

Lessons learned from remote LHD mucking and panel reliability program integration of the Grasberg block cave mine

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ABSTRACT

Grasberg Block Cave Mine (GBC) commenced its production phase at the end of 2018. By the fourth quarter of 2023, GBC produced average of 133K dry metric tonnes per day (dmtpd), accommodating 10% of total active draw points categorized as wet draw points. Historical data indicates an increasing number of wet draw points, with a wider distribution over time. To mitigate risks associated with these wet draw points, the implementation of remote Load-Haul-Dump (LHD) technology has been extensively applied with several key success. This paper presents lessons learned from the strategy on how the wet draw points in GBC are mucked using remote LHD integrated with the panel reliability program. Based on the number and locations of wet draw points, GBC panels are classified into three categories: *manual LHD dedicated panels*, *remote LHD dedicated panels*, and *alternating panels*, which refer to wet panels that are mucked using a combination of both remote and manual LHD according to a predetermined shifting schedule. To optimize the sustainability of ore reserve extraction, panel reliability program is implemented, that consists of panel maintenance to ensure the good condition of panel infrastructures & draw point availability, geotechnical monitoring that plays a crucial role in managing GBC's ground stability and panel refinement as curative action to repair and improve the performance of the panels. A schedule of wet panel production integrated with the panel reliability program is created as guidance for entire GBC production parties to achieve the production target safely and sustainably.

1 INTRODUCTION

1.1 Grasberg Block Cave Mine Profile

The Grasberg Block Cave (GBC) Mine has been developed beneath the Grasberg open pit mine, as illustrated in Figure 1. Initial access drifting for the GBC Mine was initiated in 2004, with undercut blasting starting in September 2018, followed by draw point blasting in December 2018 (Brannon et al., 2020). Haulage operations at GBC are carried out using a Loco and Wagon configuration to transport the muck from the chute, which is dumped by the Load-Haul-Dump (LHD) equipment, to the ore bin before being conveyed to the crusher. Subsequently, the crushed material is transported via a conveyor to the stockpile, where it undergoes processing in the concentrating facilities.

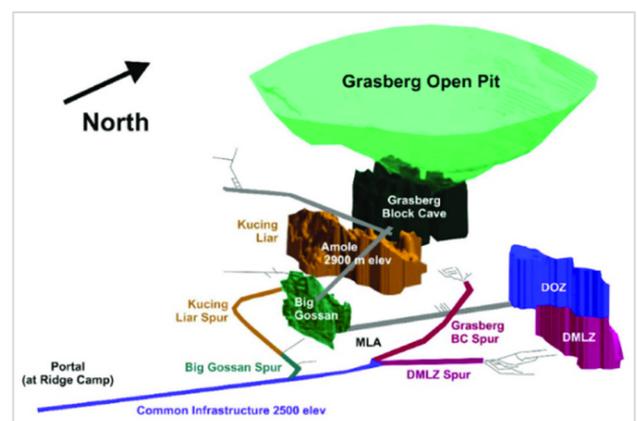


Figure 1 Grasberg Block Cave Mine.

The Grasberg mine complex has experienced high rainfall intensity, leading to the formation of wet draw points on the GBC extraction level due to the presence of fine material. This has necessitated the use of specific treatment

methods, which have ultimately impacted production flexibility in the GBC extraction level due to the spillage risk. Remote LHD technology has been increasingly utilized alongside manual LHD operations in GBC.

The first emergence of wet draw point was noted in the second quarter of 2020, with the number of wet draw points rising to 83 by the fourth quarter of 2023, approximately 10% of the total active draw points in the GBC extraction level footprint, as illustrated in Figure 2.

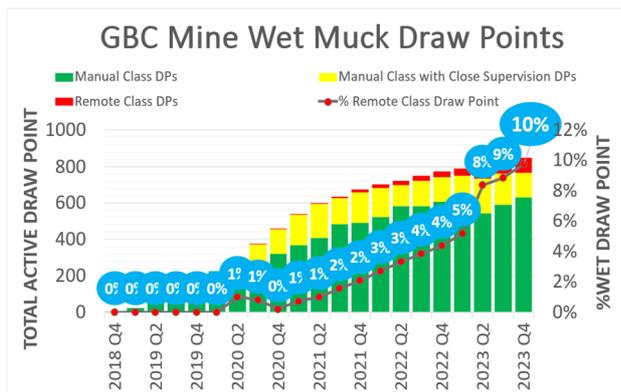


Figure 2 Quarterly Wet Draw Point Increment on GBC Mine.

1.2 Draw Point Classification

The draw point classification utilized in GBC Mine, which was adopted from Deep Ore Zone (DOZ) Mine, involves categorizing the material size into alphabetical groups (A, B, and C) and indicating the water concentration through number codes (1, 2, and 3) as shown in Figure 3. The classification of wet draw points is greatly influenced by the interaction between the material size and the water content (Edgar et. al. 2020).

Level of Wetness (Water Content)	Material Size > 5 cm (M)		
	M > 70% (domintaed by coarse material)	30% < M < 70% (mixture of coarse and fine/medium material)	M < 30% (domintaed by fine material)
Dry (< 8.5%)	A1	B1	C1
Moist - No Flowing Water (8.5 to 11%)	A2	B2	C2
Wet - Saturated with/without flowing water >0.5 gpm (> 11%)	A3	B3	C3

Figure 3 Draw Point Class Matrix.

Based on the feasibility of mucking by using either Manual LHD or Remote LHD, GBC draw points are classified as *manual class draw point*

(green and yellow) and the *remote class draw point* (red) or can be called as wet draw point. The draw point inspection is conducted twice a week to keep the draw point class up to date, involves department of Hydrology, Geology, Geotech, Operation, Engineering, and Safety with their own specific role. Once a week, a meeting is held by the wet muck committee to review the updated draw point class and discuss strategic plans related to wet draw point production.

1.3 Wet Draw Point General Protocol

Wet draw point impacts two adjacent draw points within its own panel, as well as three draw points in the neighboring panel that share the same minor pillar (*influenced draw points*) as illustrated in Figure 4. To prevent any potential slide or spillage event of wet muck material from the wet draw point, the GBC Wet Muck Committee has established a 12-hour idle protocol. This protocol requires that no mucking activity take place on the wet draw point and its five surrounding influenced draw points 12-hour prior and while accessing the wet panel.

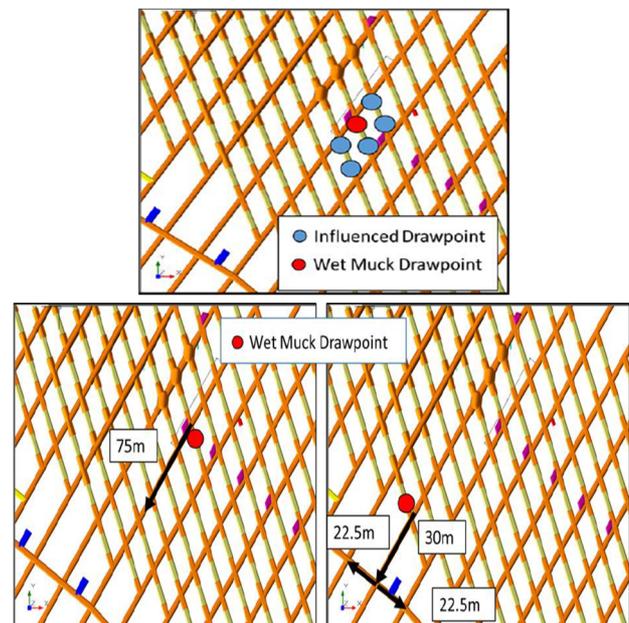


Figure 4 Wet Influenced Draw Points and Safety Distance.

To ensure safety for all individual working on wet panels, all activities near the wet panels (panel containing wet muck draw point) must be limited to a minimum distance of 75 meters from

the wet draw point, which is currently being mucked as illustrated in Figure 4. The GBC Wet Muck Committee has established this distance based on historical spill data, considering it to be the maximum distance a spill could potentially reach.

2 WET DRAW POINT OPERATIONAL CHALLENGES AND SUCCESS STORY

The wet draw point on GBC is typically situated at the periphery of the cave boundaries, formed when water from the cave boundary mixes with the fine material. There is also a wet draw point located in the middle of the panel, the interaction between the *soft zone* material type, which is predominantly composed of fine material, and water, see Figure 6 below.

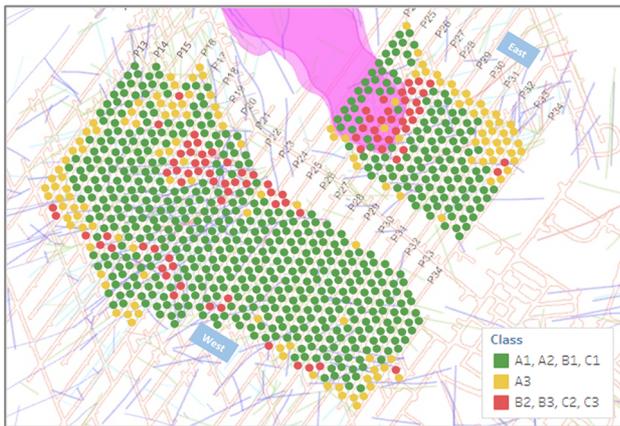


Figure 6 Actual Wet Draw Point in GBC Q4 2023.

2.1 Wet Muck Spillage Risk to Haulage Level

To mitigate risk of spillage material entering the ore pass and the haulage level, GBC muck blending is implemented after several trial and improvements. 1 bucket wet muck from B2 and B3 class draw points must be dumped and blended with 2 buckets of manual class draw point muck. As for the wet draw point of C2 and C3 class, 1 bucket must be dumped and blended with 7 buckets of muck from the manual class draw point. The specific system has been developed to remind the operator if there is any violation in bucket blending.

2.2 Interaction between Wet Production and Pre-production Activities

GBC implement *deferred stubbing* method (part of *advanced-undercutting* method) with the purpose to mitigate the adverse impact of abutment stress on the *veranda* of the cave. This approach ensures that the pre-production activities, encompassing tunnel development, ground support, construction, and draw bell blasting activities are conducted after the undercutting process above the extraction level has passed. These pre-production activities occur precisely at the edge of the active draw points on extraction level, where some of the wet draw points are situated as shown in Figure 7.

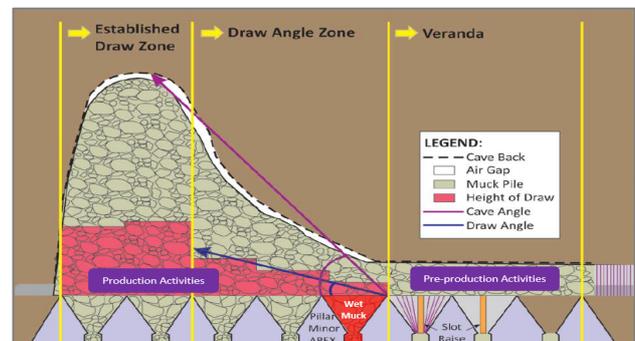


Figure 7 Interaction of Wet Draw Point and Pre-production Activities.

The personnel engaged in the pre-production area are at risk of being exposed to spillage from the wet draw points. Portable *geobrugg* or muck bumper with dimensions of 4m width, 7m length, and 3m height is installed to provide protection and reduce the 75m safe distance protocol of wet draw point. The intensity and forces of muck spillage can fluctuate depending on factors such as the mineral composition of the muck, the fragmentation, and the volume of water involved. Portable *geobrugg* and muck bumper have scientifically determined can withstand the force of the wet muck spillage rush as shown in Figure 8. The *geobrugg* is also installed on the top vent raise (intake or exhaust) to prevent the spillage material entering the service level.

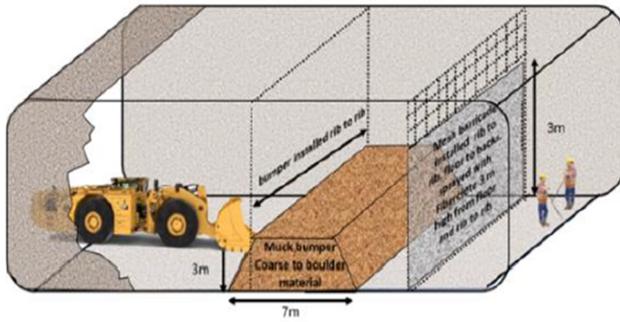


Figure 8 Muck Bumper and Portable Geobrug.

2.3 Lower Remote Productivity and Utilization Feasibility compared to Manual LHD

Ongoing improvements are being made to enhance the copilot and autopilot functionality of GBC's remote LHD. This will enable the LHD to semi-autonomously transport and unload on the grizzly after excavating on the draw point at an optimal speed. This progress in autopilot technology will diminish the requirement for multiple remote LHD operators, as a single operator will be capable of managing two LHD consoles concurrently.

Two remote LHDs have been successfully assigned in a single panel that has led to an increase in panel tonnage productivity. This advancement ensures a consistent filling of the ore pass, resulting in more efficient operations. Moreover, the blending of wet material is made easier with the use of two remote LHDs in a single wet panel. The enhancement of the remote environment has been effectively implemented, allowing the remote *mobile rock breaker & water cannon* to work in conjunction with the remote LHD mucking process.

2.4 Diverse People Skill & High People Exposure towards Wet Production

The evaluation of the operator's performance while working is consistently monitored using *scorecards*. The performance of remote operations in each of the three crews is assessed and compared, enable the underperforming crew to continuously enhance their skills by learning from the high-performing crew, thus romoting a culture of continuous improvement. Ongoing training is provided to operators with lower skill levels to enhance their capabilities.

To minimize the draw point inspector's exposure to wet draw points, an alternative approach involves conducting inspections remotely using a LHD camera on remote LHD consoles is implemented. Furthermore, the possibility of utilizing drones for inspections has been explored and is currently under review for potential continuous implementation.

2.5 Low Wet Panel Visibility for Remote Operation

The effectiveness of remote LHD operations in GBC is heavily influenced by the quality of ventilation. The airflow has been meticulously adjusted to cater to the specific requirements of remote LHD activities. However, the presence of dust has emerged as a new obstacle. The excessive accumulation of dust on the remote panels obstructs the visibility of remote operators and contributes to an escalation in engine overheating problems for remote LHDs. To address the issue of dust concentration on the panels, a chemical product is utilized on the GBC floor and ribs to capture airborne dust particles within the panels. Additionally, water mist and water sprayer systems have been installed in various areas of the GBC panels.

3 INTEGRATED SCHEDULE OF REMOTE LHD AND PANEL RELIABILITY PROGRAM

3.1 Panel Categorization

The problem of wet draw point spreading on GBC panels was resolved through the transformation of manual LHDs into remote LHDs. However, the swift expansion of dry panel into wet panel consistently surpassed the quantity of remote LHDs available on GBC, as depicted in Figure 9.

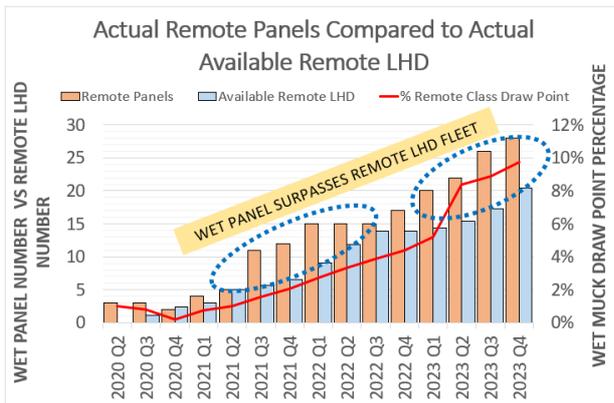


Figure 9 Remote Panel vs Available Remote LHD Trend.

GBC panels that lack any wet or influenced draw points are considered *manual LHD dedicated panels*. Conversely, panels with a minimal number of wet and influenced draw points and insignificant operational issues are labeled as *alternating panels*. Panels with numerous wet and influenced draw points and higher operational constraints fall under the category of *remote LHD dedicated panels*. Table 1 below illustrates the classification of panels and the quantity of each type based on the status of wet draw points during end of fourth quarter of 2023.

Table 1 Panel Categorization

Panel Categorization	Total
<i>Remote LHD Dedicated Panels</i>	16
<i>Manual LHD Dedicated Panels</i>	8
<i>Alternating Panels</i>	10

A comprehensive checklist must be completed when transitioning the LHD from remote to manual on *alternating panels*. During the

production cycle, the panels listed in Table 1 will undergo panel reliability program as per the integrated schedules outlined in the subsequent chapter.

3.2 Panel reliability Program

The primary objective of the panel reliability program is to ensure that the GBC panels remain in optimal condition to facilitate safe and sustainable production. A target for panel and draw point availability is set to control the number of panels and draw points that can be taken out of operation, considering the cave production and equipment capacity in line with the forecasted tonnage target.

In the fourth quarter of 2023, 5 panels will be allowed to be down during each shift for reliability programs, with 2 panels earmarked for major repair and standardization, another 2 panels allocated for minor repair, and 1 panel reserved for secondary breakage and daily panel preventive maintenance (PM) activities. The panel reliability program for wet panels necessitates a 12-hour idle protocol. Any work conducted for more than 12 hours within a 75 m safe distance of wet draw points requires shotcrete to be applied on the wet draw point.

3.2.1 Panel and Draw Point Maintenance

Daily Check and Panel Preventive Maintenance (PM) are conducted to ensure the smooth functioning of panel infrastructures including the rock breakers, chutes, pipe services, draw point water sprayers, grizzly cameras, and remote infrastructures etc. The maximum time allocated for each PM panel implementation is 6 hours.

To enhance the availability of draw points, secondary breaking activities are carried out. These activities involve conventional breaking using manual or remote *mobile rock breaker* and *water cannon*, as well as blasting activity. The secondary breaking activity schedule is determined by analyzing the historical data of *Tons between Secondary Breakage (TBSB)* as calculated in Equation 1. This data provides an average estimation of the number of tons that

can be extracted from a single draw point after the successful implementation of secondary breaking activity (SB Event), until the draw point becomes hang-up for the second time.

$$TBSB = \frac{Tons_{Total}}{SB\ Event_{Total}} \quad (1)$$

The material type and the maturity of the cave are the main determinants that have a substantial impact on TBSB. These factors play a crucial role in defining the fragmentation of the material at draw points. The TBSB number is utilized to forecast the occurrence of draw point hang ups, and it aids in estimating the schedule for hang up treatment. A lower TBSB value suggests a greater frequency of secondary breaking activity that is required.

3.2.2 Panel Monitoring

Panel monitoring activity carried out by the GBC Geotechnical Monitoring group aimed to assess the effects of abutment stress on the cave boundary and the potential displacement of under-cave panels. It is crucial to distinguish whether any damage or displacement observed is a result of the ground forces or the equipment impact. As a result of the recommendations from this monitoring activity, supplementary ground support and several ground rehabs are installed to enhance ground stability.

The GBC mine diligently monitors seismic events to ensure that all stakeholders are kept informed about the associated risks. In order to gain a deeper understanding of cave formations, the Geotech group conducts cave propagation modeling. This modeling process is supported by the installation of beacons, which aid in tracking and modeling movements within the cave system. Stakeholders of the GBC Mine should also be informed about the connection between the cave and the bottom pit of the Grasberg mine. A notification system for rainfall rates in the open pit has been established to alert stakeholders to the high potential for massive spillage risk from the wet draw point on the GBC extraction level while the rainfall rate is high.

3.2.3 Panel Refinement

Panel refinement refers to the process of enhancing and rectifying the infrastructure and environments of panels in response to any issues that cannot be resolved within a single shift. Minor repairs involve simple tasks that can be accomplished within a shorter timeframe, such as repairing the floor, fixing the lintel/brow steel set, addressing panel services, repairing the rock breaker, repairing the cover of drain holes, fixing the top frame grizzly, repairing or repositioning remote LHD infrastructures, and providing supplementary ground support. On the other hand, major repair panels require intricate procedures and a longer duration for completion, such as significant tunnel rehabilitation, lining ore-pass or chute-pass, and standardizing panels.

Panel Standardization is an ongoing process aimed at refining the single panel to ensure an optimal environment for remote LHD operations. Through this process, historical data has demonstrated a noteworthy increase in productivity, for remote LHDs operating on standardized panels. An illustration of this productivity enhancement can be observed in the case of Panel 30 West, where panel standardization was implemented as shown on Figure 10 below.

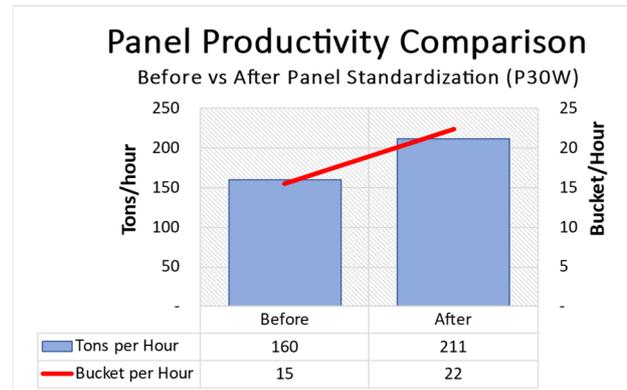


Figure 10 Productivity Remote LHD before vs after Panel Standardization.

3.3 Integrated Schedule

To foster effective communication among the stakeholders engaged in GBC Production, an integrated schedule has been devised for the mucking operation of remote LHD, manual LHD, and panel reliability program during every shift of production. The overall procedure for

preparing the integrated schedule is depicted in Figure 11 below.

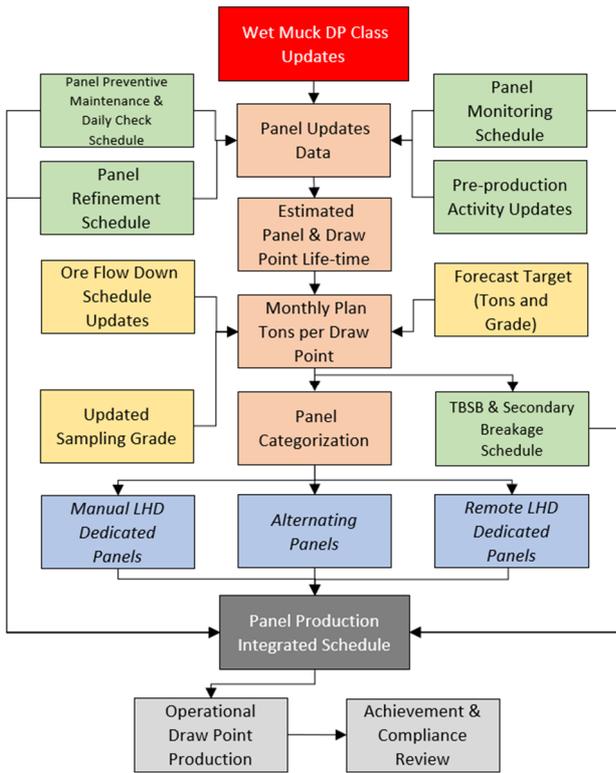


Figure 11 Integrated Schedule Preparation Flow Chart.

The integrated schedule is prepared in accordance with the monthly production plan preparation. The most recent inspection data of draw point class is used to update the actual quantity and position of both remote and manual class draw points. By working together with the operations, mechanics, electric, and automation team, a timetable is established for daily inspections and panel preventive maintenance (PM) tasks.

The schedule for panel refinement activities is formulated based on the severity of panel backlogs database. Pre-production activities progress near the wet draw point is updated and considered as well. Furthermore, Geotech monitoring is included by identifying the specific areas that necessitate regular monitoring in cooperation with the Geotech team.

Upon completion of data collection, the projected lifetime of panels and draw points for the monthly timeframe is established to be used in daily tonnage planning for each draw point and panel incorporating the updates of the

crushers & conveyor down schedule. The monthly production plan for tons and metal output (copper & gold) must be in line with the forecasted target, with a detailed explanation provided if there are any variance. The tons by draw point and panel will define the TBSB and the secondary breaking activity necessary.

Panel	LHD Assignment Status	1-Dec		2-Dec		3-Dec		4-Dec		5-Dec		6-Dec		7-Dec	
		Fri		Sat		Sun		Mon		Tue		Wed		Thu	
		DS	NS												
P24E	Manual Dedicate														
P25E	Remote Dedicate	1	1	1	1	1	1	1	1	1	1	1	1	1	1
P26E	Remote Dedicate														
P27E	Remote Dedicate	1	1	1	1	1	1	1	1	1	1	1	1	1	1
P28E	Remote Dedicate	1	1	1	1	1	1	1	1	1	1	1	1	1	1
P29E	Manual Dedicate														
P30E	Manual Dedicate														
P31E	Remote Dedicate	1	1	1	1	1	1	1	1	1	1	1	1	1	1
P32E	Remote Dedicate	1	1	1	1	1	1	1	1	1	1	1	1	1	1
P33E	Remote Dedicate	1	1	1	1	1	1	1	1	1	1	1	1	1	1
P34E	Remote Dedicate	1	1	1	1	1	1	1	1	1	1	1	1	1	1
P13W	Manual Dedicate														
P14W	Alternating Panel														
P15W	Alternating Panel														
P16W	Remote Dedicate	2	2	2	2	2	2	2	2	2	2	2	2	2	2
P17W	Alternating Panel	2	2	2	2	2	2	2	2	2	2	2	2	2	2
P18W	Remote Dedicate	2	2	2	2	2	2	2	2	2	2	2	2	2	2
P19W	Remote Dedicate														
P20W	Remote Dedicate	2	2	2	2	2	2	2	2	2	2	2	2	2	2
P21W	Remote Dedicate	1	1	1	1	1	1	1	1	1	1	1	1	1	1
P22W	Remote Dedicate	1	1	1	1	1	1	1	1	1	1	1	1	1	1
P23W	Remote Dedicate														
P24W	Remote Dedicate	1	1	1	1	1	1	1	1	1	1	1	1	1	1
P25W	Alternating Panel	2	2	2	2	2	2	2	2	2	2	2	2	2	2
P26W	Alternating Panel														
P27W	Manual Dedicate														
P28W	Alternating Panel														
P29W	Alternating Panel														
P30W	Alternating Panel														
P31W	Alternating Panel														
P32W	Alternating Panel														
P33W	Manual Dedicate														
P34W	Manual Dedicate														
P35W	Manual Dedicate														
LHD Remote Assigned		20	20	20	20	20	20	20	20	20	20	20	20	20	20
Panel Command Usage		15	15	15	15	15	15	15	15	15	15	15	15	15	15

LEGENDS	
1	: 1 Remote LHD Assignment
2	: 2 Remote LHDs Assignment
□	: Manual LHD Assignment
■	: Day Shift Remote Assignments
■	: Night Shift Remote Assignments
■	: 12 Hours Idle Protocol
■	: Panel Monitoring
■	: PM Panel & Daily Check
■	: Supplementary Abutment Cable Bolt
■	: Secondary Breaking
■	: Panel Refinement Activities

Figure 12 Integrated Schedule Matrix.

The integrated schedule is then created and shared with the relevant parties, typically in the form of a partial weekly schedule as shown in Figure 12. This integrated schedule will define the daily draw order during the whole month production. The mining supervisors on the field have the responsibility to execute this schedule

and to provide guidance to all parties involved in the daily production in GBC.

3.4 Key Success of Integrated Schedule

The engineering and operation departments collaborate closely to ensure that all tasks and their interdependencies are executed according to the predetermined integrated schedule. Any delay in the reliability program of a specific panel can have a significant impact on the overall production scenario. During the fourth quarter of 2023, GBC successfully attained an average of 133K dry metric tonnes per day (dmtpd), surpassing the target by 100.4%. Additionally, the average mucking compliance stood at 82%, exceeding the 80% target, while accommodating 10% of wet draw points. These remarkable achievements at GBC Mine demonstrate the effectiveness of the integrated schedule.

4 CONCLUSION

The remote LHD has been widely assigned in GBC mine due to the increase in the spread of wet draw points. Several key actions have been taken to promote sustainable remote production in the GBC mine, such as intensifying the use of copilot and autopilot to enhance the productivity of remote LHDs, employing muck bumpers and *geobrugg* for protection during the interaction between wet production and pre-production activities, utilizing wet muck blending to prevent spillage into haulage level, developing the skills and capabilities of operators, improving ventilation to eradicate the dust issue, and establishing a remote environment system by utilizing supporting remote equipment such as remote *mobile rock breakers*, remote *water cannons*, and drones for inspection.

The implementation of the integrated schedule of the mucking remote LHD, manual LHD and panel reliability program has proven to result in sustainable and safe production in the GBC mine in the form of achieved tonnage target and the compliance. The integrated schedule broadly incorporated all production parameter and

constraints on the field, especially the wet draw point operational with lower flexibility compared to dry draw point production.

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