24-026

Development of a Comprehensive Mine Plan Approach for the Extraction of Icy Regolith on the South Pole of the Moon Using Surface Mine Modelling Software

Víctor O. Tenorio

Geoffrey Gill

Kate Willa Brown Requist

William Riley

Mollie Hunt

Russ Downer

One of the first activities after returning to the Moon will be finding sources of water and materials for the construction of human settlements and other infrastructure. There is evidence of the existence of deposits in the bottom of craters at the South Polar region and in flat areas around. Based on geological data from the Moon, a block model representing a deposit or icy regolith has been defined in the vicinities of Shackleton Crater, with unique characteristics of shape, thickness, and water contents. A mine plan utilizing surface mine modeling software for ore extraction from an open pit- type of excavation to a delivery point near a water processing facility is proposed, with monthly, quarterly, and yearly schedules. Production results, dashboard charts and progress of the topographic changes are also presented.

INTRODUCTION

From all the things to do when arriving on the Moon, humans must find sources of icy regolith and start sampling for the definition of ore bodies and reserve estimation. As opposed to the Earth, where the target are base metals or non-metal minerals, the one of the most important is finding the areas where there is abundance of water sources, and raw materials for construction. The areas with more probability to find these resources are the Permanently Shadowed Regions at the South Pole (Figure 1).

In such locations, there is the presence of water mixed with the regolith, accumulated over millions of years as a result of comets passing sufficiently close to the Moon and the accumulated water ice not being able to evaporate due to the almost null exposition to the Sun. Discoveries such as these, have opened the immense opportunity to consider the extraction of this water to be decomposed into oxygen and hydrogen, while additionally finding adequate processes to extract other valuable minerals such as base metals, precious metals and Rare Earths.

Figure 1. The Moon South Pole and Shackleton Crater (source: Moon Trek)

With the use of Moon Trek, a public domain geographical tools, it is possible to have an enhanced view of these regions, using data from the Lunar Reconnaissance Orbiter (LRO), which has mapped the entire South Pole, removing the shadows. We can now appreciate the bottom

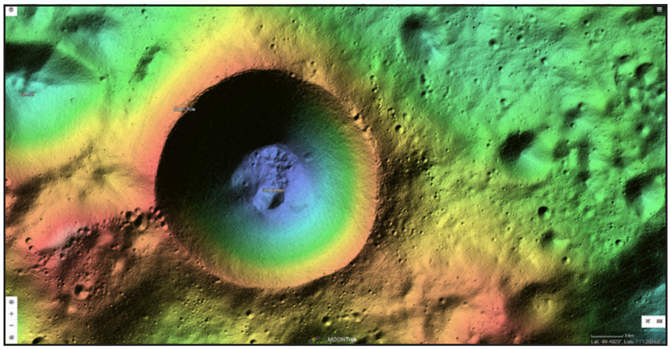


Figure 2. Enhanced view of Shackleton Crater and candidate areas for landing and mining (source: Moon Trek)

of Shackleton crater, and many of its relevant features (Figure 2).

Designated landing location

Among the different candidates available for landing and starting the first exploration works, the selected point is in the Southeast side of Shackleton Crater, in coordinates: Lat: 89.12, Long: 103,06, in a rather flat area surrounded by small craters, expected to be rich in water.

The mining site and therefore the habitat site, are planned to be 4 km away, parallel to Shackleton Crater's rim. Figure 3 shows a production area section with the layout and infrastructure distribution.

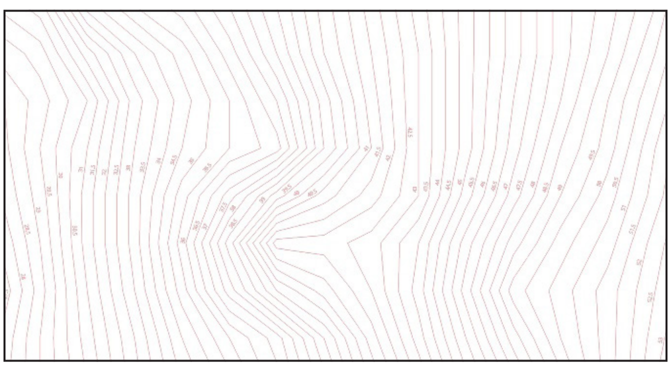


Figure 3. Moon Landing and Mining Site, 4 km long, 2 km wide, with contours every 0.5 meters (source: QGIS)

Resources on the Moon

As the Moon becomes a target for developing mining operations, classification of potential mineral resources is being developed. Among the ever-abundant regolith, a resource usable for construction materials among other things, there is a range of valuable resources such as metals including Rare Earth Elements that can be extracted (Figure 4). Another among these extractable resources is water, which opens vast possibilities for obtaining oxygen, essential for sustaining life, as well as hydrogen which can be used for fuel and other industrial applications.

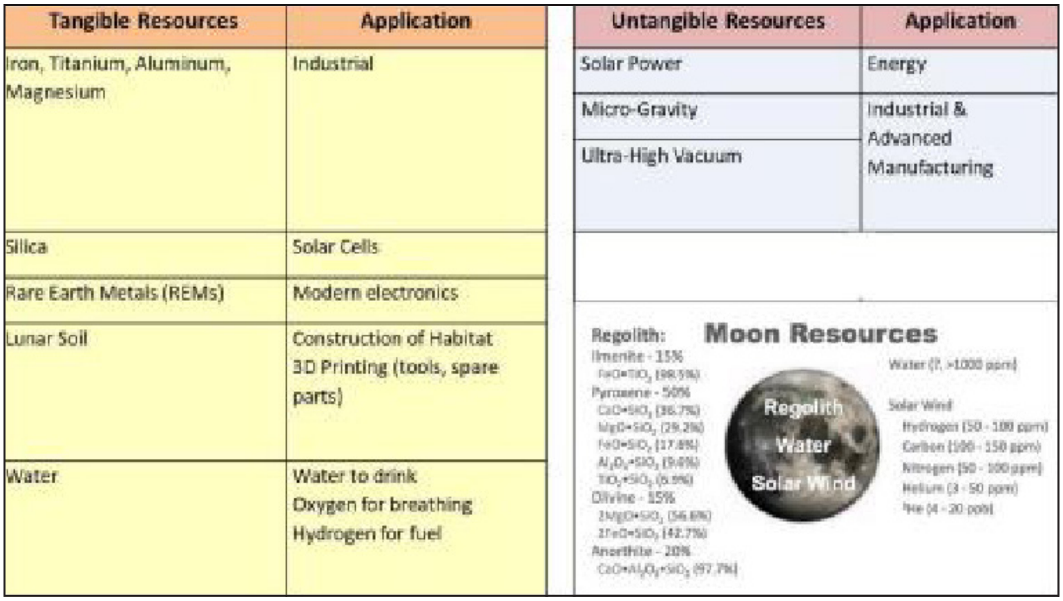
The management of a mine on the Moon must follow a process that involves the optimal use of all the resources available in the organization (human, physical, technological, and financial), given the harsh living conditions (exposure to radiation, drastic temperature change from daylight to night darkness, low gravity, dust, limited supplies, and restricted habitat premises.) So that through a newly designed planning, organization, direction, and control, the set of objectives can be achieved.

A New Type of Mine Planning

Planning is the first function to be executed. Although much of it can be done in advance on the Earth, once the equipment is deployed, assembled, and tested on the Lunar surface, pioneering operations will start. The production goals and work cycle must be defined based on the capability of humans to stand in the vacuum, and the performance of teleoperated or autonomous equipment. These production objectives, the topographic progression, and the production rates become the essence of these plans. The last phase of the management process is the control function. Its immediate purpose is to measure, qualitatively and quantitatively, the execution in relation to the action patterns and, because of this comparison, determine whether it is necessary to take corrective actions. Being on the Moon requires fast responses at the site. The adequate planning and control in a mining operation is given by the way it is designed and how the operational processes are measured and managed. The advancement of technology

with the use of communications and control systems almost in real time allows the management of operations in a more optimal way, thus reducing delays when a critical decision needs to be made.

Although there are different ways to plan and control a mining operation, one that may be effective on the Moon is by monitoring in Real- Time the most critical processes. The short historical data may give limited feedback and many of the actions to take are the result of intensive performance analysis of unmanned vehicles. New Key Performance Indicators will need to be developed, all encompassed in a comprehensive system denominated Luna Mine Planning (Tenorio et al., 2020). A Python-based prototype interface has been designed with the essential functions including digital map updates, and collections of measured data that are used for evaluating the performance of an operation. They are the tools utilized by management to evaluate the performance of a activity. Reports generated compare in Real-Time the actual and estimated efficiency, efficacy, and



Tangible Resources	Application	Untangible Resources	Application
Iron, Titanium, Aluminum, Magnesium	Industrial	Solar Power	Energy
		Micro-Gravity	Industrial & Advanced Manufacturing
		Ultra-High Vacuum	
Silica	Solar Cells		
Rare Earth Metals (REMs)	Modern electronics		
Lunar Soil	Construction of Habitat 3D Printing (tools, spare parts)		
Water	Water to drink Oxygen for breathing Hydrogen for fuel		

Figure 4. Moon Resources and its applications

quality of equipment. These results will help to determine whether the operation is fulfilling the objectives, has deficiencies, or is going beyond being successful. The indicators must be measurable, understandable, and controllable.

Examples of some aspects to be measured with the idea of performing a better control of the operation:

- Workforce tracking and location.
- Radiation Exposure
- Oxygen Saturation
- Heart Rate
- Map Visualization
- Cost Control
- Simulation (EZ-RASSOR)
- VR capabilities
- Wireless Mesh testing
- Overall Communications Testing
- Emergency response
- Geopositioning
- Topographic update
- Dust levels
- Production times and delays
- Equipment monitoring, utilization, performance, and efficiency.
- Traffic control
- Drilling & Blasting system performance.
- Excavation System
- Maintenance time and availability

A representation of the software interface is shown in Figure 5.

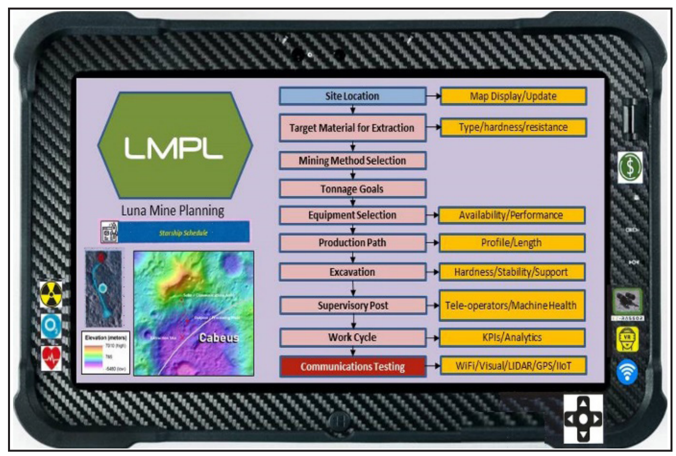


Figure 5. Interface for Luna Mine Planning (Tenorio et al., 2020)

Supervisory Post

For the observation and control of the Lunar surface operations, a building dedicated for supervisory tasks is suggested. Even though at an advanced stage of operations many production units will be autonomous, there will most likely be a need of human intervention to make quick decisions and visually verify the safety of the work. Starting on the surface, mining will gradually go underneath to add protection for personnel and equipment. The supervisory outpost must comply with a minimum set of characteristics: comfortable interior for operators; located on high ground; a panoramic window for visual confirmation of activities at the portals of the production area; shielded structure; portable to relocate to new lines of sight as excavation progresses.

By using this system, mine operators always have a complete overview of the mine and can determine who else can receive the information.

REFERENCES

Spudis, P. (2013) The Mystery of Shackleton Crater. Smithsonian Magazine. https://www.smithsonianmag.com/air-space-magazine/the-mystery-of-shackleton-crater-17072957/

Tenorio, V. et al. (2020) Luna Mine Planning: A Hands-On Approach for starting Mine Operations on the Moon. 2020 Lunar Development Conference. Moon Society.

24-027

Processing Marcasite Copper Ore with Iron Depressant, Hybrid Reagents, Advanced Data Analytics, Visiofroth™ and Breakthrough Expert Control of Entire Flotation Plant—Fundamentally Transforming Doe Run Buick Mill to Create Value and Expand Ore Resources

Weishi Mang
The Doe Run Company, Boss, MO

Adam Steimel
The Doe Run Company, Centerville, MO

Andrea Deml
The Doe Run Company, Boss, MO

Randy Hanning
The Doe Run Company, Viburnum, MO

Brian Mangogna
The Doe Run Company, Viburnum, MO

ABSTRACT

The Doe Run Company (Doe Run), a global supplier of lead, copper and zinc concentrates, and lead metal alloys, has deployed an innovative hybrid reagent system which includes an iron depressant to enable processing of high iron marcasite ores at the company's Buick Mill. The deployment of this technology has increased the ability to produce saleable concentrates from high iron marcasite ore, thereby improving ore reserves. This system utilizes VisioFroth™ as a baseline and builds on its platform with a breakthrough expert control system to operate the entire flotation plant using VisioFroth™ as a soft sensor like x-ray fluorescence spectrometry (XRF) and its bubble characteristics as process parameters. This new deployment of technology utilizing Distributed Control System (DCS) as its engine, Pi software as its data hub and a second modern floatation reagent system has been finetuned with advanced data analytics and Machine Learning (ML) for limitless optimization of the mill's operation. It has been deployed at existing mill infrastructure, fundamentally transforming Buick Mill.

INTRODUCTION

The Doe Run Company (Doe Run) is a global supplier of lead (Pb), zinc (Zn), and copper (Cu) concentrates, along with Pb metal alloys. Doe Run's Buick Mill is one of Doe Run's four concentrators in southeast Missouri. All four mills produce Pb/Zn/Cu concentrates from mining and milling metal sulfide ores utilizing conventional flotation, with primary galena and secondary sphalerite and chalcopyrite minerals. All four mills also make copper concentrates from copper ores in separate operational campaigns called Copper Specials by converting lead and zinc circuits into copper circuits. Iron sulfides in ores exist in pyrite and marcasite but historically all mills process pyrite ores not marcasite ores due to very problematic hard-to-depress marcasite, a highly active iron sulfide compared to pyrite.

Buick mill processes ores with rapidly varying lead, zinc, and copper grades from three surrounding mines, and there are extensive marcasite ores. Buick Mill refrained in the past from processing marcasite ores when possible. Marcasite naturally floats very easily, acts out while floating, and severely disrupts separations in all lead, zinc, and copper circuits, making it uneconomical, or much less economical to process than other pyrite ores. There are however a lot of high lead high copper marcasite ores accessible for mining, motivating the development of a comprehensive technology system at mill operational level and on the production line, based on fundamental principles and advanced data analytics. Such a system would most efficiently process not only marcasite ores but also the complex and changing regular ores at Buick mill and other mills as