key values, quickly modify the structure of data stores, and query Registry data without reloading the entire database create opportunities to present Registry data in formats other than traditional attribute tables. So while a SQL database is most appropriate for the way the Registry is constructed today, a NoSQL database(s) may offer a valuable alternative representation of Registry data in the long term that distinguishes the Lunar Registry as a more accessible public utility.

Development Proposal for a Lunar Registry: Strategic Work Plan

This proposal outlines a comprehensive approach for advancing the Lunar Registry initiative through four critical phases. Each phase is uniquely characterized by its objectives, deliverables, and the distinct questions it aims to address. While not exhaustive, this four-phase structure provides a robust framework that encapsulates key elements and considerations vital for the project's progression.

The phases are designed to guide the Lunar Registry from its conceptual stage to a fully functional and accessible system. The work plan for each phase includes structured activities and a projected budget, reflecting a strategic path forward.

It is important to recognize that the timelines and financial estimates provided are preliminary. They serve as a guiding framework for the strategic development of the Registry. These projections are based on current insights and anticipated requirements, offering a financial and operational blueprint. Nevertheless, the nature of project development necessitates flexibility; contingency plans and adaptive strategies are essential components of this work plan. The estimates are designed to be adjustable, accommodating the dynamic nature of the project's growth.

The development journey is segmented into four distinct phases:

1. Alpha Phase: Design and build a prototype registry.
2. Beta Phase: Test and refine the prototype to yield a proof of concept.
3. Public Launch Phase: Officially release the Registry and make it accessible to the public.
4. Expansion/Development Phase: Engage in continuous improvement and adaptation post-launch.

Alpha Phase: Building a Sample Registry Stage

The research conducted in previous fellowships (completed March 2023) outlined the need for a Lunar registry that would serve within a growing new-space economy. A goal of the Alpha stage of the project was to convert these previously defined high-order functions of the Registry into a working model that could be rapidly prototyped through alpha and beta testing. This working model, or "sample Registry", allowed for internal and external stakeholders to interact with the concept in a simulated capacity to that of public end-users once the Registry is launched. Through this alpha testing of the sample Registry, lessons were learned about content, structure, product development, and Lunar operations that spawned critical design iterations that advanced the Registry project to its current state. The initial framework of the sample Registry was intended to be a "no code" architecture that could be set up at minimal cost and with minimal development time. Knack, a no-code

online database hosting service, was selected as the construction environment for the Registry's data tables. Historical Lunar mission data was reviewed, and in conjunction with feedback from select industry professionals, an attribute set was created for both objects and activities. These attribute sets were configured in a data table within Knack, and historical mission data was gathered to populate a handful of line items for each data type.

Activities	Missions
Registry Activity ID	Mission Log Number
Activity Type	Mission Name
Current Owner/Operator	Owner/Operator
Intended Action	Launching State
Event Date and Time (Lunar Time Standard)	Launch Date
Associated Missions	Active Mission
Associated Lunar Objects	Associated Lunar Objects
	Associated Lunar Activities

Objects		
Registry Object ID	Trajectory Information Link	Requested Surface Safety Radius
COSPAR ID	Lunar Surface Landing/ Impact Coordinates	Time active Launch-Disposal
Object Type	Lunar Landing Geographic Area	Disposal
Current Owner/Operator	Bus	Associated Missions
Launching State	Mass	Associated Lunar Activities
Launch Information	Payload Instruments	Orbital Characteristics
Intended Operating Location	Transmission Frequencies	
Orbital Characteristics	Hazardous Materials	

Full List of Attributes by Registry Table

To better accommodate the diversity of the dataset, this attribute set was split into two tables: objects and activities. Object and activity definitions, which were outlined previously in this paper, were utilized to better guide the selection and configuration of sample entries within the scope of these attribute sets. It became apparent that an overarching context was needed to interrelate the two tables; this took the form of a mission log. As demonstrated in Figure 1, the mission log allows for objects and activities to be associated within this context, offering operator and branding information that often accompanies a space mission. The mission log also accommodates the movement of objects as they change possession or are re-purposed for another mission, as well as activities that are performed using objects from or in service to multiple missions. As such, the Knack database contains three tables: Mission Log, Lunar Objects, and Lunar Activities. Each of these tables features associations with the other two, and all three work in concert to provide context and definition to Lunar operations. The tables appear in Knack as in the below image:

	Auto Increment	Mission Log Number	Mission Name	Owner/Operator	Launching State	Launch Date	Act
	1	0001	Lunar Prospector	NASA/ARC	United States	1-07-1998	No
	2	0002	Artemis	NASA	United States	02-17-2007	Yes
	3	0003	Lunar Crater Observation and Sensing Satellite (LCROSS)	NASA/ARC	United States	06-18-2009	No
	4	0004	Lunar Reconnaissance Orbiter (LRO)	NASA/ARC	United States	06-18-2009	Yes
	5	0005	Ranger 8	NASA	United States	02-17-1965	No
	6	0006	Surveyor-1	NASA	United States	05-30-1966	No

The tables appear in Knack as displayed above

With the database for the sample registry constructed, it was necessary to create an access portal where project stakeholders could simulate public access. A web domain, Lunar-registry.com, was purchased to serve this purpose. The Knack data tables were embedded within corresponding navigational tabs; a full read/edit license over the data entries is permitted while in alpha and beta testing to allow for a rapid and unedited population of data by users. Open editing of this information during beta testing will demonstrate the needs and habits of potential users, allowing for standardization of these inputs after public launch.

Lunar Registry Home Mission Log Objects Activities

Mission Log

search by keyword search

Showing 1-6 of 6 Export Add filters

Mission Log Number	Mission Name	Owner/Operator	Launch Date	Active Mission	Launching State	Associated Lunar Objects	Associated Lunar Activities
1	Lunar Prospector	NASA/ARC	1-07-1998	No	United States	Lunar Prospector	1
2	Artemis	NASA	02-17-2007	Yes	United States	Artemis	
3	Lunar Crater Observation and Sensing Satellite (LCROSS)	NASA/ARC	06-18-2009	No	United States	Lunar Crater Observation and Sensing Satellite (LCROSS)	3 2
4	Lunar Reconnaissance Orbiter (LRO)	NASA/ARC	06-18-2009	Yes	United States		
5	Ranger 8	NASA	02-17-1965	No	United States	Ranger 8	

A photo of the sample database interface displaying Missions, Objects, and Activities Log

The sample Registry provides a working prototype for Open Lunar and the Registry project stakeholders to interact with and iterate towards a finished public utility. The rapid prototyping process facilitates the advancement of the project from theoretical research to a deliverable product and ensures that the processes, components, and systems logic that define the Registry have been rigorously assessed and iterated. A physical prototype also serves as the most effective marketing tool, one that Open Lunar can leverage to gain support and garner interest in the Lunar operations marketplace. Ultimately, a utility such as this registry will provide value only through broad adoption, democratic access, and an intuitive user interface; the construction of a sample registry was undertaken to ensure this project can succeed in each of these dimensions.
With the Alpha stage completed, the Lunar Registry is ready to conduct stakeholder solicitation and further development through the Beta: Proof of Concept Phase.

Beta Phase: Proof of Concept Stage

The Proof of Concept Stage is primarily focused on rigorous beta testing of the prototype by examining inputs, assumptions, and workflow enhancements. A significant aspect of this stage involves engaging an initial group of at least ten key stakeholders. These stakeholders, crucial for developing a preliminary network and user base, will provide invaluable feedback, share their experiences and preferences, and assist in building a relationship of trust with both stakeholders and end users of the Lunar Registry product.

This collaboration is pivotal for evolving the prototype and strategizing the development of the Lunar Registry in preparation for the preceding Public Launch. By working closely with these stakeholders, the project will not only validate the concept's viability but also refine the Registry's parameters. This process will encompass understanding mechanisms for incentivizing stakeholders and addressing any outstanding design considerations, thereby ensuring a comprehensive and user-centred approach to the development of the Lunar Registry.

Key Objectives:

- Establish connections with key Lunar stakeholders, encompassing government, commercial, scientific, and academic sectors. These stakeholders are envisioned to be the primary users of the product.
- Promote dialogue around the field selection and establish a multi-stakeholder dialogue process
- Gather input from these stakeholders to understand their current perceptions and potential engagement with the product.
- Convene a working group dedicated to defining the minimum viable product for The Lunar Registry, aiming for its public release and use.
- Establish preliminary data verification and tiered access infrastructure.

The stage is estimated to require 6–12 months to complete, with a projected investment of USD 20,000 to USD 45,000 depending on the project's pace. Essential resources for this stage include a part-time project lead, focused on stakeholder engagement and managing prototype data. The project will build upon the foundation laid during the Alpha test, optimizing the existing technology stack and subscriptions. The budget also covers legal and intellectual property consultations, essential operational subscriptions, and funds allocated for travel to key conferences and stakeholder meetings.

Public Launch Phase

The Public Launch / Startup Year builds upon the lessons learned through Alpha/Beta testing, and marks a public transition for the Lunar Registry project. During this phase, the focus is transforming its developmental stages to a publicly accessible, minimum viable product Lunar Registry.

The main objective of this phase is to launch a refined version of the Lunar Registry. This entails not just the unveiling of a product but the establishment of the Registry as a standalone entity.

The projected budget for this phase stands at USD 91,500 and is estimated to take 8–12 months. It encompasses the costs of evolving the project from a concept into a tangible, interactive platform for Lunar stakeholders. Central to this phase is the enhancement of staffing, with a devoted project lead managing its efforts. This increase is not merely a quantitative change but a strategic shift, reflecting the heightened complexity and expanded scope of the project. Additionally, a new, more sophisticated tech stack is invested in and developed, utilizing the lessons and attributes learned from consultation with stakeholders in previous stages.

Key Objectives:

- Product Development and Launch: Utilize feedback from the Beta Phase to build and launch a minimum viable product tailored for high engagement among Lunar stakeholders. Included are:
- A tool to scrape and input information that exists elsewhere.
- Functional data verification infrastructure
- A minimum viable tiered access system that can be scaled separately depending on demand, scalability, revenue, and risk mitigation needs.
- Advisory Committee Establishment: Form a committee to guide the Lunar Registry's strategic direction, exploring various governance models.
- Stakeholder Expansion: Increase the number of stakeholders to provide diverse insights and feedback on the development of the Registry.
- Organizational Identity and Governance: Focus on establishing the Registry as a separate legal entity, creating a comprehensive governance model to incorporate edits and evolve to the quickly changing needs of the industry.

Development and Expantion Phase

Objective: Establish a robust business model with expanded revenue streams and reinforced industry trust.

The Development and Expansion Phase works to build on the newly established Lunar Registry system. With the minimum viable infrastructure in place, this phase works to increase stakeholder use and uptake, along with modifying the system to the evolving landscape of Lunar activities. In this phase, an established, robust business model with expanded revenue streams is acted upon.

Key Objectives:

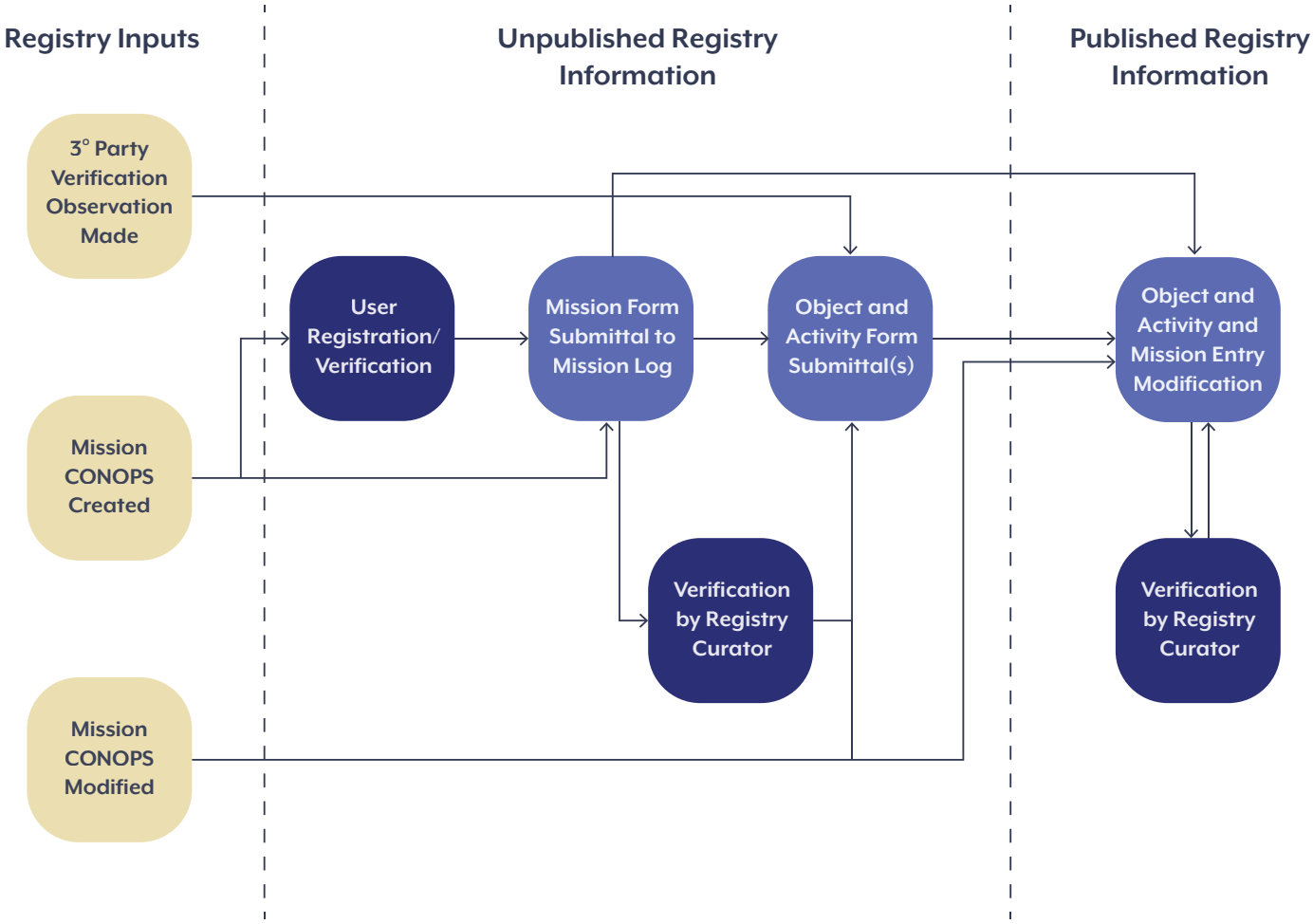
- Formalize and operate governance models to include emerging and established Lunar actors.
- Continually update and modify the Lunar Registry from MVP to a complex system that meets a variety of needs, such as third-party verification, unique data display, and automated data integration.
- Stabilize funding for the Lunar Registry through partnerships, grants, and income.
- Consider third-party data verification architecture and solidify tiered access infrastructure.

With the Lunar Registry developed and firmly established, the budget estimates around USD 152,000 to support the Registry into its fully operational phase. The project lead now assumes a full-time position, and the addition of contracted advisors and verification services represents the need for strategic diversification of knowledge and administrative expertise. This phase's efforts focus on increasing stakeholder participation and incentivization, integrating lessons learned and feedback, building a sustainable business model through fundraising and tiered access modelling, and ensuring robust data protection.

Public Launch and Expansion Phase Considerations

Public Launch Phase Process Flow

The diagram below offers a visualization of registry process flow once the above features are implemented:



Complementary NoSQL Databases

In the expansion phase and beyond, the Registry will house an unparalleled collection of Lunar operational data. In this future state, users will likely be leveraging Registry data to infer and calculate other information; in service to this, the Registry may pursue the use of NoSQL databases as a complement to a central SQL database to produce visualization tools and other accessory registry features. Such functionality may be assistive in democratizing access to and interpretation of Lunar operating data via the Registry, especially for hobbyists and third-party actors, and may also serve as a modality by which the Registry can remain competitive in the information marketplace as other utilities are developed.

Scalable Input and Modification Methods

In addition to the concept of data verification, the very input and modification methods used to exchange data with the Registry must evolve to facilitate scalability without jeopardizing feasibility or disproportionately increasing staffing costs. At present, the Registry resides in a password-protected domain but is otherwise fully editable; this will not be possible post-launch. A free and public utility must be accessible by all, but the ability to add information to the Registry must have some measure of responsibility and validity associated with it, even prior to curator verification. Fillable forms, accessible through a separate link in the Registry, offer a manageable way to do this.

For new operators with no pre-existing registry entries, the first fillable form will be for certain identifying information such as organization/company, email and contact information, and launching state or country of operation. Additional verification features such as a captcha, IP address lookup against operator info and to ensure blacklist status or other digital safety measures can exist within this fillable form as well. Note that completion of this form does not mark the new user as a "verified user", rather these features exist simply to safeguard the Registry against overpopulation with malicious or irrelevant data.

Existing operators, or those who have successfully submitted the "new user form", may now submit other fillable forms for missions, objects, and activities. As has been previously established, the Registry will operate under the assumption that all objects and activities exist within the context of a mission, thus any new entries of objects and activities will require an existing mission in the mission log to complete those forms. While these users have been granted access to submit entries via their "new user form" completion, both their identity and the entries that they submit will remain displayed as "unverified" until the other aforementioned verification steps take place. Automation and careful selection of required information, especially within the "new user form", will be critical in ensuring the scalable, public use of the Registry without subjecting it to broad misuse or misappropriation.

The Risk Mitigation Value Proposition

Framing a proper value proposition is a key component of encouraging early adoption. Operators who use this Registry as a part of their mission planning and execution process will only do so if its use returns a commensurate value to their operations. To this end, the Registry needs to posture itself as a risk mitigation modality.

The high-cost barrier to entry for space operations yields a mission development process measured in years and hundreds of millions of dollars. Such an expenditure of time and money on high-risk operations in space offers a motivation to pay down this risk. Insurance payers are understandably tentative to value the risk favourably for operators, given the comparatively small number of potential insureds and space operations failure rates. As such, beyond the mandate of launch insurance, few underwriters will offer terms to operators for operations risk mitigation, leaving these highly complex CONOPS to seek other more expensive risk mitigation modalities such

as mission systems redundancies.

The Registry presents a unique opportunity to affordably pay down Lunar operations risks. As a public, universally accessible utility, any operator can contribute to and avail themselves of the information published in the Registry. This information is chiefly designed to add clarity, standardization, and detail to international Lunar operations, providing operators the chance to identify risks, as well as beneficial resources, that may be presented by other space operations and proposed missions. If the existence, maintenance, and growth of this public registry utility represents a six or seven-figure cost to the space industry it will substantially outweigh the savings in risk reduction that it affords operators; this value proposition offers a clear incentivization plan to promote the benefits of registry use while mitigating pain points for first movers.

The Registry as a Public Utility

The Lunar Registry aims to be a neutral, accessible platform offering free information access, underpinned by apolitical governance, credibility, a solid organizational structure, and financial stability. Its success hinges on the participation of diverse stakeholders, including Lunar mission operators, spacecraft manufacturers, policymakers, and the general public, who are key to maintaining the Registry's integrity and usefulness.

Central to the Registry's ethos is its role as a public utility, providing a standard framework that enhances predictability and reduces risk in space-related activities. The Registry acts as a repository of information, with users independently deriving value from the data, without any compulsion for specific actions based on the information provided.

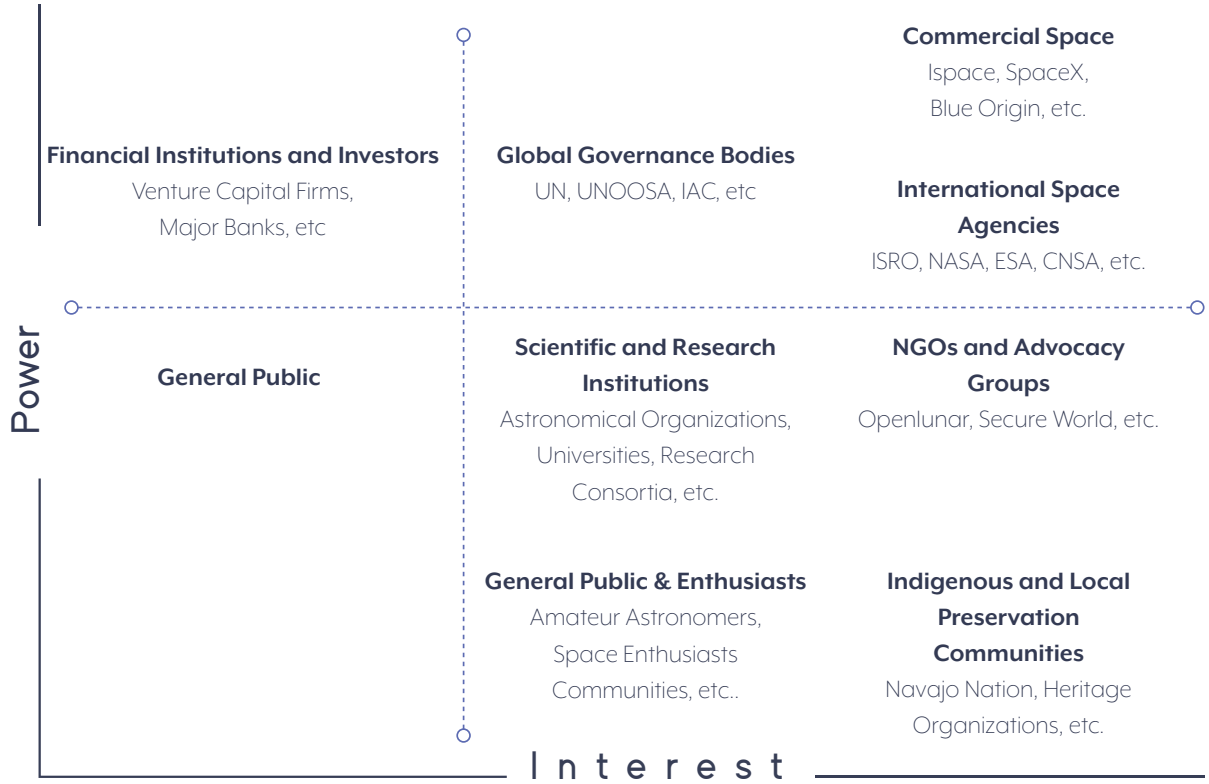
Structurally, the Lunar Registry must operate independently, free from national or commercial biases. Various organizational forms are considered to align with this goal, such as a Global Nonprofit Entity, Independent Commission, Intergovernmental or Supranational Organization, or a Public-Private Partnership. The selection of a neutral incorporation site is critical to ensure global acceptance and effectiveness.

Governance involves a multi-stakeholder model, potentially including a Board of Directors representing space-faring nations, the private sector, academia, and the public. Decision-making might be consensus-based or majority rule, with each having implications for stakeholder engagement.

Financially, while the Lunar Registry isn't profit-driven, it requires a sustainable model. This could include tiered access to information, with a free access layer, supplemented by membership fees, service charges, and the acceptance of donations and grants. Considering a tax-exempt status could enhance its ability to attract funding.

Legitimacy and Credibility Through Stakeholder Engagement

Stakeholder engagement is a strategic imperative that underpins the Lunar Registry's potential to foster collaborative, sustainable, and equitable Lunar exploration and use. In the development of the Lunar Registry initiative, identifying and engaging the right stakeholders is paramount to ensuring its success. The stakeholder map created for this project categorizes stakeholders into four quadrants based on their levels of influence and interest, ranging from international space agencies, commercial space enterprises, and global governance bodies in Quadrant I, to the general public and enthusiasts in Quadrant IV. Key players with high influence and interest (Quadrant I) such as NASA, ESA, ISRO, and UNOOSA, are critical for securing support and legitimacy, while those in Quadrant IV, including academic institutions and space enthusiasts, provide valuable perspectives and public support that can drive the initiative forward. Engaging these stakeholders through a comprehensive approach not only facilitates a well-rounded and informed registry development process but also ensures a wide array of voices are heard, enhancing the Registry's acceptance and adherence to its goals.



Legitimacy and Credibility through Principles of International Space Law

The pursuit of legitimacy and credibility through principles of international law has historically been a cornerstone in governing shared spaces, reflecting a broad pattern of global cooperation essential for peaceful exploration and use. Principles supported by international law, frameworks, and treaties such as those found in

the Outer Space Treaty, the Antarctic Treaty System, and the United Nations Convention on the Law of the Sea have facilitated a common understanding, mutual respect among nations, and the establishment of universally agreed-upon norms and regulations.

Historically, these types of guiding principles have played out in the earthly environment to set norms and standards of behaviour. For example, the Antarctic Treaty has prohibited military activity and preserved the continent for scientific research, while UNCLOS has defined the rights and responsibilities of nations regarding the world's seas. These frameworks have not only addressed specific challenges—such as, environmental protection, and the sustainable use of marine resources—but have also illustrated the effectiveness of legal instruments in enhancing safety, fostering collaboration, and promoting the peaceful use of shared spaces.

In space, treaties and agreements such as the Outer Space Treaty, the Registration Convention, the Artemis Accords, and the establishment of the International Lunar Research Station Cooperation Organization have laid down principles emphasizing peaceful purposes, transparency, Interoperability, information sharing, and international cooperation - all of which are central principles of the Lunar Registry.

Principles	Framework and Treaties
Peaceful Purposes and Exploration	Outer Space Treaty, 196, Article VI; Article VIII; Article XI; prohibits the placement of nuclear weapons in space, claims sovereignty, ensures peaceful exploration, and outlines State responsibility for national space activities. Artemis Accords, 2020, Section 11- Deconfliction of Activities. [2]
Transparency	Artemis Accords, 2020, Section 4 - Transparency; Section 5 - Interoperability; Section 8 - Release of Scientific Data Hague Building Blocks for Space Resource Activities
International Cooperation	Artemis Accords, 2020, Section 5 - Interoperability. International Lunar Research Station Cooperation Organization, 2021, Cooperation Guidelines: Coordination of Scientific and Technical Research, Scientific and Technical Data Sharing Analysis and Sharing
Registration and Accountability	The Registration Convention, 1976, Requires States to furnish to the United Nations with details about the orbit of each space object; emphasizes transparency and accountability in space activities. Artemis Accords, 2020, Section 7 - Registration of Space Objects;

These precedents underscore the potential for efforts like the Lunar Registry to create a stable and predictable environment for space activities, drawing lessons from the successful governance of other global commons to navigate the complexities of Lunar exploration and beyond.

Legal Analysis and Risk Mitigation

The Lunar Registry, serving as a repository for Lunar data to facilitate collaboration and research, must carefully address risks associated with legal and privacy considerations. Privacy concerns arise from the collection and sharing of data, which would necessitate the establishment of a comprehensive privacy policy outlining data collection, sharing, and usage procedures. To mitigate ownership disputes over submitted data, clear policies and user credential verification would be employed.

Balancing collaboration with legal and privacy considerations requires prioritizing transparency and informed consent. To minimize liability when publicizing shared information, clear policies and disclaimers would inform users of data usage limitations, allowing users to identify whether they are submitting public domain information or possess the appropriate credentials. Additionally, measures such as open-source licensing, clear terms of use, access controls, legal review, and community guidelines can help maintain platform openness while minimizing the sharing of proprietary data. Ensuring the security of shared data is paramount and can be achieved through authentication, monitoring, and compliance with data protection policies.

Addressing potential risks and liabilities involves mitigating factors such as data breaches and intellectual property theft through security measures, clear policies, and liability projection steps like indemnification clauses and user education.

Next Steps

The Lunar Registry project as it stands today is prepared to begin the Proof of Concept phase of the work plan with select stakeholders. The processes, systems, technical stack, staff, and budget that will be required to usher the Registry through this phase are largely already in place. As the phased work plan is executed, several questions will need to be answered: What is the overarching value proposition of this Registry to stakeholder end-users and the general public? What is the most viable CONOPS to steward this Registry to long-term sustainability? How can practice, language, and accessibility be standardized to serve a diverse, multicultural, international community of space operators?

(2) https://www.nasa.gov/wp-content/uploads/2022/11/Artemis-Accords-signed-13Oct2020.pdf

A long-term time horizon offers the opportunity to address these challenges through strategic growth initiatives. Operator usage of the Registry as a part of regular mission planning and execution will only scale if its use returns a commensurate value to their operations. Framing a proper value proposition is a key component of encouraging early adoption; this will likely require a clear incentivization plan to promote the benefits of Registry use while mitigating pain points for first movers.

Should Registry adoption broaden the user base, input variability will increase in kind. To protect this value proposition to operators, the Registry will be tasked with standardizing language and data that can be interpreted universally while also catering to the habits and expectations of a diversifying user base. Standard practices and language will need to acknowledge not only the input types and demands of the present but also the potential expansion of variability in Lunar operations over the long term.

In addition to enabling scalability, the Registry must also endeavour to position itself as a free and public utility for an international space-faring community. The provision of any good or service requires sound business principles, and the Registry will require the formation of an entity that facilitates access to sustainable forms of revenue and funding. Remaining in favour of industry opinions, fostering partnerships, exploring private funding availability, and ultimately the ability to secure the required growth capital for the proposed work plan are all necessary factors in determining an appropriate entity to house the Registry.

The need for a Lunar registry as outlined in this proposal is apparent. Such a registry, when offered as a free and public utility, appears increasingly crucial for a variety of space industry stakeholders. This report has provided a detailed analysis and actionable work plan to create and sustain a fundable, staffable, competitive registry of Lunar objects and activities. The execution of this plan, and the operation of the business entity therein, will depend heavily on the continued support of Open Lunar's leadership and donors. If successful in garnering this continued support, the Registry of Lunar Objects and Activities will foster unparalleled transparency around Lunar activities and serve as a key component of Lunar exploration, empowering the public to engage with and participate in a new era of multi-planetary socioeconomic development.

Appendix

Full List of Attributes by Registry table:

Objects	Activities	Missions
Registry Object ID	Registry Activity ID	Mission Log Number
COSPAR ID	Activity Type	Mission Name
Object Type	Current Owner/Operator	Owner/Operator
Current Owner/Operator	Intended Action	Launching State
Launching State	Event Date and Time (Lunar Time Standard)	Launch Date
Launch Information	Associated Missions	Active Mission
Intended Operating Location	Associated Lunar Objects	Associated Lunar Objects
Orbital Characteristics		Associated Lunar Activities
Trajectory Information Link Lunar Surface Landing/		
Impact Coordinates		
Lunar Landing Geographic Area		
Bus		
Mass		
Payload Instruments		
Transmission Frequencies		
Hazardous Materials		
Requested Surface Safety Radius		
Time Active Launch-Disposal		
Disposal		
Associated Missions		
Associated Lunar Activities		