doi:10.36487/ACG_repo/2435_A-02

Loop de Loop – An innovative block cave extraction level design for BC1 at Carrapateena

S. Mariager and M. Fargher
BHP, Adelaide

ABSTRACT

Block cave mining is a mining method aimed at achieving a high tonnage output from a single extraction level. Ensuring that production loaders can operate as efficiently as possible on this level is critical in achieving the planned tonnage output. Given the long-life span of block cave extraction levels, it is important the level is designed with the future in mind, in terms of allowances for enabling technology and future operating strategies.

Other key considerations that are given to the design of a block cave extraction level are related to geotechnical considerations (pillars, impact of abutment zones), civil infrastructure (concrete roadways, drawpoint infrastructure, dewatering), ventilation infrastructure (doors, fans) among other things. Careful consideration to the layout of the extraction level is required to ensure all elements are allowed for in the design.

This paper explores an innovative block cave extraction level design, which incorporates a loop philosophy for the operation of the level in steady state (all drawbells established and operational), while still providing the means to extract material using the conventional drawpoint to crusher approach. This design is being proposed as an option for Block Cave 1at BHP's Carrapateena mine, located in the Gawler-Craton region of South Australia. At the cost of minor additional fleet requirement, the maximum potential output from an extraction level can be increased significantly on what was previously thought possible. Pending real world application, the loop design has the potential to create a paradigm shift in the thinking of how block cave extraction levels are designed and operated.

1 INTRODUCTION

The Block Cave 1 (BC1) Mine Design at Carrapateena consists of an extraction, undercut and apex level, as well as supporting levels for ventilation and civil infrastructure among other things. Arguably, the extraction level is the most important of these levels as it is where the cave material is transported from the drawpoints to the materials handling system (MHS). An extraction level in a block cave is generally designed mainly to maximize ore extraction and mine stability (Gomez et al. 2020).

At Carrapateena, an underground crushing station, Crusher Station 3 (CS03), is the destination where cave material will be tipped once loaded from the drawpoints. CS03 contains four tipping points, or tipples, to cater for the 8 extraction drives currently planned for the extraction level. This level is situated on the 3680 RL, approximately 1500m below surface, and is the lowest level of the BC mining area. The level consists of several elements, including:

- Extraction drives
- Draw point drives
- Draw points
- Drawbells

- Crusher tipple approaches
- Extraction level accesses
- Exhaust airway drives
- Perimeter drives
- Fresh airway drives
- Sumps
- Material passes (from undercut level)

An isometric of the BC1 extraction level design at Carrapateena is shown in Figure 1.

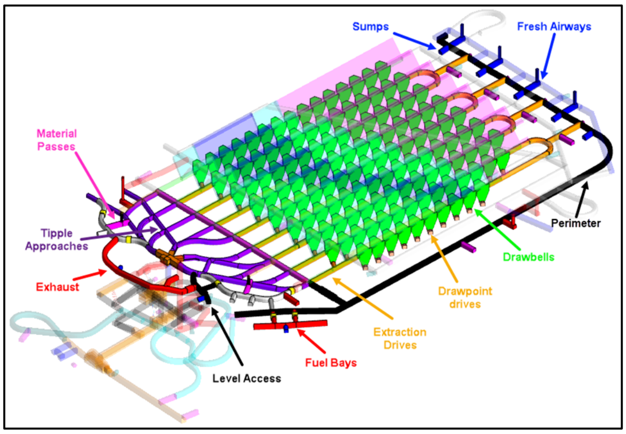

Figure 1 BC1 extraction level isometric.

Many of the above elements are common to most block cave extraction levels, although the layout, location and detail of each element can vary significantly.

The efficiency of the extraction level is critical in ensuring production targets can be achieved. Therefore, it is important to undertake a robust and rigorous assessment on the design of the extraction level to ensure the consideration of a number of different aspects, including:

- Geotechnical
- Ventilation
- Vertical development
- Material movement strategy
- Technology
- Infrastructure
- Services/drainage
- Emergency response
- Fleet

Once all constraints related to the above have been considered and addressed, the extraction level design needs to be checked to ensure compliance to the functional requirements of the asset. These functional requirements generally relate to cave management, personnel safety, meeting production targets, utilising practical mine design, catering for future technologies and maximizing efficiency.

2 MINE DESIGN PROCESS

2.1 Design considerations

The following areas, and their sub-topics, have been considered when designing the extraction level. These items are important to understand and assess, from a risk and schedule impact point of view, regardless of operational philosophy utilised on the extraction level:

- Geotech
  - Geological uncertainty
  - Stability/pillars
  - Hydrogeology (saline and hot water)
  - Ground support
  - Cave propagation, dilution and recovery
  - Major hazard management considerations (eg inrush)
  - Caving beneath SLC
  - Stress (mining depth 1.5km)
  - Seismicity
  - Structure
  - Abutment zones
- Ventilation
  - Heat (virgin rock temperature)
  - Radon
  - Dust
  - Contaminants
  - Cooling
  - Infrastructure (doors, fans etc.)
- Vertical Development
  - Raises
  - Ore passes
  - Drawbells
  - Undercut rings
- Material Movement
  - Production rate requirements
  - Materials handling strategy

- Impact of secondary breakage
- Cave flow

- Technology
  - Remote and autonomous
  - Monitoring
  - Wifi
  - Communications
- Infrastructure
  - Facilities
  - Concrete roadways
  - Ventilation
- Services/Drainage
  - Mine water (saline)
  - Fire water
  - Power
  - Compressed air
  - Ground water
  - Gradients
  - Sumps
  - Pumping capacity
- Emergency Response
  - Egress
  - Refuge chambers
  - Fire suppression
  - Ventilation
- Fleet
  - Drivetrain (diesel vs electric)
  - Equipment specifications
  - Fleet size
  - Maintenance requirements

2.2 Loop design considerations

At Carrapateena, a unique and innovative concept has been proposed for the extraction level in order to de-risk the ability of the asset to reach its pre-determined production target, as well as maximise the efficiency and throughput of the cave footprint. This concept proposes to utilise a loop arrangement, whereby multiple loaders operate within a pair of extraction drives in a one-way tramming route, increasing extraction drive throughput and draw optionality by maximizing drawpoint utilization. The application of this operating philosophy will be dependent on the draw order that is being followed, with the conventional drawpoint to tipple arrangement still being the primary operating strategy where practical.

When considering an innovative or new level design, such as the loop arrangement outlined above, due consideration was given to each of the items listed in section 2.1. Without benchmarked data on similar designs, additional rigour needed to be included in this assessment. Particular focus was given to certain areas, such as ventilation, fleet, material movement and technology, given the implications of the loop operational strategy on these areas.

2.3 Functional requirements/Design Parameters

From the design considerations listed in section 2.1, the functional requirements for the updated loop design, as well as all mine design for the BC1 footprint, were established. Functional requirements are defined as what a product must do, and what its features and functions are (AltexSoft, 2024). The product, in this instance, is the extraction level. The functional requirements, or the features and functions, for the extraction level are as follows:

- Must deliver target ore tonnes to the primary crushing system.
- Must optimize and support cave management, ore recovery and dilution management.
- Must support major hazard management eg inrush, and incorporate safety-by-design elements.
- Must have geotechnically stable pillars.
- Must utilise appropriate profiles and gradients to suit fleet, ground support and ventilation requirements.
- Must utilise appropriate gradients to suit level drainage requirements.
- Must be operable for both ramp-up and steady state conditions.
- Must cater for the operation of both diesel and electric equipment.
- Must have an optimised loader route (e.g. efficient turning radii) in steady state operation to maximise efficiency.

- Must allow for automation and associated technology.

The intent of the functional requirements is that they are satisfied when considering each element of the final mine design and operating philosophy.

3 EXTRACTION LEVEL DESIGN

The BC1 Extraction Level is used as the main haulage level for the transport of caved material, via a loader fleet, from the block cave draw points to the materials handling system (CS03), which is located off-footprint.

The draw points are located underneath draw bells, which are the fired excavations used to create a link between the cave orebody material and the extraction level. The extraction drives link the draw point drives to the tipple approaches, allowing a fleet of loaders to load the cave material from the drawpoints, tram to the tipples and tip into CS03. This type of mining system implies a significantly lower excavation density per square metre compared to those based on the tipping of loaders into orepasses inside the footprint (Paredes et al, 2018), one of the reasons this arrangement was selected.

The BC1 Extraction Level consists of the following elements:

- Extraction drives (EXD)
- Draw point drives (DPD)
- Draw points (DPT)
- Drawbells (DBL)
- Crusher tipple approaches (TPA)
- Extraction level accesses (ACC)
- Northern exhaust drive (RAW)
- Fuel Bay (FBY)
- Northern perimeter drive, located in between extraction drives and tipple approaches (PER)
- Southern perimeter drive (PER), including fresh air drives (FAW's), sumps (SMP's) and an allowance for development for barrier control panels (BCP's).
- Western perimeter drive (PER)
- Material passes from undercut level (MAP)
- Stockpiles (STP)

The image below shows the proposed layout of the BC extraction level, labelled with the location of the elements listed above.

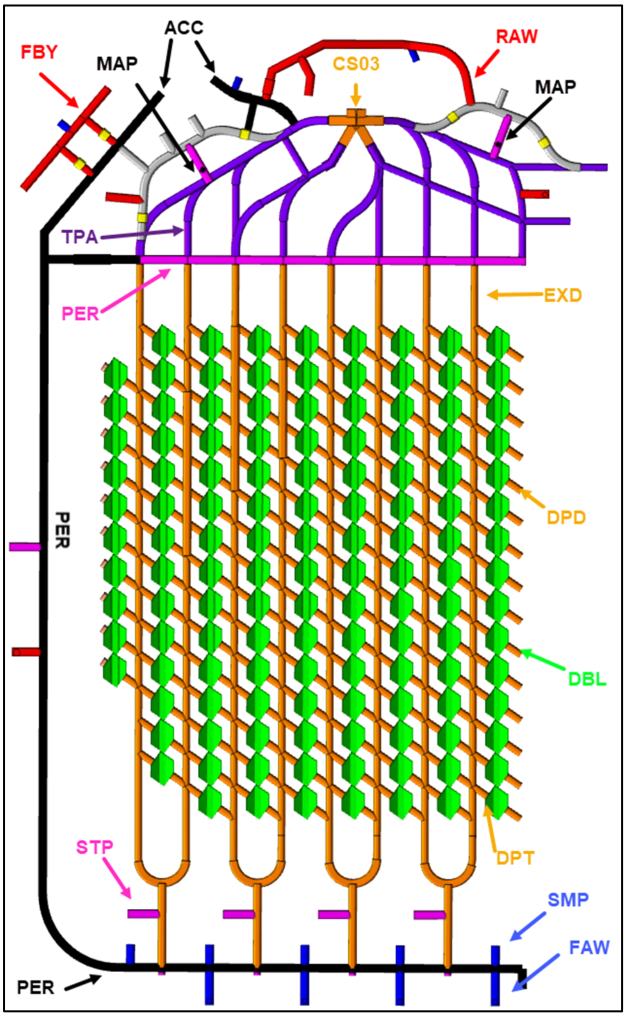

Figure 2 BC1 Extraction Level.

3.1 Layout and Purpose

The extraction level can be broken into two sections – on-footprint and off-footprint. On-footprint is considered to be any development that falls within the northern and southern perimeters, and includes the extraction drives, drawpoint drives, turn bays and drawbells. All other elements are considered off-footprint.

3.1.1 On Footprint

The layout of the on-footprint development on the extraction level for BC1 can be seen in Figure 3, with specific areas labelled and described below.

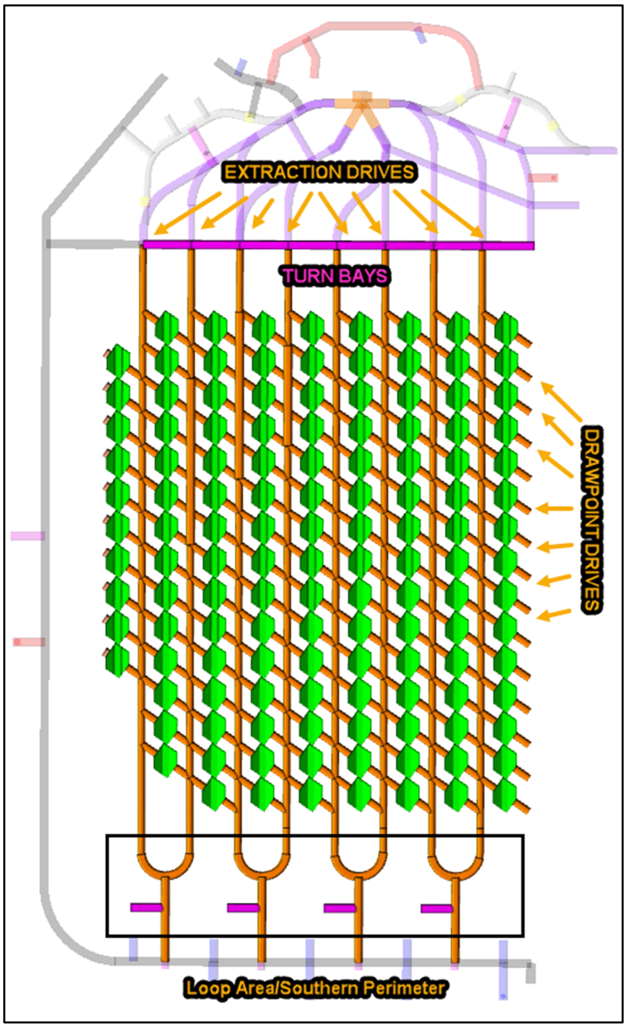

Figure 3 On-footprint extraction level layout.

Extraction drives

- Used to access the drawbells and transport material from the drawpoints to the MHS via the tipple approaches.
- Used for access to drawpoints for secondary breaking activities.

Drawpoint Drives

- Used to access and extract the drawbells.

Turn bays

- Initially used as Northern perimeter drive, to allow ventilation of the extraction/drawpoint drive mining.
- Allows loaders to change direction to orientate with the drawpoints or crusher tipples or hold off the main tramming route to allow other loaders in the same extraction drive to pass.

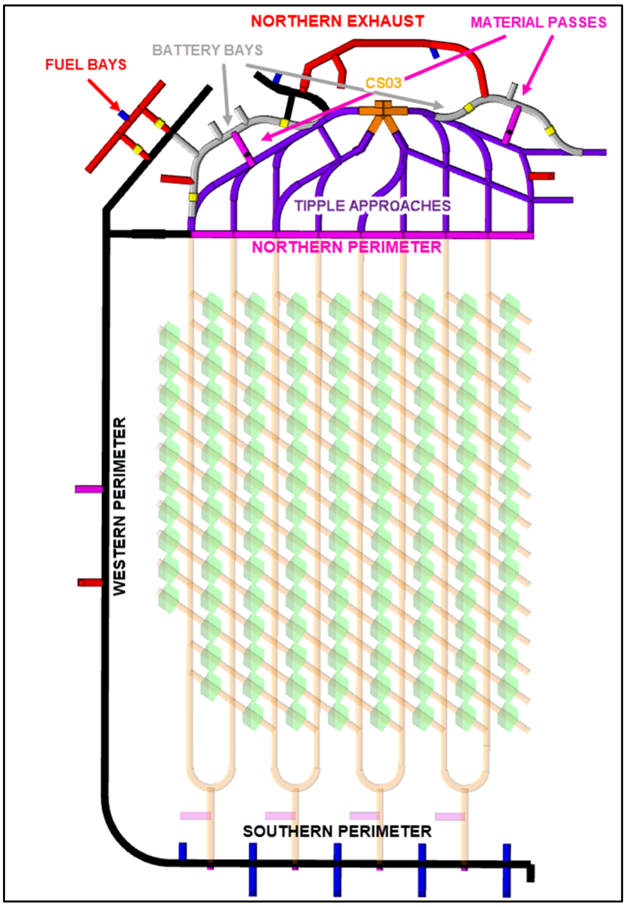

Figure 4 Off-footprint extraction level layout.

Loop area and Southern perimeter

- Access point for mining extraction drives from South. A stockpile is included to allow fired development material to be stockpiled and truck loaded.
- Primary access point for equipment/personnel to enter the extraction level. Remote barriers will be located here to allow remote/autonomous operation of extraction level.
- Loop design allows smooth and continuous loader tramming to improve

efficiency. Loop can operate in either direction, depending on the drawpoint being loaded from.

3.1.2 Off Footprint

The layout of the off-footprint development on the extraction level for BC1 can be seen in Figure 4, with specific areas labelled and described below.

Northern perimeter drive

- Access for extraction drive mining.
- Location for secondary ventilation ducting to ventilate extraction drives during development before they are broken through (from North and South).
- Turn around bays for loaders during loading cycle from draw points to CS03.
- Technology infrastructure location (comms cabinets).

Southern perimeter drive

- Access to the mining of the extraction drives from the South side of the level (allowance to mine extraction drives from both sides to establish at a faster rate).
- Connection between fresh air system and extraction drives.
- Water storage area via sumps for any water generated from sprays, water-bearing faults etc.
- Barrier control panels for checking in and out equipment from extraction drives.

Western perimeter drive

- Access to Southern perimeter area.

Northern exhaust drive

- Mining/trucking access to development to the East of CS03 off the main extraction level access
- Exhaust connection for CS03 from the underpocket.
- Exhaust connection for the battery bays

Material passes

- Used to rehandle material from the undercut level to the extraction level then direct tipped into CS03. These will only be active during operation of CS03 and mining of the Northern undercut development and ring firings.

Fuel Bays

- Utilised for refueling of diesel equipment, as well as a daily servicing bay for loaders.

Battery Bays

- Utilised for battery swapping/charging for a battery electric loader fleet.

Further detail on the battery bay design and requirement is discussed in section 3.1.3.

3.1.3 Diesel and Battery Loader functionality

The extraction level for BC1 has been designed with the intent of being an all-purpose footprint that caters to the use of either a conventional diesel loader fleet or a battery electric (BeV) loader fleet. This design is based on the current information available regarding these two equipment types, with the design for a diesel fleet being benchmarked from other operations, specifically in terms of drive size and level layout. Information around battery loaders, particularly any loaders with a size relative in comparison to the largest diesel loaders, is scarce. Therefore, the excavation sizes have remained constant when considering BeV loaders.

Information that is starting to become available in in relation to battery changeout methodology for BeV loaders, with several options being developed. For the Carrapateena BC1 extraction level, two battery bays have been included in the design, adjacent to the CS03 tipples, to allow for efficient battery bay change outs should BeV loaders be the chosen path forward. The design is flexible to cater for different battery changeout methodologies that are being developed, with three methodologies being considered:

- Gantry style, drive through
- Drop and replace
- Park and charge

Figures 5-7 show visual examples of each of these methodologies.

Figure 5 Gantry style, drive through battery changing (Zero emission | Epiroc).

Figure 6 Drop and replace (Sandvik presents 'world's first 18-t battery loader' (tradelinkmedia.biz).

Figure 7 Park and charge (Reimagining the future of mining | Epiroc).

Regardless of the battery charging/changing methodology, the assumption is that a direct exhaust connection is required in order to exhaust any harmful fumes or smoke in the event of a battery fire. The layout of the battery bays that have been included in the extraction level design for Carrapateena BC1 is shown in Figure 8.

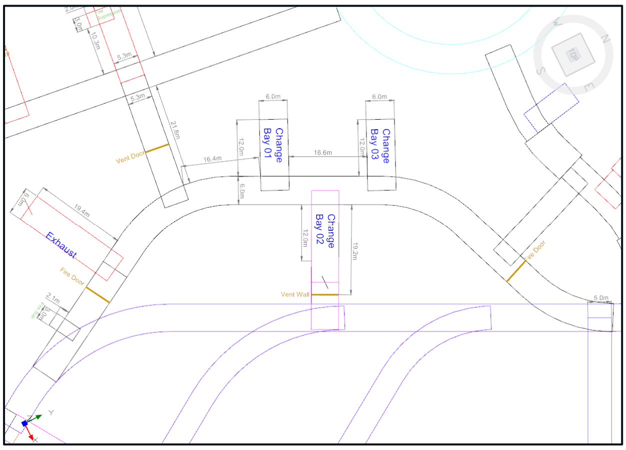

Figure 8 Battery bay conceptual design.

In terms of diesel equipment, a fuel bay has been designed off the extraction level access to service refuelling of a diesel fleet (refer to Figure 2 for location). The battery bay may also be setup as a fuel bay should a diesel fleet be the chosen path forward, as the battery bay is connected directly to exhaust. See Figure 9 for proposed layout of fuel bay.

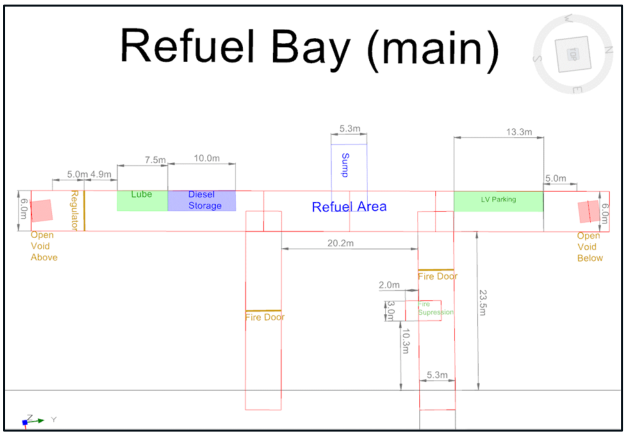

Figure 9 Proposed fuel bay layout.

3.2 Battery Loader Fleet Considerations

The requirement for a diesel fleet operating on a Block Cave extraction level is reasonably well understood from benchmarking, as this has been the most common practice historically. More of an unknown is how a battery electric fleet may perform on a block cave extraction level. Key elements that were deemed of importance to be considered when designing the footprint for battery electric vehicles included the following:

- Equipment dimensions and performance metrics of proven, available electric fleet

(speed, acceleration, deceleration, bucket size, battery life etc.)

- Battery change out methodology (location and frequency)

These elements have informed the battery bay and extraction level development dimensions.

4 EXTRACTION LEVEL OPERATING PHILOSOPHY

The base case proposed operating philosophy for the BC1 extraction level will be a conventional operating strategy, however the inclusion of the southern loop arrangement on the level design allows for additional variations of the operating philosophy.

4.1 Conventional Operation

The conventional operating strategy for a block cave extraction level is utilizing a single loader in an extraction drive, either tipping into an on-footprint ore pass, which feeds to an independent materials handling transfer level, or tipping directly to an off-footprint crusher tipping point.

The Carrapateena block cave footprint design incorporates an off-footprint crusher tipping point, with loaders tramming directly from the drawpoints to the crusher tipples. Using the conventional operating strategy, a single loader operates in an available extraction drive in a bi-directional manner, with turn-around bays used to change tramming direction to orientate with the crusher tipple or the drawpoint orientation as required. An example of this strategy, applied to the Carrapateena BC1 footprint, is shown in Figure 10.

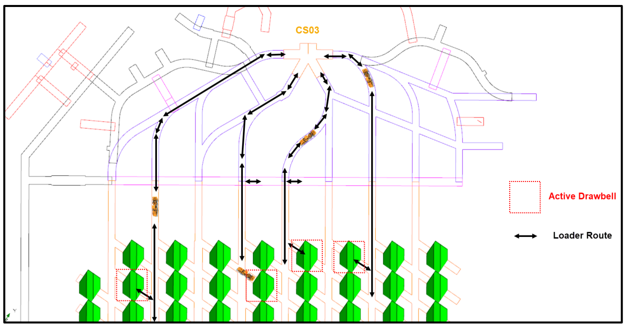

Figure 10 Conventional Operating Strategy.

This operating strategy is proven and widely utilized, however has its own limitations in regard to number of loaders that can operate on the footprint at any one time, and throughput rate, which is highly dependent on the location of the drawpoints that are being extracted in relation to the crusher tipple location. The further away these drawpoints are from the tipping location, the less tonnes per operating hour can be achieved due to the longer tram routes. This results in less overall tonnage throughput that the footprint can achieve. Conversely, should the drawpoints being extracted be in closer proximity to the crusher tipple, the overall throughput rate from the footprint will be higher. This assumes that only a single loader can operate in an extraction drive using the conventional drawpoint to tipple approach, to eliminate the risk of a loader-to-loader vehicle interaction event, or the occurrences of un-productive time events due to loaders passing.

In other mines, this bottleneck (single loader in extraction drive) has been a factor behind:

- Including on-footprint tipping into ore passes, and the establishment of a haulage level to transfer material to the crusher to reduce tramming lengths on the extraction level.
- Utilising rim tipping by installing crushing infrastructure at each end of the footprint with associated construction and capital requirements.

4.2 Variations

The proposed operating philosophy of the BC1 extraction level is multi-variant, with the inclusion of the southern loop design allowing an additional 2 operating arrangements to be utilised, depending on the required draw order.

4.2.1 Loop Operation

The loop operation involves multiple loaders within a pair of extraction drives being dispatched to the same, or multiple, drawpoints. With the southern loop connections, a one-way path of travel can be achieved through the extraction drive pair, with only the tipple approaches, adjacent to the CS03 tipples, being bi-directional. The loop operation has the ability to be operated in either clockwise or anti-clockwise configuration, depending on the drawpoint/s in the draw order. The turn bays on the north side of the extraction drives can be used to re-orientate to the preferred direction to suit the drawpoint or the tipple. This method of operation is unproven, however has been analysed using simulations to ensure plausibility. An example of the loop operation can be seen in Figure 11, with the red dots signifying drawpoints that are awaiting secondary break activities, the green dots signifying actively mined drawpoints and the grey extraction drives being utilised for secondary break activities only.

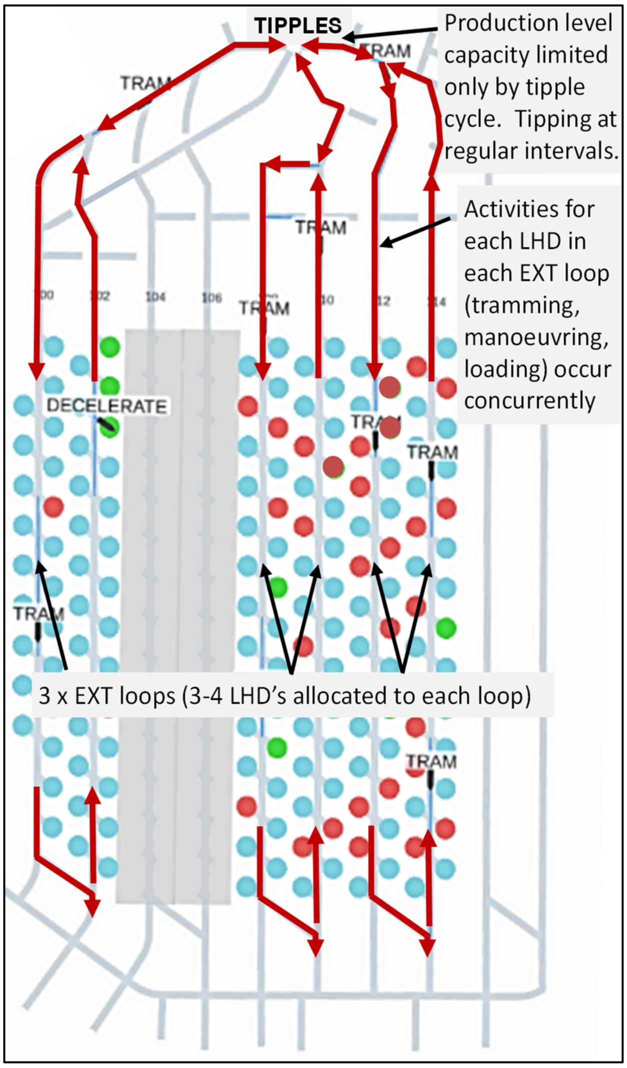

Figure 11 Full loop operation (Mariager et al, 2022).

This operating strategy is most preferable and provides the most benefit from a production rate point of view, if all of the drawpoints to be extracted from are located in the Southern part of the extraction level. This is due to the significant tram lengths that would be required for a single loader in the extraction drive to operate with.

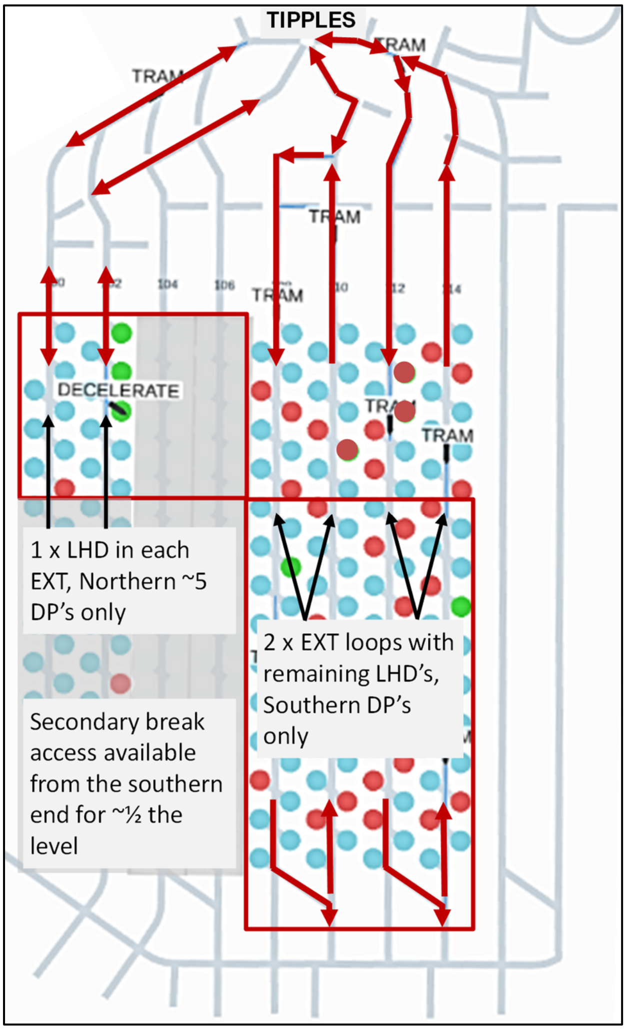

Figure 12 Hybrid operation (Mariager et al, 2022).

4.2.2 Hybrid Operation

Depending on the draw order, the hybrid strategy may be the preferred operating strategy for the BC1 footprint. This strategy involves some extraction drives operating in the conventional arrangement, while some will operate as a pair with the neighbouring extraction drive, in a loop arrangement. It would be expected that this strategy would be used if there are a mixture of drawpoints located in the far north and far south of the footprint in the draw order. An example of this strategy is shown in Figure 12.

4.3 Initial Simulation Assessment

A simulation assessment was completed to compare a number of different operating strategies for the BC1 extraction level. These strategies involved combinations of loader only strategies as well as loader/truck combinations. The loop strategy proved to be a promising solution to achieving the required production profile, as well as providing an efficient means to increase throughput beyond the production targets, notwithstanding other potential system constraints such as the capacity of the underground crushing station (Mariager et al 2022). However, this assessment was only based on a single point in time, and a single variation of the loop operating strategy. When considering all possible combinations given the variables of draw orders, operating extraction drives vs unavailable extraction drives and the 3 operating strategies discussed in Section 4, there are countless combinations and configurations that could be assessed. To simplify this assessment, to be progressed to an updated simulation model, a number of variables were kept constant in the models, including:

- Draw order (a single month at the maximum production rate was used).
- Crushed ore bin (COB) capacity
- Loader to drawpoint allocation (Single draw point per loader)
- Hang-up frequency
- Extraction drive closure logic, and number of extraction drives unavailable at any point in time due to secondary breakage or other ancillary activities (25%, or 2 extraction drives).
- Loader specifications, including bucket size (18t) and drivetrain type (battery electric)

4.4 Updated Simulation Assessment

If the first simulation assessment showed there was some merit in utilising a loop arrangement on the BC1 extraction level, the intent of the updated assessment was to show the sensitivity of the footprint throughput to differing variables and operating strategies.

The variables in Table 1 were adjusted and simulated, with total footprint production rate being the key metric that was compared between each variation.

Table 1 Simulation sensitivities

Variable	Variation	Code
Operating strategies	0 (direct tip only - conventional)	A
	1 loop - Hybrid	B
	2 loops - Hybrid	C
	3 loops (loop only)	D
Production target	Target	E
	Maximum	F
Maximum gear ratios	4	G
	3	H
	2	I
Acceleration/ deceleration	50% of base	J
	75% of base	K
Loader Load Times	45s average	L
	35s average	M

Adjusting certain variables creates a suite of operating configurations which are intended to replicate real-world situations. These situations may be due to the following:

- Variable extraction drive closures (loop arrangement)
- Variation in operator skill (gear ratios, acceleration/deceleration, Loader load times)
- Variable floor conditions (gear ratios, acceleration/deceleration)
- Variable fragmentation in drawpoints (loop arrangement, Loader load times)

From Table 1, there are 35 scenarios which could be created and simulated, with each having a different variable adjusted. Note that the direct tip (A) was not assessed against the maximum (F) scenario as the direct tip operation is limited to a single loader per operational extraction drive, and so there is no ability to flex the fleet numbers. The production rate reaches its capacity before the target is met in this scenario (scenario AE).

The image in Figure 13 shows the layouts that were used in the simulation models to inform the updated simulation assessments and results.

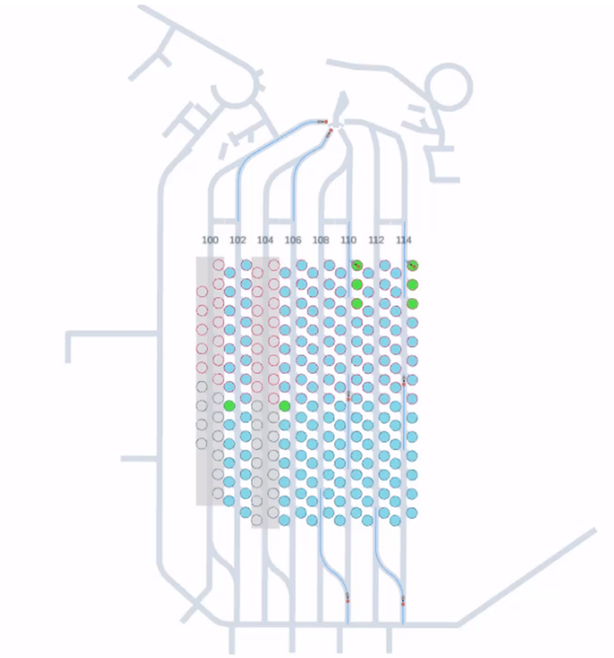

Figure 13 Simulation assessment layout.

The resulting production rate of each of these scenarios relative to the target production rate is shown in Figure 14 (legend in Figure 15), along with the associated fleet required to execute.

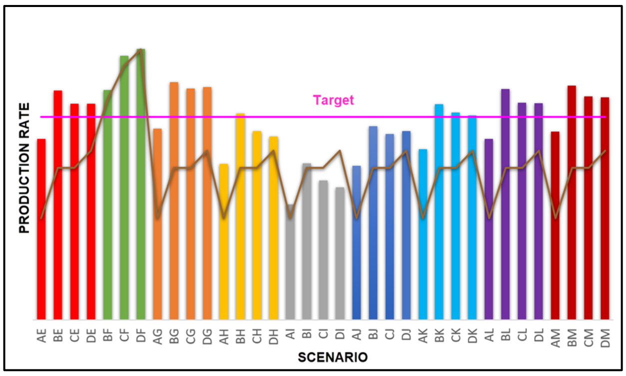

Figure 14 Production Rate Scenarios.

From the graph in figures 14, the hybrid (B/C) or loop (D) strategies have a higher production rate capacity, and in some sensitivity analyses, are the only situations where the desired production target is met. This generally comes at the minor cost of some additional fleet required to be operating in the extraction drives, this being an output of the simulation models.

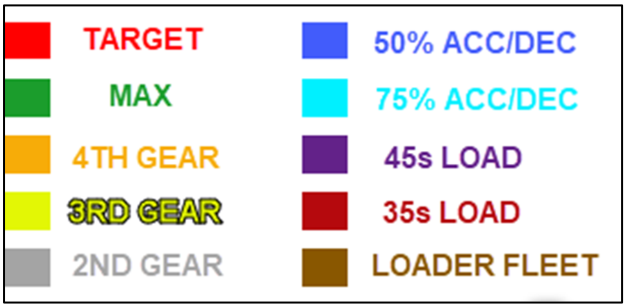

Figure 15 Figure 14 legend.

4.5 Drawpoint strategy allocation

In general, as the loader tramming distance increases in a conventional loader to tipple strategy, the loop strategy becomes more favourable for an individual drawpoint. At a certain tramming length, the loop strategy will likely become the preferred strategy, as additional loaders can be added to the system to increase drawpoint turnover. This tipping point, whereby a loop arrangement with multiple loaders becomes more efficient than a single loader to tipple arrangement, has been determined as variable, as it is dependent on what drawpoints are being drawn at the same time holistically on the footprint. This is based on keeping a consistent production profile and crusher feed. As an example, for an overall hybrid operation, whereby 4 extraction drives are operating in conventional manner and 2 extraction drives operating in a loop fashion, the following Figure 16 shows the breakdown of what is defined as the direct tip area and what is defined as a loop arrangement, based on the inputted draw order.

4.6 Additional benefits of loop arrangement

From Figure 14, several of the hybrid and loop scenarios provided a production rate greater than the target rate. This means that, in theory, there is some buffer created when using these strategies. This presents the following opportunity - Reduce the loader size, resulting in underperformance during the direct tip configurations (which may then result in more drawpoints being loaded using the loop configuration), offset by overperformance during the hybrid or loop configurations. This could potentially allow the extraction drive dimensions to be reduced, increasing the pillar size and stability, reducing risk of drive instability, seismic risk etc. on the footprint.

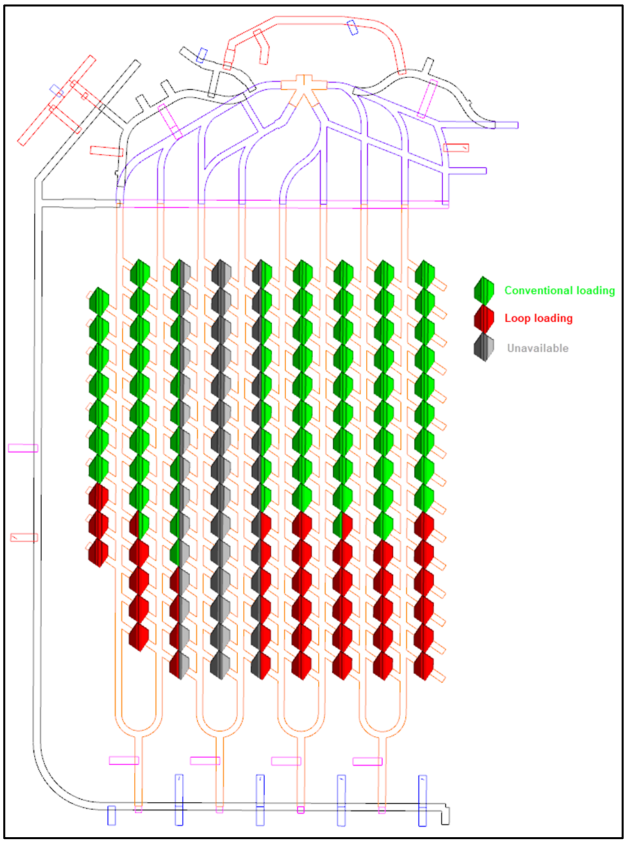

Figure 16 Operating strategy breakdown example.

5 NEXT STEP

In order to further prove up the loop operating philosophy, an assessment of the key risks with the loop strategy, and development of action items, is required, with key consideration to be given to the following:

- Collision avoidance and development of a traffic management system to support different operating variants
- Management of tyre overheating and tyre/roadway development (tyre compounds, roadway design)
- Explicit representation of impacts of drive blockages through drive damage and rehabilitation and inrush exclusion zones.

In addition, real world testing, either using surface or underground trials would be required. The outputs from this could then be used compared against previous simulation modelling to verify accuracy, as well as used to inform longer duration simulation assessments to effectively create a digital twin estimation of the life of the BC1 extraction level.

From a BeV loader point of view, the battery changing logic requires further assessment to then input into any future simulation modelling, to be able to reflect this aspect of operability explicitly.

6 CONCLUSION

Two separate simulation assessments have shown that a slight increase in production fleet required has the potential to increase the ceiling of extraction level production in the BC1 extraction level at Carrapateena when utilising the loop strategy in extraction drive pairs.

The proposed loop configuration for the BC1 footprint challenges the belief that the most efficient mining system is the one that minimizes the loader tramming distance (Chacón et al. 2004). The loop configuration results in an increase in tramming distances for loaders utilizing this strategy. The intent of applying the loop strategy is, however, related to maximizing drawpoint and crusher utilization and maximum mine throughput capacity, not individual loader efficiency. However, without the additional capital expenditure required to establish on-footprint tip points, ore passes, dedicated haulage levels and multiple crusher tip points, the loop strategy presents an attractive option for block cave mines looking to reduce their capital expenditure at the cost of a minor increase in operational expenditure due to the additional loader fleet required. An additional benefit to maintaining the ability to tip directly into crushers outside of the footprint is the elimination of bottlenecks associated with oversize control, relating to grizzlies and rock breakers, making the system more continuous and reducing the amount of equipment required (Paredes et al, 2018). Another opportunity is the potential to utilise more loaders of a smaller size on the extraction level, allowing the extraction drive dimensions to be reduced. This would aid in increasing the pillar size and stability which would reduce the risk of footprint instability, seismic activity etc.

The loop strategy is intended to be a stepping stone in bridging the gap between a conventional loader extraction method and a continuous production system, by increasing the ore transfer rate relative to the conventional drawpoint to tipple material movement arrangement. In effect, the loop configuration could be considered to be a form of continuous production system, with the ability of continuous production systems to require fewer active extraction drives to achieve the same throughput (Shelswell et al 2018). Utilising this form of continuous production system allows better management of oversize material than a true continuous production system (conveyors, drawpoint feeders etc.) as it still uses loaders which can more easily identify oversize material. Further work will need to be carried out to better quantify the risks associated with the implementation and operation of the loop strategy, however this configuration has the potential to increase current benchmark values of tonnes per extraction drive per year for block cave mines.

ACKNOWLEDGEMENT

The authors would like to acknowledge the contributions of the Deswik simulation team, particularly Colin Eustace (head of simulation) and Katherine Hynard (Senior Data Analyst) for their work in developing and analysing the extraction level simulations. They would also like to acknowledge the Carrapateena mine Technical and Technology team for providing the opportunity to write this paper. Additionally, the authors acknowledge Troy Newman, Team Manager and Elton Peebles, General Manager, Carrapateena for their support and feedback on this work. Finally, the authors acknowledge BHP for allowing us to publish this work.

REFERENCES

AGB’s Epiroc Deutschland GmbH, 2024, Zero-emission, 24/01/2024, https://www.epiroc.com/en-dk/innovation-and-technology/zero-emission.

AGB´s Epiroc Deutschland GmbH, (2024). Reimagining the future of mining, 24/01/2024, https://www.epiroc.com/en-dk/customer-stories/2023/reimagining-the-future-of-mining.

AltexSoft, (2024). Functional-and-non-functional-requirements-specification-and-types, 01/02/2024, https://www.altexsoft.com/blog/functional-and-non-functional-requirements-specification-and-types/.

Chacón, J., Göpfert, H. & Ovalle, A. (2004). Thirty years of block caving evolution in Chile. in A Karzulovic & MA Alfaro (eds), Proceedings of MassMin 2004, Instituto de Ingenieros de Chile, Santiago.

Gómez, R. E., Saéz, K., Pino, N., Labbe, E. & Marambio, E. (2020). Analysis of extraction level layouts for block caving. in R Castro, F Báez & K Suzuki (eds), MassMin 2020: Proceedings of the Eighth International Conference & Exhibition on Mass Mining, University of Chile, Santiago, pp. 773-786.

Mariager, S., Zhang, Q., Eustace, C., Hegarty-Cremer, S. & Nguyen, K. (2022). A simulation comparison of operating strategies for electrified block cave mines. in Y Potvin (ed.), Caving 2022: Proceedings of the Fifth International Conference on Block and Sublevel Caving, Australian Centre for Geomechanics, Perth, pp. 315-330.

Paredes, P., Leaño, T. & Jauriat, L. (2018). Chuquicamata underground mine design: the simplification of the ore handling system of Lift 1, Vancouver, Caving 2018.

Shelswell, K. J., Labrecque, P. O. & Morrison, D. M. (2018). Increasing productive capacity in block caving mines. in Y Potvin & J Jakubec (eds), Caving 2018: Proceedings of the Fourth International Symposium on Block and Sublevel Caving, Australian Centre for Geomechanics, Perth, pp. 107-118.

Trade Link Media, (2024). Sandvik presents ‘world’s first 18-t battery loader. 24/01/2024, https://www.tradelinkmedia.biz/publications/7/news/2457.