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Safe and sustainable production: a deep dive into the GBC Mine's extraction level journey

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ABSTRACT

Commencing undercutting operations in September 2018, the Grasberg Block Cave (GBC) mine in Indonesia is an exemplary model of modern mechanized block cave mining. The block cave production capacity has rapidly increased to surpass an average of 133,000 tons per day (t/d) within a significantly brief timeframe. This paper articulates a thorough analysis of the challenges encountered in the initial mucking phase at the extraction level and the innovative strategies used to overcome them. The central focus of our discussion revolves around the optimization of the Load-Haul-Dump (LHD) operator productivity through a concerted emphasis on the personal development aspect under stringent supervision and operational discipline. Safety enhancements have also been prioritized through the strategic reduction of operator's head-cabin interactions. Another key contributor to record-breaking extraction production performance is the innovative approach to addressing the secondary breakage sequence, with the aim of maximizing drawpoint availability. By conducting a thorough analysis, we have extracted valuable lessons and insights, focusing on methodologies that effectively reduce scheduling disruptions and address production bottlenecks. This study is positioned to serve as a valuable resource for professionals in the mining industry, providing strategies that are crucial for achieving optimal performance in block cave mining operations.

1 BACKGROUND

PT Freeport Indonesia (PTFI) initiated the development of the Grasberg Block Cave (GBC) mine in 2004, with a strategic plan to commence caving operations by 2018. The objective was to achieve a steady production rate of 130,000 to 160,000 t/d of ore by 2025, as outlined by Brannon et al. (2020). Currently, the Grasberg Mining District hosts three active underground mining operations: the GBC mine with a production target of 130,000-160,000 t/d, the Deep Mill Level Zone (DMLZ) block cave mine with an 80,000 t/d target, and the Big Gossan open stoping operation at a 7,000 t/d production rate. Notably, the GBC mine is projected to be the primary source of mill feed, for the next two decades.

GBC estimated diluted ore reserves are 959 million metric tons at a grade of 0.97% copper and 0.73 g/t gold. This translates to 17 billion pounds of copper and 14 million ounces of gold in payable metal, with an annual average production expected to reach approximately 850 million pounds of copper and 700,000 ounces of gold upon reaching full production rates.

The GBC mine was designed as a fully mechanized block caving mine using LHDs and a train haulage. Key components include an 0.8-meter grizzly opening at the extraction level and 4.1 meter diameter ore passes leading to the train haulage level, where ore is loaded onto 12-14 trains via loading chutes located in chute galleries.

The ore handling system is designed to manage the maximum particle size accommodated by the 63 x 89 inch (1,000 kW) gyratory crusher. The mine's footprint is divided into five production blocks, as illustrated in Figure 1, showing a plan view of the GBC Extraction and Haulage level.

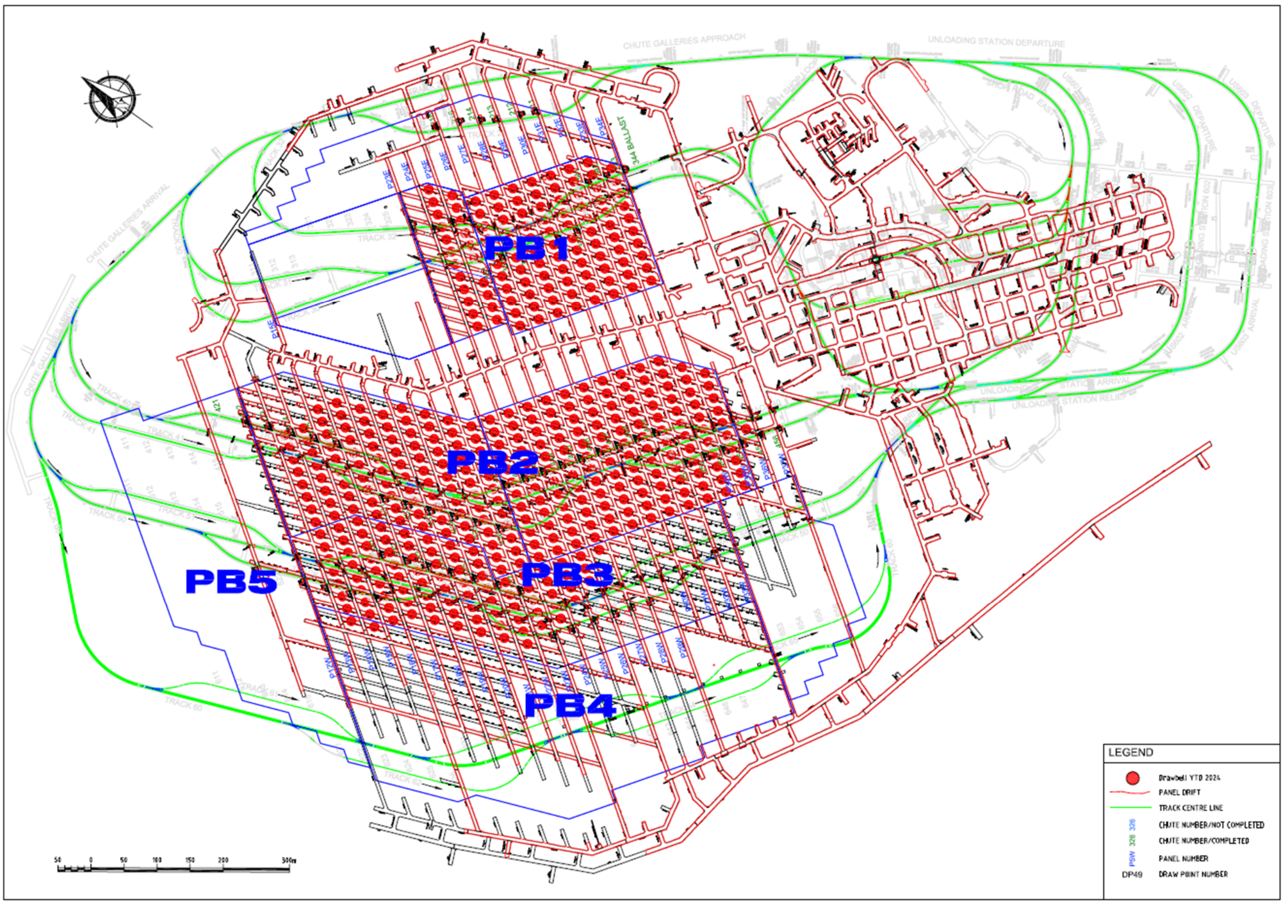

Figure 1 GBC production level.

Undercutting operations commenced in late 2018, followed by the initial drawbelling in January 2019. As of December 2023, the total area undercut includes approximately 291,000 square meter, across three production blocks, with around 427 drawbells blasted (equating to 854 drawpoints) - from the total of 2,400 drawpoints over the mine's life. However, typically, 45% of these drawpoints are temporary closed, primarily due to scheduled maintenance, wet muck panel, or sulfur dioxide (SO_2) exposure. The mine also utilizes 46 active grizzlies and 10 of the total 20 chute galleries for train loading, each containing 6 to 9 chutes. A notable production record of 184,000 t/d was achieved on December 25, 2023.

Since its inception, PTFI has navigated challenges during the startup and ramp-up phases of GBC production, requiring continuous optimization to ensure safe and sustainable operations. A critical focus has been on maintaining consistent ore feed and balance between extraction level and the ore handling system to sustain mill operations.

Figure 2 showcases the production ramp-up, delineating a significant increase in production rates for the first 24 months. This improvement aligns with the strategic opening of drawbells to increase drawpoint availability. The mine achieved a significant milestone by blasting 21 drawbells in August 2020.

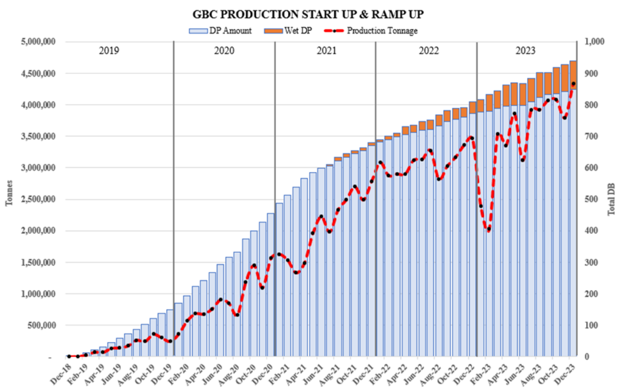

Figure 2 GBC production ramp up.

The year of 2020, shows a ramp up rate of 2.5Mt per month up to an average monthly rate of over 4.0Mt per month. Two main factors were responsible for this change in production rate: 1) productivity improvement 2) secondary breakage strategy.

The goal of any ramp up is to compress the start-up period as much as possible. Although the different key production drivers encountered in the GBC are discussed within this paper, the ability of the project team to recognize and react to these issues was the real key in exceeding the planned production rates.

Benchmarked parameters for the productivity of LHD units in cave mining operations are delineated in Table 1. Consistent with the metrics established by Power (2021), productivity within such mines is quantitatively assessed by considering both the mass of ore produced and the availability of drawpoints alongside the fleet of LHD units dedicated to production activities. Table 1 encapsulates the productivity rates of LHD units from a selection of benchmarked mines, with detailed comparative data illustrated in Figure 3.

Regarding overall productivity, GBC mine is distinguished as the operation with the second-highest production volume per day globally. This metric underscores the mine's substantial contribution to the industry, reflecting both the scale of its operations and the effectiveness of its productivity-enhancing strategies.

Table 1 Benchmarked parameters for the productivity of LHDs

Mine	Number LHD in Production Levels	LHD Type	LHD Bucket size (tonnes)	Average Tonnes per day	Tonnes per LHD per day
Diavik (A154S Pipe)	1	Diesel	13.4	1,000	1,000
Dutoitspan NWC SLC	3	Diesel	7.0	1,200	400
Bultfontein SLC	3	Diesel	7.0	1,350	450
Diavik (A418 Pipe)	1	Diesel	13.4	2,000	2,000
Mt Wright	3	Diesel	17.8	2,400	800
Koffiefontein	5	Diesel	8.1	2,500	500
Capricorn Copper	2	Diesel	21.0	2,800	1,400
Black Rock (Mt Isa)	2	Diesel	12.5	3,000	1,500
Venetia K02	2	Diesel	21.0	3,300	1,650
Perseverance	5	Diesel	17.5	3,750	750
Subika	2	Diesel	15.0	4,000	2,000
Big Bell	4	Diesel	17.0	4,400	1,100
Mt Lyell	4	Diesel	21.0	7,000	1,750
Northparkes	2	Diesel	17.8	7,000	3,500
Finsch	9	Diesel	10.0	9,000	1,000
Venetia K01	7	Diesel	21.0	11,550	1,650
Carrapateena	5	Diesel	21.0	15,000	3,000
Ridgeway	6	Diesel	17.2	16,500	2,750
Telfer	7	Diesel	21.0	17,500	2,500
Ernest Henry	6	Diesel	21.0	19,500	3,250
Malmberget	14	Diesel and Electric	25.0	42,000	3,000
Kiruna	29	Diesel and Electric	25.0	130,500	4,500
GBC	35	Diesel	10.6	140,241	4,007

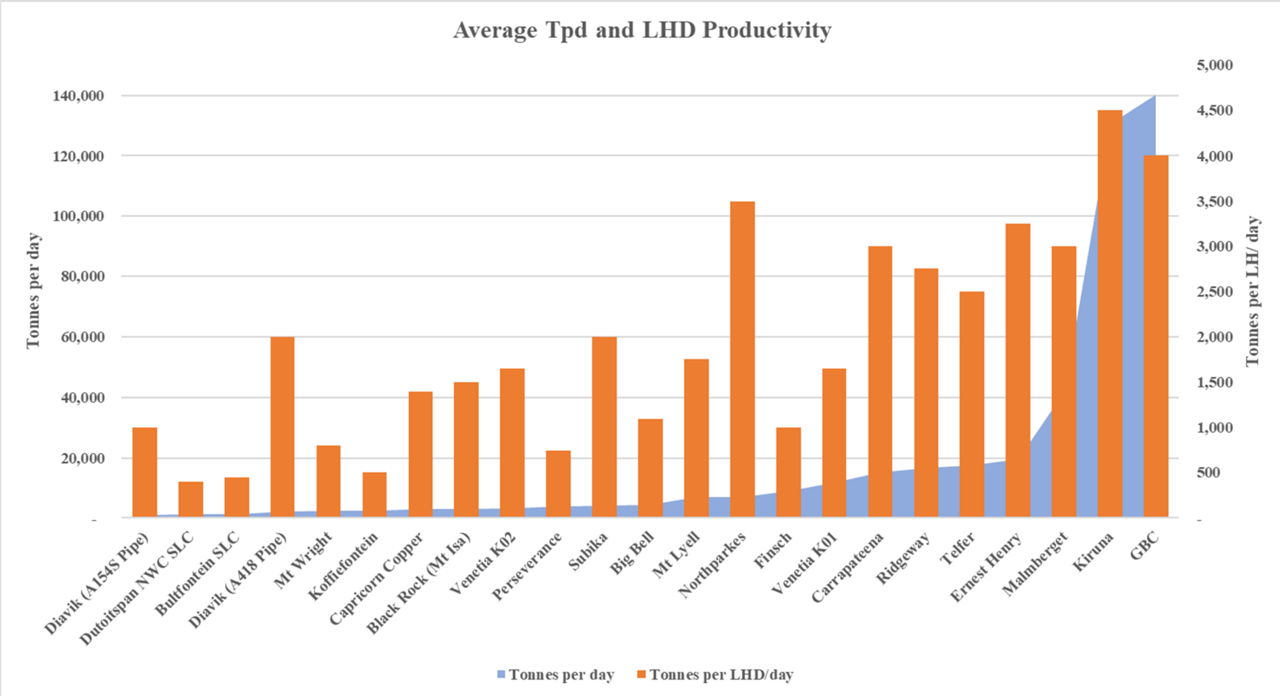

Figure 3 Average daily production and LHD productivity comparison.

This paper provides an update to the progress of production ramp up, from focal point of the extraction level of the GBC mine. It has also highlighted the lessons learned during the mine's startup phase and addressed the critical bottlenecks encountered. Through a focused examination of these challenges and the strategies applied for overcoming them, this study contributes valuable insights into achieving safe and sustainable production in one of the largest block caving mining operations in the world.

2 SAFETY AND LESSON LEARNED

In the underground mining industry, meeting the demands for sustainability in safety and productivity is crucial for maintaining operational licensure. Unforeseen events, such as traffic collisions and other types of accidents, not only pose significant risks to human life but also adversely affect productivity levels.

The extraction level presents substantial challenges for short-term scheduling due to multiple activities occurring concurrently. Following the initiation of production in a panel, it becomes necessary for production LHD, secondary breakage units, production drills, pre-production ground support, construction, and development crews to share access. Given that each panel has only three access points, the presence of multiple teams in the same area increases the risk of safety incidents and disrupts ongoing operations.

During the ramp up phase, GBC production team learned the lesson through journey including safety aspect of the operations.

2.1 Traffic Management Plan

The complexity of underground mining operations necessitates an effective traffic management plan to safeguard assets and personnel. Accidents involving vehicles and personnel are not uncommon in such environments and can lead to increased maintenance costs, reduced productivity, and, most critically, injuries to workers.

Numerous crews working in the same area caused interference and delay. It also reflects the typical mine start-up issues normally encountered such as the problems with limited grizzly number and production panel area.

GBC's implementation of a traffic management plan aimed to segregate production LHDs from other equipment and activities, thereby ensuring smoother operations. The plan designated the middle access route exclusively for loader production use, while the east and west fringes were allocated for non-production activities, including development, maintenance, and special projects. The success of this plan hinged on clearly defined roles and responsibilities, as well as the thorough planning of traffic flows within the extraction footprint to prevent conflicts and ensure the safety of all personnel.

At the beginning of each shift, groups submit their location to the live Underground Operations Management System (UOMS), enabling effective planning and coordination among different teams.

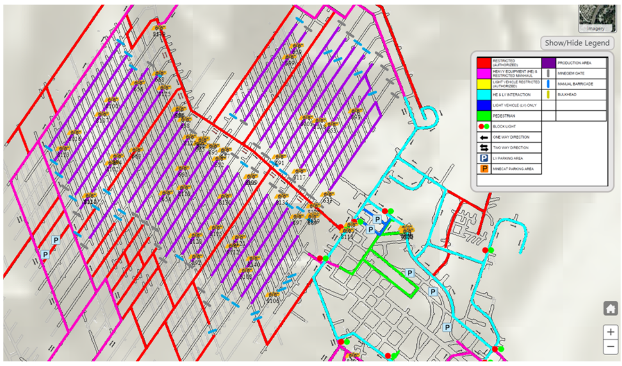

Figure 4 Real time GBC production traffic management plan.

2.2 Minimizing operator's head-cabin interactions

Due to the nature of production operations, LHD operators are forced to perform repetitive tasks such as loading ore from drawpoints, tramming, and dumping it into the orepass. This frequent repetitive task often leads to injuries involving the interaction between the operator's head and cabin. Since the commencement of production at GBC, there have been several reportable injuries attributed to such interactions.

An in-depth investigation into these incidents revealed a lack of understanding of the dynamics within the cabin at the moment of impact. This led to a comprehensive audit of loader cabins to identify and mitigate potential impact points. Initial improvements included the reconfiguration of cabin equipment and the addition of foam padding to hard surfaces. While these measures reduced the frequency of injuries, they were not entirely effective, as evidenced by incidents where operators sustained facial lacerations despite the presence of foam padding.

In response to these challenges, a harness-style seatbelt, previously introduced at the DOZ mine, was tested. However, this solution was found to restrict operators movement, potentially leading to back or neck injuries. A subsequent trial involving full-face helmets equipped with chin bars - similar to those used in aviation for hang gliding - offered promising results by providing comprehensive facial protection. Despite the initial success of this trial, long-term use of the helmets was deemed impractical due to discomfort caused by heat accumulation.

The most impactful modification was the redesign of the internal door handle to eliminate sharp edges and reduce the risk of injury, in alignment with the hierarchy of control principles as shown in Figure 5. This approach, coupled with repositioning the proximity detector (CAS 110) out from operator's body part in the cabin, significantly mitigated the risk of head injuries.

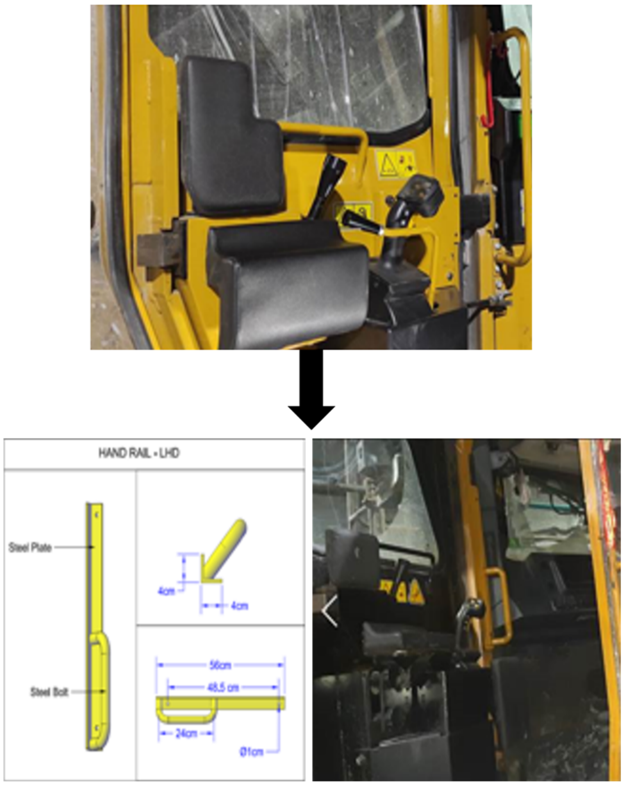

Figure 5 Redesigning LHD door handle.

2.3 Training and Competency

To address the challenges posed by repetitive tasks and the potential for injuries, the mine has established a dedicated training location for a new operator and low performance operator at Panel 35 West area aimed at enhancing LHD operators' skills. This initiative is pivotal in ensuring operators are well-versed in both the technical operation of LHD and the critical operational procedure and risk management strategies pertinent to their roles.

In an effort to enhance operator involvement in safety protocols, a High Impact Targeted Training (HITT) workshop was implemented. This program was designed to encourage operators to not only recognize and articulate potential hazards but also to actively participate in the development of mitigative measures during the mucking process using LHD. Figure 6 presents a Pareto chart detailing the top five sub-system failures of the LHD 1700K model for the year 2021, highlighting the areas with the highest incidence of reported issues. The HITT program specifically addresses these common failure points, offering best practice solutions to mitigate the identified operational risks.

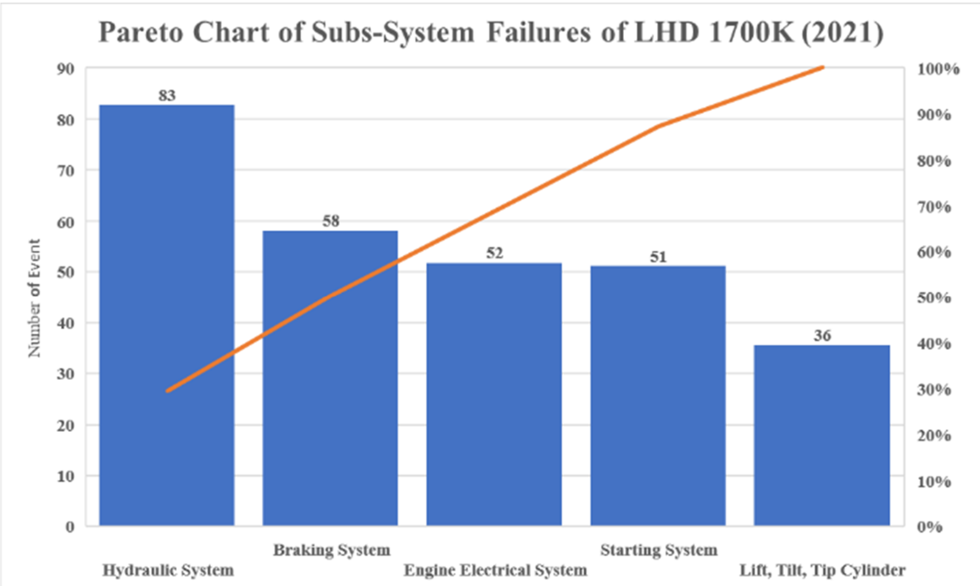

Figure 6 Pareto chart of sub-system failures of LHDs.

Additionally, supervisory staff conduct regular planned job observation during shifts to evaluate and ensure operators' adherence to established operation as per standard operating procedure.

3 EXTRACTION OPERATIONS PRODUCTIVITY

Productivity within block cave mining operations, such as those conducted at the GBC mine, is primarily evaluated through the metrics of production tonnage and the availability of drawpoints for extraction (Power, 2021; Paravarzar et al., 2021).

Efficiently managing over thirty-five LHDs in the GBC mine's extraction area, including both manual and Minegem units, demands rigorous planning to ensure each is correctly allocated to its designated panel. GBC mine has implemented a multifaceted strategy to elevate productivity and production levels through draw order strategy, LHD-panel arrangement, wetmuck management, operator assignment and scorecard, panel standardization, lintel set redesign aimed at refining operational efficiency.

3.1 Draw Order Strategy

At the inception of the cave management plan, an even draw strategy was employed across a 250-meter column height to minimize dilution and ensure the maximization of reserve recovery. As the mining operation progressed and the cave matured, a transition to a "best height of draw" strategy was adopted. This nuanced approach entails drawing each column in proportion to the remaining ore above the drawpoint, thereby optimizing the recovery process.

The formulation of a draw order is crucial for guiding LHD operators towards maintaining a uniform cave health, enhancing productivity, and ensuring production output optimization. Such a strategy is intricately designed, taking into consideration various factors including ore grade, proximity to extraction points, and equipment availability. This enables operators to prioritize tasks effectively, focusing on high-grade ore zones or areas proximal to extraction points.

Production engineering generates a draw order composed of three distinct elements: the primary order, the extra order, and the cross-shift order as shown in Figure 7. The primary order delineates the baseline tonnage target for mucking within the standard shift duration. The extra order serves as a contingency plan to address potential disruptions such as drawpoint hang-ups, rock breaker malfunctions, and drainage issues that might arise during the same shift. Finally, the cross-shift order sets additional targets to bolster LHD operations in the interlude between shifts, specifically aimed at addressing drawpoints that are falling short of the month-to-date production goals. These three stages of the draw order are designed to maintain constant mucking activity, thereby maximizing the performance of the LHD operators throughout their shifts.

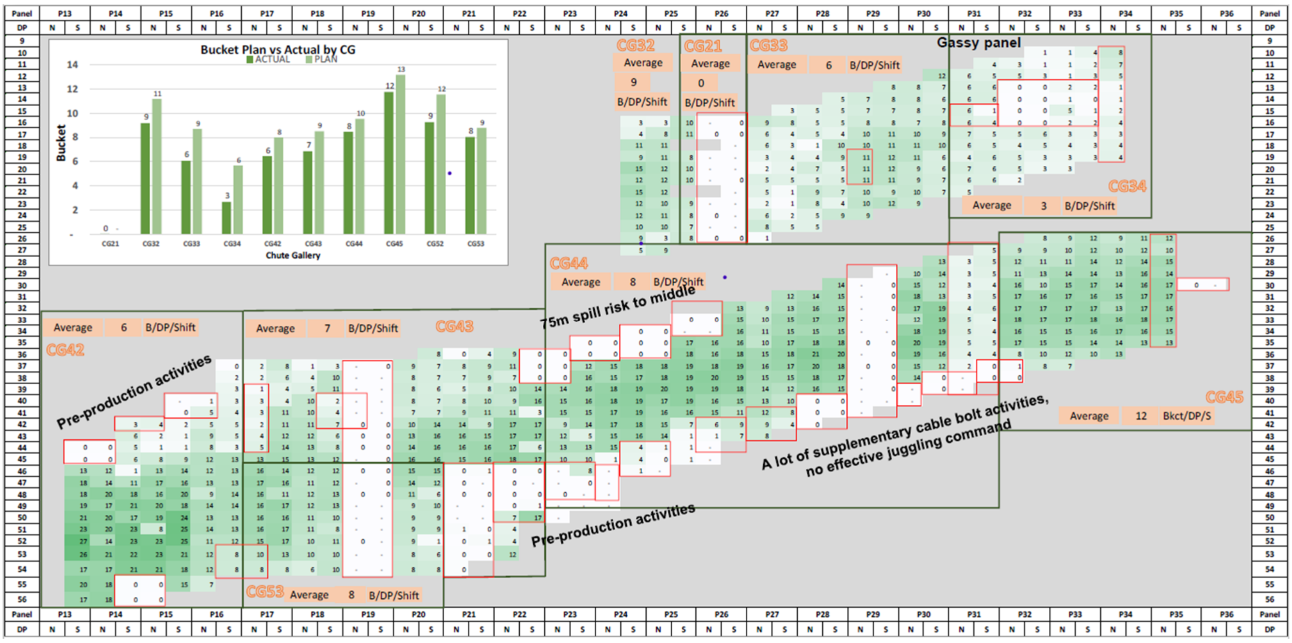

Figure 7 Typical draw order arrangement.

3.2 LHD-Panel Arrangement

The GBC mine's extraction level is strategically divided into east and west sections, each facilitated by two grizzly tips and designed to support efficient LHD operation and panel access. This division allows for simultaneous activities in each panel section with minimal interference, thereby streamlining the workflow and reducing operational delays.

The allocation and distribution of LHDs are critical elements that influence operator productivity within block cave mining environments. Operational planning for productive panels is conducted 12 hours in advance of a shift, taking into account variables such as necessary repairs (e.g., rock breakers, mine services, drain covers), scheduled preventative maintenance (PM), and chute inaccessibility, which may result in panel downtime.

Consequently, the draw order is adjusted - either reduced to zero or closed temporary (CT) - for panels undergoing maintenance or that are otherwise inoperative. LHD assignments are determined by a range of factors, including panel availability, draw order volume, ventilation requirements, the number of grizzlies, and the physical condition of each LHD unit. To reduce delays and enhance safety, LHDs remain in their assigned panels across shifts, except when blasting requires their removal.

3.3 Wet muck Management

As of December 2023, GBC has 84 drawpoints considered as a wet muck drawpoints. During its operation, the wet muck hazard and the consequent management approach has evolved. Spills have become more frequent and very large spills, although rare, have begun to occur as the draw columns have matured. In addition, the location of inrushes has expanded from the production footprint to the haulage level. The mine has adapted to these changes by increasing the number of tasks completed remotely, developing spill hazard assessment criteria, increasing the pedestrian free areas and stand-off distances as well as pursuing an active blending strategy.

As a result of these changes, the mine has evolved as a prototype for an underground autonomous caving operation. This prototype has allowed PTFI to implement operating autonomous, remote and manual operations seamlessly within the same Autonomous Mining Area (AMA) that is managed from a single Remote Operating Room (ROR) on the surface, in the main office building..

The GBC began experiencing wet muck in drawpoints while still constructing new drawpoints as part of the panel cave development. This provided the flexibility to produce from the new coarse and dry material in preference to the wet material. It also allowed the wet drawpoint to be managed and drawn while blending and still maintain sufficient inventory of drawpoints to achieve the mining plan. The first wet drawpoint appeared in June 2020 and evolving to 85 drawpoints by the end of 2023, the GBC drawpoint composition class is shown in Figure 8.

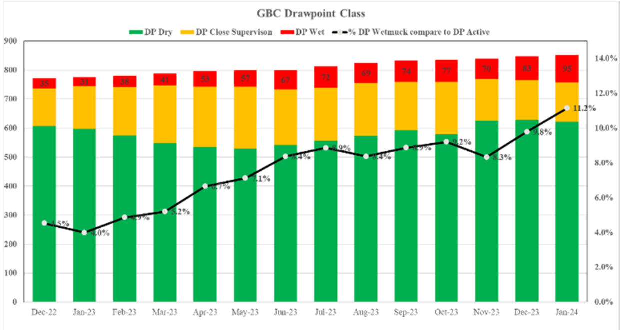

Figure 8 GBC drawpoint class - December 2023.

PTFI has established a Safe Operating Procedure (SOP) for extracting wet muck, which seeks to prevent people exposure from working or travelling in an area with a spill risk. This is achieved through a combination of Minegem LHD, time-based and distance-based exclusions.

Balancing Minegem operations and manual operations is a key to achieving high productivity operations. Figure 9 presents a comparative of the average daily tonnage handled by manual and Minegem-operated LHD. The data shows trends and fluctuations in the operational efficiency of both LHD systems. The graph depicts a significant increase in tonnage moved by Minegem LHDs over the course of the year, suggesting an enhancement in the automated system's productivity. Concurrently, the manual LHDs show a steady contribution to the total tonnage, with occasional peaks that correspond to strategic operational adjustments.

Achieving this balance involves several key measures:

1. The prompt establishment of Minegem systems by a setup crew.
2. The utilization of a copilot system for Minegem LHDs to enhance operational precision.
3. The deployment of a rapid response team for maintenance and service repairs.
4. Efficient management of water drainage within the mine.

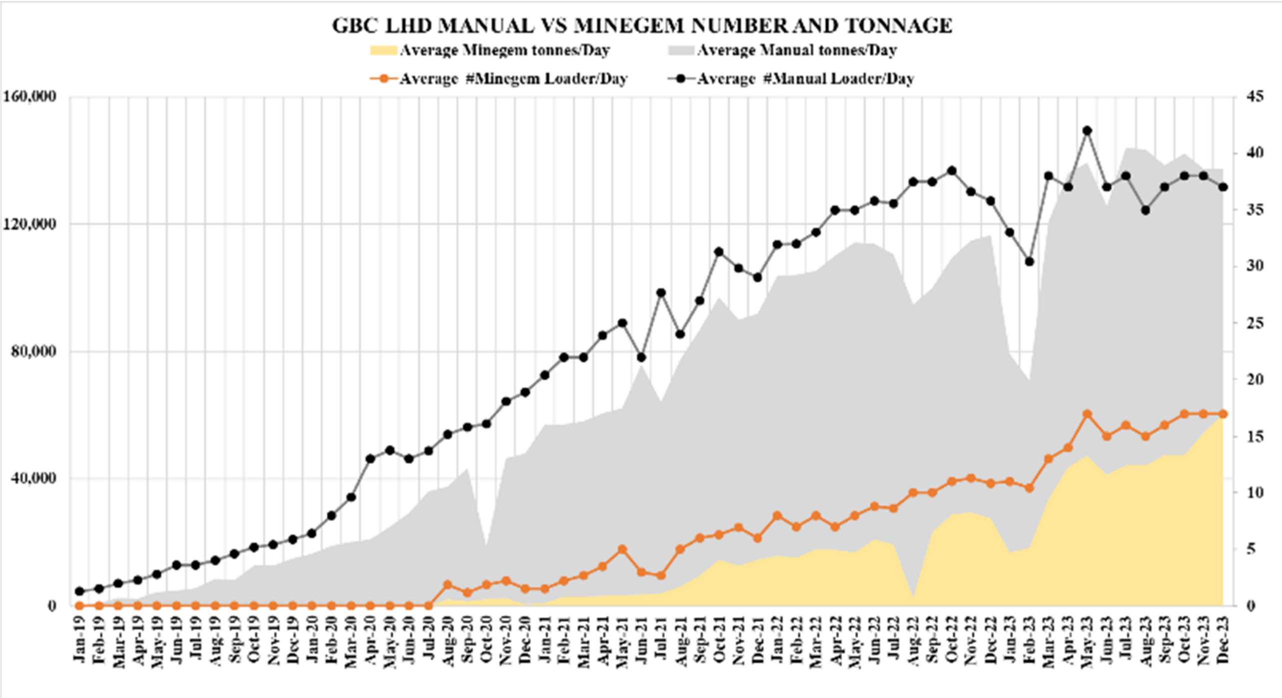

Figure 9 Tonnage and LHD comparison.

3.4 Operator Assignment and Scorecard

To ensure optimal operator productivity, GBC employs a strategic approach to operator assignment and utilizes a scorecard system for performance evaluation. Operators are assigned to specific areas or panels based on their skills, experience, and knowledge of the geology and extraction processes in that particular area. This allows operators to become experts in their assigned areas, resulting in increased efficiency and productivity. Additionally, GBC mine continually monitors operator performance through the scorecard system for both manual and Minegem operator.

This scorecard system evaluates various metrics such as production output, equipment utilization, safety compliance, and adherence to production schedules. By utilizing this scorecard system, GBC mine can identify areas for improvement and provide targeted training and support to operators.

The utilization of the Underground Operations Management System (UOMS) facilitates the real-time monitoring of operator productivity. This live data stream is critical in ensuring that operator assignments are strategically aligned with throughput per hour (TPH) performance in relation to the total draw order. Daily shift panel assignments for the LHD operators are thus informed by this data, allowing for an adaptive and responsive approach to operational demands.

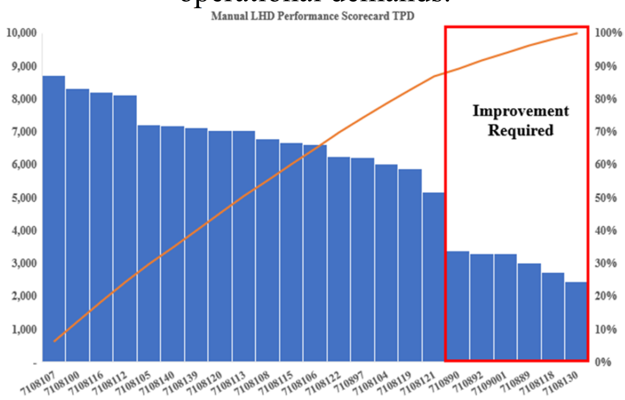

Figure 10 Manual LHD performance scorecard.

Current efforts are underway to refine the precision of this real-time data, with a particular focus on enhancing the service installation of panel instrumentation.

3.5 Panel Standardization

Panel standardization is another key aspect of GBC mine's approach to safe and sustainable production in the block caving operation. This involves maintaining uniform panel sizes, services, and layouts to streamline operations and ensure consistency throughout the mine.

For the LHD units, both manual and Minegem, to operate optimally, comprehensive scheduling of panel standardization activities is imperative. Panel standardization is divided into two temporal categories: short-term daily preventive maintenance (PM) and long-term uniformity maintenance.

The short-term PM for each panel is meticulously planned to facilitate expedient repairs, accommodating services such as water pipe and electrical cable maintenance, cleaning of the pedestal grizzly, routine rock breaker maintenance, and other critical repairs that can be completed within a six-hour window.

Long-term panel standardization is oriented towards maintaining the uniformity of panel configurations. Given the complexity of such projects, completion is projected to span ten weeks. The panel reliability program includes a comprehensive set of activities ground rehabilitation by jumbo drilling for bolt mesh, resin bolt, and cable bolting for additional ground support; civil works for floor, hanging brow, drain hole, and grizzly maintenance; equipment and camera repairs conducted by the auto electrical crew; general services maintenance; and geotechnical monitoring, including cave scanning by geoservices, and secondary breakage activities to remove any protruding steel along the panel.

These activities are diligently tracked and monitored to ensure adherence to the project timeline, with adjustments made as necessary to mitigate delays. Figure 11 presents the current status and progress tracking of panel standardization initiatives as managed by production field engineers.

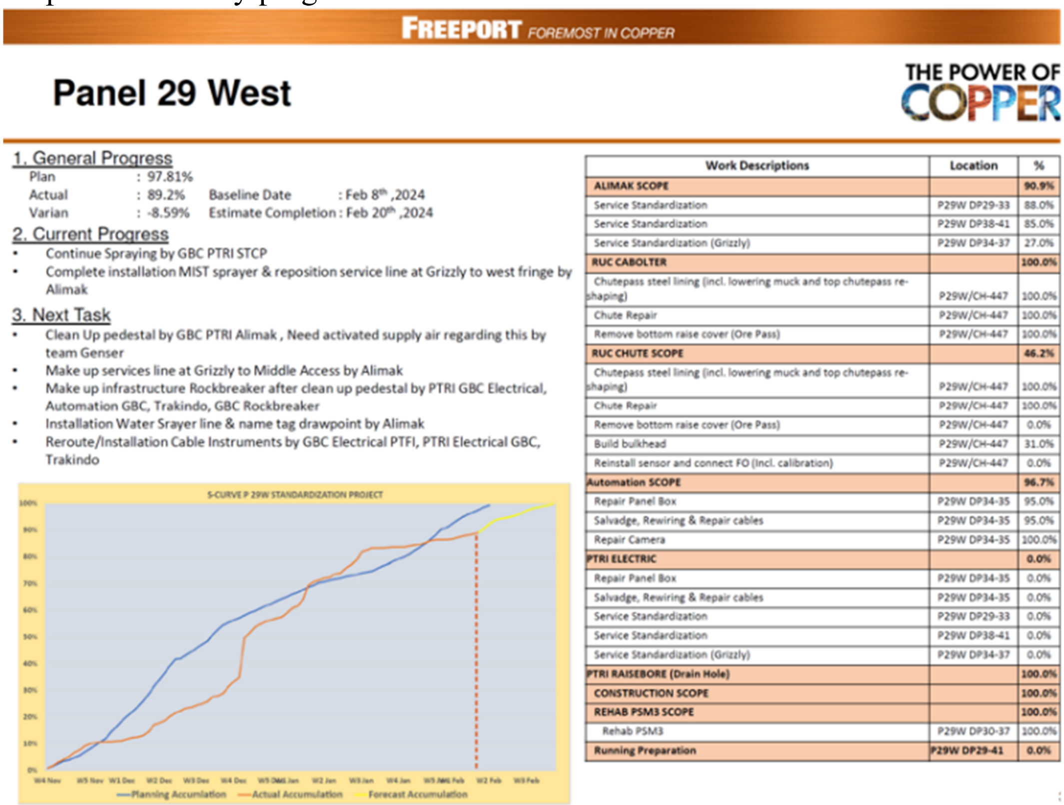

Figure 11 Panel standardization progress.

3.6 Lintel Set Re-design

A review of the key problem areas was undertaken in the GBC, and the drawpoint design and construction was identified as an area that could be improved. The lintel sets were redesigned by the onsite central engineering group and were fabricated in the operations Light Industrial Park (LIP) rather than being built as required by the underground shops. Figure 12 shows a comparison of the other type lintel set on site and GBC mine standard hanging brow type of lintel set designs.

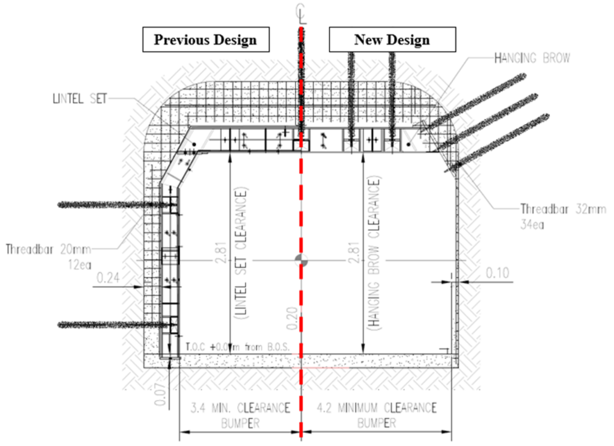

Figure 12 GBC lintel set and hanging brow comparison.

This design change will create a wider drawpoint opening up to 4.2m clearance allow for efficient and effective operation of the larger 1700K production loader. If the hanging brow is damaged due to convergence in the drawpoint, wear due to muck flow, hang-up blasting, or other sources of potential damage, the effort required to safely rehabilitate the brow is expected to be less than that required for the steel lintel set due to the simpler nature of the design and lower quantity of material used.

4 SECONDARY BREAKAGE STRATEGY

At production start-up, the main secondary breakage practices utilized for the GBC drawpoint oversize were concussion bombing and drilling of accessible boulders with Secondary Breakage Unit (SBU).

Although production met the feasibility targets, the ability of the secondary breakage workforce to effectively handle drawbell hang-ups and to size large blocks of ore was impacting the drawpoint availability and interfering with mucking operations. Packing of fine-grained, clay-bearing material within the drawbells was also experienced for one rock type.

4.1 Panel sequence/schedule for secondary blast

GBC's secondary breakage team is comprised of two units specializing in drill and blast operations for boulder fragmentation, two water cannon units for addressing low hang-ups, and three mobile rock breakers (MRB) for quicker and more substantial breakage tasks. A critical aspect of enhancing the secondary breakage process involves a strategic analysis that informs decision-making within the operational constraints. The planning phase for secondary breakage takes into account several key parameters:

- Which type of hang-up can be effectively treated with the different options available.
- Scheduling of secondary blasts.
- Determination of the number of drawpoints to be closed for blasting operations.
- Allocation of drilling crews based on operational needs.
- Evaluation of drawpoint availability for continued mining activities.

In considering the number of secondary breakage crews required to work in parallel with the LHD fleet, the principal variables that govern this decision might include:

- Type of hang-up and treatment desired.
- Cave health and draw compliance.
- Maximizing drawpoint availability.
- Drilling, blasting, ventilation time.
- Probability of oversize blocking the drawpoint.
- Tons between secondary breakage (TBSB).
- Accessibility issues regarding wet or gassy panel conditions.

The operational strategy to optimize secondary breakage involves staggered shifts for the breakage crew, ensuring sufficient time for safe re-entry into blasted areas and subsequent mucking activities. This staggered timing minimizes drawpoint hang-ups and maximizes the availability of drawpoints for production.

Figure 13 illustrates the Secondary Breakage Performance, delineating the actual versus planned blasting activities, the involvement of SBU drills, and the use of water cannons. It reflects the efficacy of the secondary breakage strategy over time, particularly in managing wet panels through a remote infrastructure system.

The figure indicates the operational interplay between MRBs, water cannons, and the control console in the execution of secondary breakage tasks.

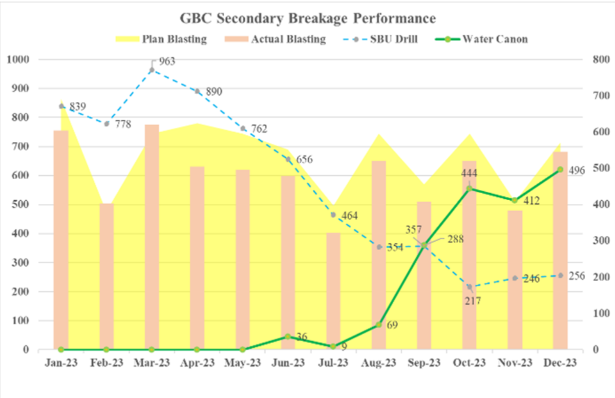

Figure 13 Secondary breakage performance.

Figure 14 outlines the Workflow Treatment for Hang-Ups at the Minegem Panel. It provides a visual representation of the procedural steps taken from the initial identification of a hang-up to its resolution. The workflow begins with LHD operators reporting hang-ups, which then triggers a series of strategic decisions and actions across different departments - ranging from on-site inspection by engineers to the deployment of water cannons or mobile rock breakers as needed.

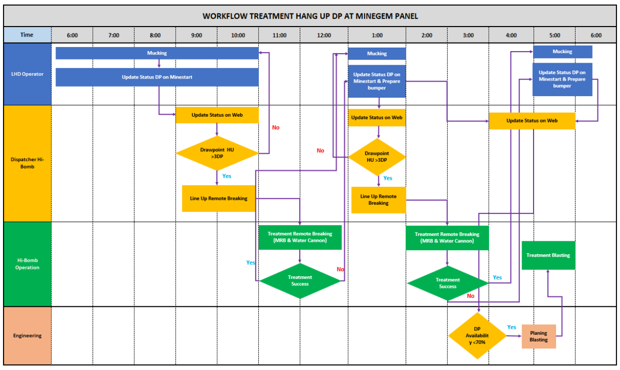

Figure 14 Secondary breakage workflow.

4.2 *Real-time information to optimize the secondary breakage process*

The utilization of real-time information is instrumental in optimizing the secondary breakage process. By employing the fleet onboarding VPC system optimally, LHD operators can accurately identify hang-up occurrences real time during mucking operations as shown on Figure 15. This allows for immediate verification by the secondary breakage crew through surveys, reducing delays across multiple panels. The immediate action by MRB and water cannon teams on identified hang-ups or boulders streamlines the secondary breakage process, enhancing overall operational efficiency.

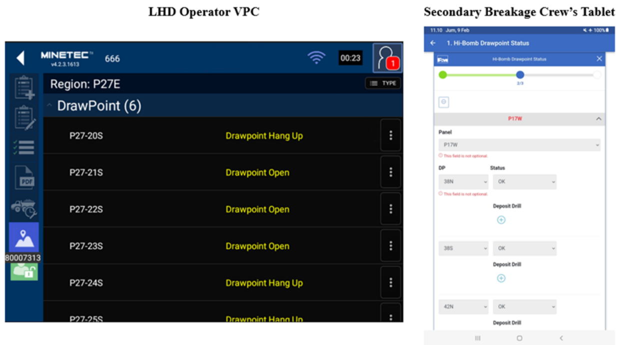

Figure 15 Fleet onboarding VPC system and secondary breakage crew information.

5 KEY PRICIPLES FOR PRODUCTION SUSTAINABILITY

The cornerstone of a successful ramp up and maintaining sustainable production at GBC mine is the principle that values the workforce above all. This collective effort involves operators, maintenance, supervisors, and management, all committed to creating a safe and communicative environment. Adopting a culture of continuous improvement and regular refinement of safe production practice is central to this commitment. The strategy is straightforward: equip every team member with the necessary training and support, ensuring their readiness to contribute to the mine's enduring production and safety standards.

Dedication to systematic planning and adaptability is the second principle approach to sustain with ramp up production output. Adjustments to the draw order, informed by real-time insights into equipment availability and panel conditions, have yielded significant enhancements in mucking efficiency. This flexible strategy is regularly updated to meet the ever-changing demands of the mine, utilizing a thoughtful approach that leverages basic elements influencing production.

The third key principle, drawn from lessons learned, is the value of interdepartmental collaboration, especially when addressing operational challenges like hang-ups. Immediate involvement of all relevant departments upon detection of an issue is critical for a quick and coordinated resolution, minimizing the risk of extended production halts. This collaborative approach simplifies complex problems by focusing on the basics: clear communication, prompt action, and continuous feedback, leading to an effective and timely resolution.

One view that is generally accepted is that ‘you can’t manage what you don’t measure’. Incremental improvements, although seemingly minor when viewed in isolation, have collectively led to a substantial increase in the GBC mine's daily production rates. A notable improvement, initiated in mid-2023, involved reducing the blasting window time for footprint development, caving, and secondary breakage from two hours per shift to merely 45 minutes, immediately recapturing more than an hour per shift. Additionally, a review of safety protocols has allowed LHD operators to continue mucking in unaffected panels, rather than halting operations during blasting activities.

Further contributing to this efficiency is the practice of cross-shift mucking, where secondary breakage crews, upon securing their areas, operate an LHD to maintain production until the next shift begins. Complementing this, the introduction of an auto wash system for LHDs before daily servicing has replaced the less efficient manual washing process, streamlining maintenance and reducing downtime.

6 CONCLUSION

The initiation of caving and production startup has been achieved successfully in the first three production blocks. As the footprint expands, the complexity of the operation also will grow for planning and executing the increasing scale of the drawbelling and production activities.

A principal challenge is the ongoing development and enhancement of production infrastructure, including managing water inrush risk, to adapt rapidly to evolving cave fronts across production blocks. In this dynamic environment, there will undoubtedly be lessons learned to be recognized and managed in the ongoing journey toward operational excellence to achieve the largest world-class safe production.

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REFERENCES

Brannon, C., Beard, D., Pascoe, N., & Priatna, A. (2020). Development of and production update for the Grasberg Block Cave mine – PT Freeport Indonesia. MassMin 2020: Proceedings of the Eighth International Conference & Exhibition on Mass Mining. https://doi.org/10.36487/acg_repo/2063_51.

Paravarzar, S., Askari-Nasab, H., Pourrahimian, Y. & Emery, X. (2021). Simultaneous multi-sector block cave mine production scheduling considering operational uncertainties. *Mining Technology*, 130(1), 36–51. https://doi.org/10.1080/25726668.2021.1872261

Power, G. (2021). An analysis of productivity in sublevel caving mines. UG Operator Conference 2021. AusIMM. Perth, WA, (pg. 510-516). https://www.ausimm.com/globalassets/pdf-files/publications/1-21_ugops/1-21_g-r-power.pdf.