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Operationalising remote data acquisition in block caving: a case study at Oyu Tolgoi

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Abstract

In the dynamic environment of high-production block cave mines, the interplay between geotechnical assurance and operational tempo is critical. The requirement for frequent, high-fidelity monitoring of cave propagation, drawpoint status and ground support integrity often conflicts with production demands, as manual inspections necessitate the stoppage of mining equipment and exposing personnel to hazards such as mud inrush or seismic events.

This paper presents the results of a comprehensive remote data acquisition study conducted at the Oyu Tolgoi underground mine. The study systematically audited the site's cave management plan, ground control management plan and trigger action response plans to evaluate the feasibility of transitioning from manual to robotic data collection.

The analysis identified and characterised 126 distinct inspection and monitoring tasks currently performed by geotechnical, survey and production teams. A critical operational finding was that 95% of these mandatory tasks currently require production to cease to allow human access, creating significant 'white space' in the operational cycle.

We outline the methodology used to map these tasks against the capabilities of current off-the-shelf mobile robotic platforms (quadrupedal and tracked). The case study details the selection process for deploying remote systems into the hostile mining environment to perform specific high-value tasks, including post-blast apex inspections and automated tunnel and drawpoint inspections.

The study concludes that integrating ruggedised mobile robotics is not merely a safety initiative to remove personnel from hazardous areas; it is a production enabler. By allowing data acquisition to occur concurrently with mucking operations, the mine can achieve higher-resolution geotechnical datasets without compromising the extraction rate, effectively decoupling safety monitoring from production interruptions.

Keywords: *remote data acquisition, mobile robotics, geotechnical monitoring, block caving, Oyu Tolgoi, safety integration*

1 Introduction

As block cave mining pushes into deeper, higher-stress environments, the interplay between geotechnical assurance and operational tempo has become a critical determinant of success (https://acgcaving.com; SRK Consulting n.d.; Stegman et al. 2022). The management of an active cave, specifically, the propagation of the caving back, fragmentation of the ore, abutment stress management, and extraction level stability, relies heavily on continuous, high-fidelity data acquisition.

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Historically, these data have been gathered through manual inspections performed by geotechnical engineers, surveyors and production personnel. However, placing humans in active extraction levels introduces severe safety risks and fundamentally disrupts the mining cycle. At the Oyu Tolgoi underground operation, the sheer volume of required monitoring tasks (Ulziijargal et al. 2024) highlighted a growing operational bottleneck: the inverse relationship between geological assurance and production throughput.

To address this, Oyu Tolgoi commissioned a study to comprehensively audit existing monitoring practices, quantify their impact on production, and evaluate the feasibility of integrating autonomous or semi-autonomous robotic systems to conduct these critical tasks.

2 Remote data acquisition study methodology

The remote data acquisition study (RDAS) was structured around a systematic review of the documentation governing underground risk mitigation and operational procedures. The study aimed to identify every instance where personnel were required to observe, measure or sample the underground environment. The audit encompassed:

- Parent standards: overarching safety and operational frameworks such as Rio Tinto’s D1 standard, and more specifically the cave management plan (CMP), ground control management plan (GCMP) and ventilation management plan (VMP)
- Trigger action response plans: predetermined responses to specific events, such as wet and dry inrushes, ground support damage, seismicity and overbreak
- Standard work procedures: step-by-step instructions for tasks like vertical excavation inspections, pull-out testing and face mapping.

Once identified, each task was categorised by the department responsible, the frequency of execution, the type of data collected (visual, point cloud, digital entry), and crucially, whether the task required the stoppage of production machinery (a ‘blocking’ task).

3 The true cost of geotechnical assurance

3.1 Task characterisation and resourcing

The RDAS identified 126 distinct inspection and monitoring tasks, translating to 199 individual data capture events across various departments. The distribution of these tasks is heavily skewed towards safety and stability monitoring (this distribution is further presented in Figure 1):

- Geotechnical: 45 tasks (e.g. convergence monitoring, ground support inspections).
- Ventilation: 34 tasks (e.g. gas monitoring, airflow checks).
- Surveying: 13 tasks (e.g. raise scanning, heading mark-ups).
- Production and development: 21 tasks (e.g. pre-shift inspections, blast clearance).
- Geology: 8 tasks (e.g. face mapping).

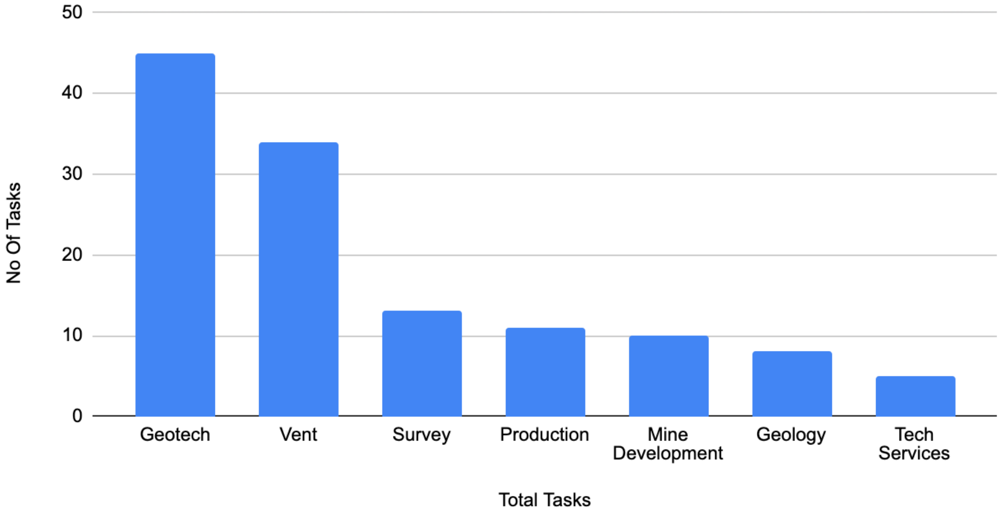

Figure 1 Distribution of underground inspection and monitoring tasks. Total tasks = 126

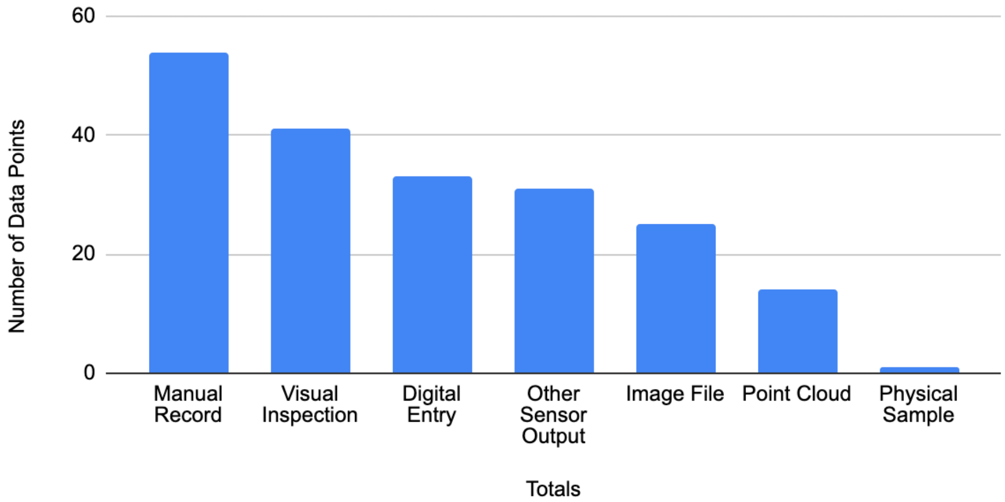

Figure 2 Distribution of data types generated. Manual data acquisition

3.2 Production interference

The most significant finding of the RDAS was the profound impact of monitoring on the production cycle. Of the documented tasks, 95% (120 out of 126 distinct tasks) were classified as 'blocking' tasks (illustrated in Figure 3). These activities cannot be executed concurrently with production or development. Heavy machinery (load–haul–dump [LHD] units, haul trucks) must be powered down and parked to allow personnel safe access on foot or via light vehicles.

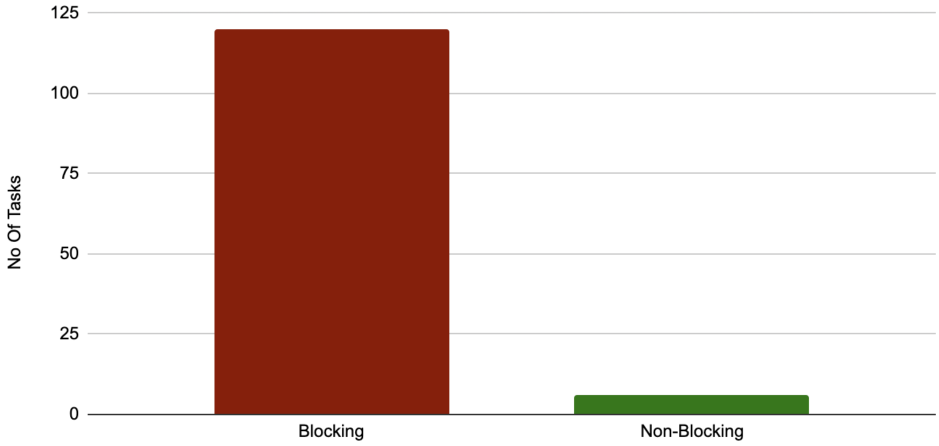

Figure 3 Distribution of production blocking versus non-blocking inspection activities

Analysis of task frequencies and average durations revealed that these manual inspections generate significant hours of operational 'white space' per month within the active production footprint. This represents a substantial loss of throughput driven by the logistical constraints of human-led data acquisition. Consequently, the transition to an automated robotic data acquisition system represents a high-yield investment, capable of achieving full capital payback in under a month of operation.

3.3 Human risk exposure

Beyond production delays, the reliance on manual inspections frequently places personnel near critical risks. Activities such as apex and undercut drive inspections, post-blast re-entry, and drawpoint hang-up assessments expose workers to hazards that need to be managed, including:

- unplanned initiation of explosives (misfires)
- asphyxiation from hazardous post-blast or strata gases
- exposure to unsupported ground or dynamic seismic events
- ejection of rock from drawpoints
- mud inrushes from wet drawpoints.

3.4 Eliminating human occupancy to unlock efficiency

Designing and operating production areas to accommodate human inspections also imposes a substantial burden on mine productivity. Every human entry into an active production zone triggers a cascade of preparatory requirements that collectively consume significant time and labour that could otherwise be directed towards production.

In block cave operations, drawpoints must be bunded prior to any personnel entry to guard against the hazard of uncontrolled material ejection (for example, from hung drawpoints, mud and/or fines rush events). This process requires equipment and operator time, and must be completed, and subsequently reversed, for each inspection cycle. In high-frequency inspection regimes, this alone can represent a meaningful reduction in drawpoint availability and loader utilisation rates.

Beyond physical safeguarding, personnel entry to areas mandates the active management of the underground atmosphere. Dust suppression systems and ventilation circuits must be confirmed as functional and appropriately configured before personnel are cleared to enter.

Taken together, these requirements mean that the act of inspecting a production area carries a productivity cost that extends well beyond the inspection itself, using equipment and personnel who could otherwise be engaged in value-adding tasks.

Transitioning to inspection regimes conducted exclusively by automated or remote-controlled robotic platforms fundamentally changes this requirement. Areas never occupied by personnel can potentially be released from the regulatory and procedural obligations tied to human presence. Bunding requirements are eliminated, atmospheric management can be optimised for production rather than human occupancy, and inspection cycles can be decoupled from shift patterns and production schedules. The result is a material improvement in the utilisation of both equipment and mine time, with inspections conducted continuously or on demand, without interrupting the production cycle.

4 Robotic integration and platform evaluation

To recover lost production time and remove personnel from hazardous environments, the RDAS evaluated commercial off-the-shelf robotic platforms. The evaluation matrix moved beyond basic mobility, focusing on endurance (run time), environmental resilience and sensor payload capabilities.

4.1 Sensor payload requirements

To replace human observation, a robotic platform must carry a multi-modal sensor suite, such as those shown in Figure 4, capable of gathering objective, survey-grade data:

- High-resolution 3D LiDAR: essential for convergence monitoring, volume calculations and structural mapping.
- PTZ visible and thermal cameras and appropriate lighting: required for inspecting ground support, identifying misfires and monitoring thermal anomalies (e.g. fires from battery electric vehicles [BEVs]).
- Environmental sensing: continuous monitoring of CO, NO_2, LEL and NH_3 to clear headings post-blast.

Figure 4 Multi-modal sensor suite for underground inspection and monitoring

4.2 Technical integration

The technical integration of autonomous data acquisition systems is increasingly facilitated by the shift towards fully automated mining environments, where automated LHD units, haul trucks and development drills are becoming the operational standard. This transition relies on high-bandwidth communication backbones, such as industrial Wi-Fi and LTE, coupled with sophisticated vehicle-to-everything (V2X) protocols like dedicated short-range communications (DSRC) 802.11p. By utilising these existing networks alongside high-precision tracking and integration with mine-wide fleet management systems at the application programming interface (API) level, robotic platforms can be integrated into the site’s traffic management API. This integration offers a dual-layered value proposition for safety and productivity.

Firstly, using simultaneous localisation and mapping (SLAM) or the site's broader infrastructure-based location services, the robots maintain full visibility within autonomous traffic management systems, effectively eliminating the risk of unplanned interactions with heavy production equipment.

Secondly, these platforms serve as mobile diagnostic tools; by monitoring signal strength, throughput and latency during their inspection missions, they generate near real-time heat maps of the mine's digital infrastructure. In an environment where the loss of communication directly translates to a cessation of autonomous production, this proactive monitoring of the 'communications health' becomes a critical enabler for both operational safety and maximum throughput. An example tactical screen capture is shown in Figure 5.

Figure 5 Screenshot of mine network and access point communications health monitoring dashboard

4.3 Platform evaluation

A weighted index was applied to 15 different ground and aerial systems. Aerial systems (drones), while highly agile, generally lacked the endurance required for long-range underground inspections of more than an hour.

Among ground robots, the Australian Droid & Robot (ADR) Explora XL (pictured in Figure 6) scored the highest (48 points), followed by the Taurob Surveyor (37 points) and ANYbotics ANYmal (35 points). The Explora XL's superior ranking was driven by its purpose-built mining design, extended endurance (over 4 hours), IP67 rating (critical for traversing mud and water), and its ability to autonomously deploy from a ruggedised charging station without human handling.

Figure 6 Remote inspection and monitoring system from ADR

5 Operationalising the data: a phased approach

The successful integration of robotics into a high-tempo caving operation requires a staged approach to manage change and validate capabilities. The RDAS recommended a ‘now, next, then’ implementation strategy, as outlined in the following subsections.

5.1 ‘Now’: immediate risk mitigation

Initial deployment focuses on high-risk, inaccessible environments where human presence is either prohibited or highly dangerous:

- Drawpoint status and anomaly reporting during autonomous operations: automated scanning during shift changes to provide consistent, accurate drawpoint status, preventing hang-ups and improving availability. An example is shown in Figure 7.

Figure 7 Example drawpoint image with fragmentation analysis and oversize overlay

- Apex level inspections: using robotics to provide rapid visual confirmation of blast outcomes and LiDAR scans in unmeshed environments filled with blast gases.
- Post-blast re-entry: automating gas clearance and misfire identification to expedite the return to production.

5.2 'Next': recovering production time

The secondary phase integrates robotics into routine operations to actively reduce the 110 hours of monthly 'white space':

- Convergence monitoring: conducting routine LiDAR scans of production drives concurrently with loader operations, removing the need to clear the drive for geotechnical engineers. An example is shown in Figure 8.
- BEV battery fires: deploying thermal and gas-equipped robots to monitor emergency situations without exposing emergency response teams to toxic fumes and extreme heat.

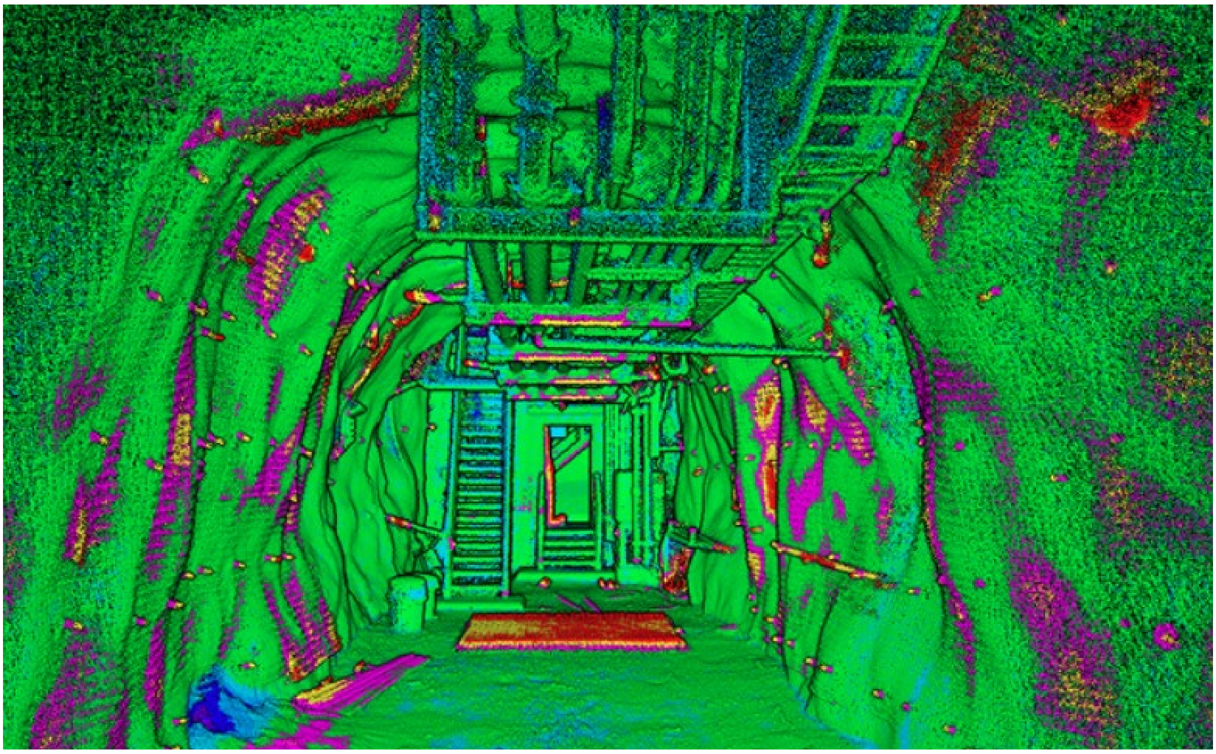

Figure 8 Example convergence monitoring result (courtesy of Emesent)

5.3 'Then': the digital twin and artificial intelligence futureproofing

The ultimate value of robotic integration lies in the data itself. By transitioning from subjective human observations to mathematically objective point clouds and multispectral imagery, the mine can construct a true, continuously updated digital twin.

Integrating this data stream seamlessly into platforms like CaveCAD and Deswik ensures the data are actionable. Where current tooling cannot manage the data volumes, ADR and its partners have supplemented the tools available to provide systems to manage mine-scale datasets. Furthermore, the systematic archiving of high-quality drawpoint and drift scans creates a robust training dataset for future artificial intelligence (AI) models. These models will eventually predict events such as ground support failure, brow failures, mud rushes or convergence spikes based on micro-patterns in the data invisible to human analysts, positioning the operation at the forefront of predictive mining.

However, achieving this future-state operational paradigm introduces significant infrastructural and operational challenges that must be systematically managed:

- Critical network infrastructure reliance: The viability of an autonomous or semi-autonomous digital twin framework is linked to the underground communication backbone. Data backhaul demands continuous, capital-intensive expansion and maintenance of industrial high-bandwidth networks (e.g. Wi-Fi or LTE).
- Change management: The shift to remote data acquisition and the use of remote monitoring systems often changes operational behaviours. Often the remote monitoring assets deliver significant additional value for production and development teams. Typically, there is a shift where the remote monitoring assets, initially anticipated to be technical assets, often become operational ones, where the resulting data are then shared with multiple stakeholders.

6 Conclusion

The transition to deep block caving necessitates a fundamental shift in how geotechnical and operational data are acquired. The Oyu Tolgoi RDAS clearly demonstrates that the current reliance on manual inspections is unsustainable, inherently dangerous, requires continuous safety management and incurs a massive opportunity cost.

By evaluating and deploying ruggedised, multi-sensor robotic platforms like the ADR Explora XL through a phased implementation strategy, mining operations can successfully decouple mandatory geotechnical assurance from production interruptions. This transition not only offsets the capital expenditure of a robotic fleet through recovered operational capacity but fundamentally replaces subjective human assessment with a permanent, objective digital record. Remote data acquisition is no longer an innovative luxury; it is an uncompromising operational necessity for the future of deep block cave mining.

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- Australian Droid & Robot: for providing technical data, field evaluation matrices and hardware imagery related to the Explora XL platform deployment.
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References

SRK Consulting n.d., *Addressing The Challenges And Future Of Cave Mining*, viewed 20 January 2026, https://www.srk.com/en/publications/addressing-the-challenges-and-future-of-cave-mining

Stegman, CL, Togtokhbayar, O, Herselman, S & Altankhuu, B 2022, ‘Oyu Tolgoi: engineering a Mongolian caving dynasty’, in Y Potvin (ed.), *Caving 2022: Proceedings of the Fifth International Conference on Block and Sublevel Caving*, Australian Centre for Geomechanics, Perth, pp. 625–634, https://doi.org/10.36487/ACG_repo/2205_43

Ulziijargal, M, Enkhtaivan, E, Purevdorj, M, Purwanto, H, Simanjuntak, K & Moorcroft, T 2024, ‘Oyu Tolgoi geotechnical monitoring system’, in D Johansson & H Schunnesson (eds), *MassMin 2024: Proceedings of the International Conference & Exhibition on Mass Mining*, Luleå University of Technology, Luleå, pp. 383–397, https://doi.org/10.36487/ACG_repo/2435_C-07