AiSTRAEUS: Adaptive Integrated Space Trajectory Resource Allocation & Economic Utility System

Santiago Gonzalez Aguado[1], [1]AiSTRAEUS (Santiago.GonzalezAguado@AiSTRAEUS.com)

Introduction and Background: Space resource exploration, while still in its infancy, is on the cusp of evolving into a promising industry [1]. The dramatic decrease in launch costs combined with the rise of commercial spaceflight has shifted the economic landscape. The reduction in costs exceeding 95% for heavy launches to low-Earth orbit (LEO) is making extraterrestrial mining an increasingly viable prospect [2]. Additionally, the potential for an economy enriched by rare earth metals could revolutionize modern infrastructure and global competitiveness [3]. These factors, among others, are poised to accelerate the development of the space resource industry.

Green Energy: The global market for key energy transition minerals has experienced substantial growth, doubling over the past five years to approximately $320 billion in 2022 [4].

National Mineral Independence: The United States continues to face deep vulnerabilities in its mineral supply chains due to its reliance on imported minerals. According to the recently released *Mineral Commodity Summaries 2025* report by the United States Geological Survey (USGS), the United States was 100% net import reliant for 12 critical minerals, and an additional 28 critical mineral commodities (including 14 lanthanides) had a net import reliance greater than 50% of apparent consumption [5].

Demand for In-Space Resources: In-space activities such as satellite servicing, propellant depots, and space manufacturing will be key to enabling more ambitious space missions and reducing the cost of space operations [6].

Due to these and other factors, the need for a system integrating real-time resource pricing, trajectory modeling, and economic analysis will become increasingly apparent. Given the shift from a mission-driven space enterprise towards a self-sustaining space-based economy, such a system will provide both private and public sectors with the data-driven insights needed to navigate the complex economics of space resource endeavors [7].

The conceptual platform described in this paper to address this need is AiSTRAEUS: Adaptive Integrated Space Trajectory Resource Allocation & Economic Utility System.

Problem Statement and Objectives: From live economic and mineral market data to detailed celestial body and launch vehicle databases, integrating these data streams will be an initial objective of AiSTRAEUS. In addition to data integration, the platform will aim to:

1) Serve as a comprehensive database for economic and logistical information on celestial bodies.
2) Utilize resource valuation and economic modeling techniques to rank potential mining targets based on mineralogical value and mission feasibility.
3) Optimize mission planning through accurate trajectory and cost modeling, reducing estimation error to within an acceptable tolerance.

Establishing an accurate economic baseline for space mining projects poses a significant challenge, primarily due to the integration of diverse data sources. *Figure 1* outlines a high-level initial concept depicting the relationship between data sources and the necessary data analyses to deliver a comprehensive product.

Additionally, the mining and space industries face difficulties in managing complex real-time data streams. Inconsistent data formats and latency challenges hinder the effective use of automation and AI techniques, complicating decision-making for integrated platforms [8].

The challenges that AiSTRAEUS aims to address will underscore the need for sophisticated integration frameworks to harmonize data formats, reduce latency, and enhance data reliability.

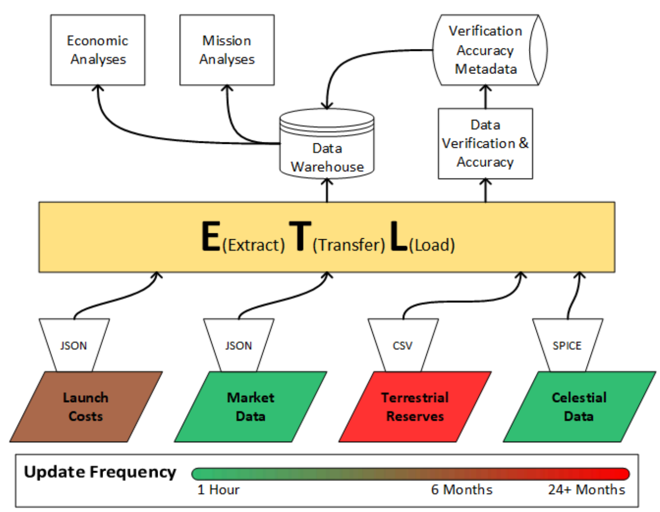

Figure 1. Data Acquisition & Data Processing Flow: Extract, Transfer, Load and Metadata Annotations

Concept of Operations: The system will be comprised of three major components:

Data Acquisition:

- Live Economic and Mineral Data: Collect global and national reserve data alongside dynamic mineral market prices.
- Celestial Body Repository: Aggregate data on mineral composition and orbital parameters.
- Launch Vehicles: Incorporate detailed information on vehicle capabilities and cost structures.

Data Processing:

- Resource Valuation Analysis: Continuously evaluate the value of celestial bodies.
- Economic Modeling: Perform on-demand projections of mineral market fluctuations using techniques such as Monte Carlo simulations and game theory [9].
- Mission Modeling: Provide a breakdown of mission options, cost structures, and comparative analyses [9].
- Net Present Value Calculation: Quantify economic feasibility with an integrated Net Present Value (NPV) model [9].

User Interface:

- Data Visualization: Present insights via interactive charts and 3D models.
- Comparative Tools: Allow users to contrast different mission options and cost scenarios.

Methodology: The technical approach will build on state-of-the-art techniques in asteroid composition analysis, economic modeling, and mission simulation. In the initial phase, existing models and visualization tools will be integrated into AiSTRAEUS. However subsequent enhancements will focus on the development of custom, in-house software to optimize efficiency and improve modeling accuracy.

The platform will implement a dynamic NPV model combining Hein's techno-economic analysis framework with supply-demand elasticity projections [9]. Building on established asteroid mining economics from Hein, the system will optimize profitability through multiple key adjustable parameters: fleet scalability, throughput optimization, mission phasing, spacecraft reuse, and other cost reduction strategies [9].

The model will incorporate real-time commodity price elasticity and projected terrestrial reserve depletion rates, using game theory simulations to anticipate market impacts from space-sourced material inflows.

Expected Outcomes and Impact: AiSTRAEUS will aim to deliver within these parameters:

- Fast and reliable performance with user *First Contentful Paint* load times under 1800 milliseconds [10]. Also response times for full simulations and modeling under 10 seconds.
- Economic modeling with an error margin of ±15% compared to internal data [11].
- A platform accessible via modern web browsers with WebGL support and optimized for devices with integrated graphics.

Anticipated Benefits: By providing a centralized, reliable source of information, AiSTRAEUS will empower stakeholders—ranging from government agencies to private enterprises—to make informed decisions regarding space resource exploration. This platform will foster a collaborative community for planning, policy-making, and further technological development.

Future Directions and Implications: The immediate next steps will include setting up a robust data infrastructure and developing initial prototypes for data processing. In the long term, partnerships with mission executors and data providers will solidify AiSTRAEUS's role as the central hub for space resource planning.

Broader Impact: As the platform evolves, it could set standards for data-driven decision-making in space exploration, influencing policy, and opening up opportunities for international collaboration.

Conclusion: To summarize, AiSTRAEUS will deliver a transformative framework for evaluating the economic feasibility and operational potential of extraterrestrial mining. By integrating diverse data streams with advanced modeling techniques, the platform will provide robust, real-time insights for mission planning and serve as a vital decision-support tool. As a pioneering solution, AiSTRAEUS will catalyze innovative strategies in space resource exploration and foster collaborative progress, thereby paving the way for sustainable growth in this industry.

References: [1] Space Foundation Editorial Team (2023) *Space Report*, Q2. [2] Brukardt, R. (2022) *McKinsey Q.*, November 28. [3] Cuadros-Muñoz, J.-R. et al. (2024) *Land*, 13, 1220. [4] IEA (2023) *Critical Minerals Market Review* [5] United States Geological Survey (USGS). (2025). *Mineral Commodity Summaries 2025.* [6] Metzger, P. T. (2023) *Acta Astronautica*, 207, 425 - 444. [7] Komerath, N. and Nair-Reichert, Usha (2008) *AIAA SPACE 2008 Conference & Exposition,* 2008-7791. [8] Lenzerini, M. (2002) Proceedings of the Twenty-First ACM SIGMOD-SIGACT-SIGART Symposium on Principles of Database Systems, 233-246. [9] Hein, A. M. et al.(2020) Acta Astronaut., 168, 104–115. [10] Google for Developers (2023) Make the Web Faster, Insights, *Google PageSpeed Insights*. [11] Kolassa S. (2008) *International Institute of Forecasters*, 11, 6-14.