Determining Economic Viability Thresholds for Space Resource Missions Using an Analytical Framework

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Introduction and Background: As we step into the next era of human expansion, there must be a viable explanation for why such expansion is worth pursuing. Economics provides one of the most compelling mechanisms for identifying this value and enabling organizations to commit resources toward it. Historically, the expansion of trade networks and economic opportunity has driven major periods of exploration and growth in human potential, suggesting that similar dynamics may shape humanity's future expansion into space [1][2].

The current exploration landscape is changing rapidly thanks to lower-cost access and enabling space technologies [3][4]. A broader set of actors (commercial firms, new startups, national agencies, and academic teams) now make strategic decisions that once required nation-state scale [5]. This broader access elevates the importance of space resources (particularly in the context of ISRU, in-situ resource utilization) in mission planning and long-term strategy [6][7]. Private capital and research institutions increasingly face decisions about launch options, infrastructure investments, mission lifespans, and whether to source capabilities from Earth or in-situ [8].

Moreover, the decision environment is fragmented. Siloing information due to proprietary data and legacy institutional compartmentalization practices increases the uncertainty even further [9]. This uncertainty surrounding space resource decisions limits the ability of stakeholders to form consistent and comparable mission assessments underlying long term planning and funding.

To address this gap, there is a clear need for a trusted and shared analytical framework that can unify these disparate inputs into a coherent decision-making process.

AiSTRAEUS, Adaptive Integrated Space Trajectory Resource Allocation & Economic Utility System, is an analytical architecture designed to address this gap by integrating technical and economic datasets into a unified mission evaluation framework.

Problem Statement and Objectives: While the need for a standard architecture is apparent, the factors that determine when space resource missions become economically viable and worth investing in remain unknown. AiSTRAEUS aims to provide the analytical framework required to perform this economic evaluation by developing a collaboratively driven data architecture to support the evaluation of space resource mission economic viability across multiple space environments and mission types.

Concept of Operations: AiSTRAEUS functions as an integrated analytical platform designed to evaluate the economic viability of space resource missions. There will be varying levels of interaction with this architecture as different organizations, such as commercial space companies, government agencies, and academic institutions, have distinct objectives.

For a mission economic evaluator, the primary interaction would be through mission parameter inputs while receiving economic and sensitivity analysis outputs.

For researchers and data providers, the data verification and processing functions of the tool will be the most applicable. Certain data can be provided by commercial or institutional organizations, enabling researchers to validate, refine, or augment the datasets used within the framework.

All system interactions will be managed and visualized through the AiSTRAEUS dashboard and interface tools. F*igure 1* outlines tiered interactions.

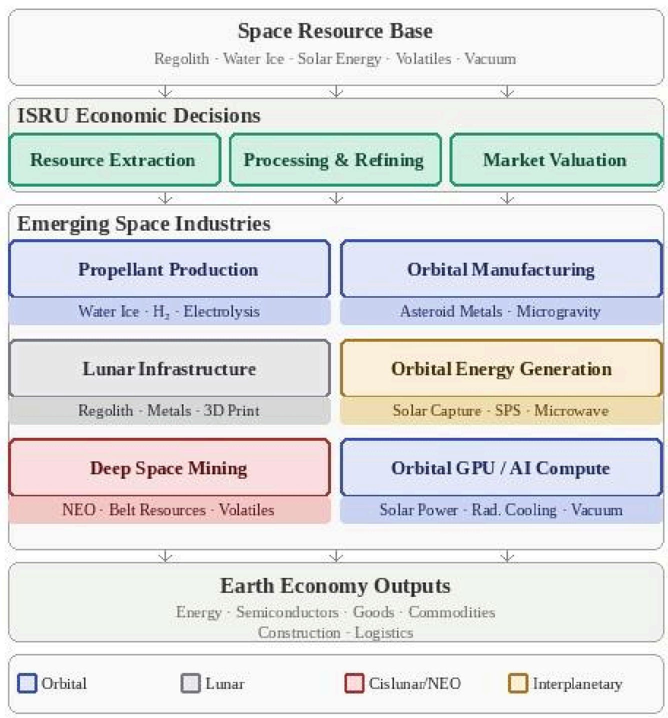

Figure 1. Tiered Flow of Emerging Space Markets in Relation to Resource Inputs & Economic Outputs

Methodology: The framework evaluates the economic viability of space resource missions by integrating heterogeneous datasets into a unified economic evaluation model. The framework is staged as follows:

Data Integration and Mission Parameter Definitions: The system integrates datasets across various domains (including orbital mechanics, resource composition, transportation costs, and market prices) each with varying update cadences.

Once data is pulled into AiSTRAEUS, it is cleaned and compiled according to the parameters defined for a given mission scenario.

Economic Modeling: Once model parameters and data requirements are set, a standard economic approach based on discounted cash flow (DCF) analysis is applied to determine the net present value (NPV) of the mission. This framework captures the time value of money and reflects established investment evaluation practices used in terrestrial resource extraction and large-scale infrastructure projects [10][11], facilitating consistent and decision enabling comparisons across mission architectures.

This framework intentionally adapts validated economic methodologies from terrestrial resource extraction and infrastructure investment domains to the emerging context of space resource markets.

Future extensions may incorporate probabilistic and real-options-based methods to better capture uncertainty and operational flexibility [12].

A mission is considered economically viable when the expected net present value exceeds cost and risk-adjusted investment thresholds. Mission parameters can alter the value proposition depending on the mission architecture:

• In-Situ Resource Utilization Missions: evaluates the economic benefit of using resources within the mission environment relative to Earth-supplied alternatives. For example, an expedition mission that uses lunar water as a source of oxygen for habitation.

• Earth Return Commercialization Missions: assesses missions where space-derived resources or products generate value in terrestrial markets.

Sensitivity and Comparative Analysis: The final phase compares outputs from the economic modeling across different mission architectures and probabilities of success. Variables that can be explored depending on mission objectives include: cost multipliers, mission timeline alternatives, demand elasticity assumptions, etc.

This includes identifying break-even surface scenarios that define conditions under which missions transition to economic viability, a method commonly applied in energy systems and resource extraction economics [11].

This structure enables a standardized evaluation of feasibility across diverse mission cases.

Expected Outcomes and Impact: The expectation is that the framework will help address several critical questions: whether certain missions may already demonstrate economic potential for terrestrial markets, the extent to which launch costs and delta-v requirements dominate mission viability [3][13], and whether new economic opportunities exist beyond traditional satellite infrastructure [4].

Anticipated Benefits: A framework like the one suggested would facilitate entry into the space resource markets by structuring the value assessments, aid established parties in validating their predications, and serve as a standardization channel when making space resource valuation decisions.

Future Directions and Implications: Current limitations in data reliability and availability will need to be further addressed. As the use of the architecture increases, the maturity of the framework's data is expected to improve.

Additional research is required to better understand several key issues, including how to justify space mission risk premiums [10], how spectral data converts to resource concentration estimates [7], and how reserves are derived from resource data.

Broader Impact: A foundational understanding and trusted baseline for evaluating the economic elements of space resource utilization will be paramount for the maturation of the space-based economy and domain. As humanity expands the range of activities conducted in space, the associated economic implications will expand accordingly.

Conclusion: AiSTRAEUS proposes a unified analytical framework for evaluating the economic viability of unique space resource missions. By establishing a standard method to process and economically model assorted data, the architecture aims to reduce uncertainty in space resource mission decisions. This would fill the need for a framework that works across governments, industry, and academic institutions. As the space resource markets continues to expand, frameworks like AiSTRAEUS may play a critical role in guiding economically sustainable exploration and infrastructure development beyond Earth.

References: [1] Metzger, P. T. et al. (2013) J. Aerospace Eng., 26, 18–29. [2] Spufford, P. (2002) Thames & Hudson, Power and Profit. [3] NASA (2015) NASA Space Technology Roadmaps. [4] Morgan Stanley (2020) Space Economy Report. [5] OECD (2019) The Space Economy in Figures. [6] National Research Council (2011) Vision and Voyages. [7] Elvis, M. (2014) Planet. Space Sci., 91, 20–26. [8] Space Capital (2021) Space Investment Quarterly. [9] World Economic Forum (2021) Space Data Sharing Report. [10] Brealey, R. A. et al. (2020) McGraw-Hill, Principles of Corporate Finance. [11] Damodaran, A. (2012) Wiley, Applied Corporate Finance. [12] Trigeorgis, L. (1996) MIT Press, Real Options. [13] NASA JPL (2020) Small-Body Database.