

A simulation comparison of operating strategies for electrified block cave mines

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Abstract

Block cave mining is a mining method aimed at achieving a high tonnage output from a single production level. Interactions between production loaders and consequent cycle delays can constrain overall production level performance. Together with access restrictions associated with the control of caving progression and secondary break requirements, these constraints can prevent block cave mines from reaching throughput targets. Careful layout design and development of operating strategies for the production level are critical for minimising equipment interactions and building an optimised block cave operation.

In striving for a net zero emissions mining operation, many companies are actively investigating the option of electrification of their mining fleet. This adds another dimension to design considerations and creates new possibilities for block cave designs and operating strategies. The potential impacts for charging of battery electric vehicles requires consideration and ventilation limits on the practical number of production loaders are reduced, giving rise to different design solutions.

This paper explores the capability of a number of alternative production level operating strategies for the Carrapateena mine, which is an OZ Minerals owned, South Australian copper-gold mine, ramping up to a rate of 12 Mtpa from 2029 utilising the block cave mining method. A comparison of the performance characteristics for each alternative is assessed using a detailed simulation model of the block cave operations. Relationships between fleet size and production level throughput are developed for each alternative operational strategy to demonstrate relative performance over a target throughput range for the mine. The assessment demonstrates how alternative operating strategies can be used to alleviate production level bottlenecks and improve output for block cave mining operations. Outcomes from the case study are broadly applicable to other block cave operations, particularly those that will move to, or are being designed as an electric mining operation.

Keywords: *simulation, electrification, decarbonisation*

1 Introduction

Carrapateena is a copper-gold mine, which is owned by OZ Minerals, located approximately 160 km north of Port Augusta in South Australia's highly prospective Gawler Craton region. The Carrapateena mine is currently producing 4.25 Mtpa from the upper levels of an underground sublevel cave (SLC). Development of lower levels of the SLC is ongoing while the upper levels are in production.

Development for an expansion to a 12 Mtpa production rate from 2029 is currently underway, by utilising block caving for the lower portion of the orebody. The defined footprint of the block cave portion of the orebody is approximately 310 m wide and 430 m long. Given the distribution of high-grade material within the block cave portion of the orebody, the footprint has been split into two portions, BC1 and BC2. The BC1 portion of the footprint is approximately 310 m wide and 270 m long.

Access to the block cave footprint will be via two declines, with one for access and the other being utilised for a materials handling (conveyor). Once the block cave footprint has been established, run-of-mine (ROM) material from the drawbells will be trammed to a central, off-footprint tipple that feeds into an underground crushing station. The crushing station will consist of a coarse ore bin, apron feeder, jaw-gyratory crusher, crushed ore bin, and tramp metal removal before being transported to the surface crushed ore stockpile via the main conveyor system.

The pre-feasibility study (PFS) for the Carrapateena block cave expansion identified 21 t diesel loaders as the preferred means of achieving 12 Mtpa production output from the block cave footprint.

Through its Decarbonisation Roadmap (OZ Minerals 2022), OZ Minerals aims for its current operating assets to reduce Scope 1 emissions by 50% by 2027, relative to a FY21 baseline, with a medium-term commitment of net zero emissions by 2030. Scope 1 refers to emissions produced directly by operations, primarily resulting from combustion of various fuels (OZ Minerals 2022). The electrification of the materials handling system to reduce reliance on diesel equipment will form a significant part of this reduction, as will the commencement of trials of zero emissions equipment. These measures will also help to inform a pathway to reducing remaining operational emissions.

The block cave production level operations will form a significant part of the Carrapateena underground mining activities. Given that the baseline PFS assumption for the production level was to utilise a diesel loader fleet, re-evaluation of the current designed block cave footprint and operating strategy was necessary. The re-evaluation considered the electrification options available for underground mobile equipment, to enable the Carrapateena block cave operation to meet the priorities which have been set out in the Decarbonisation Roadmap.

OZ Minerals and Polymathian conducted an initial analysis of production level operations for the Carrapateena block cave as part of the PFS for the expansion to a 12 Mtpa production rate. The findings for that study indicated that reaching the full production target was likely to require modifications to the production level design and operation strategy.

Polymathian was then engaged to perform a number of operational simulations on the base case footprint design, as well as various alternative footprint designs and operating strategies. Alternative equipment, fleet size and other scenario parameters were varied to determine whether the combination was capable of reaching production targets. The design inputs to this analysis were a set of three different footprint designs catering for four operating strategies with either battery electric loaders or a combination of battery electric loaders operating in conjunction with battery electric trucks. Estimated performance for battery electric loaders of varying sizes were also provided, along with historical performance data, to inform the simulation model input assumptions. Further detail is provided in Section 2.3.

The objective of the simulation analysis was to evaluate the relative performance of alternative footprint designs and operating strategies at the target production level. Use of detailed simulation analysis ensured that interactions between loaders and effects on operational performance was appropriately accounted for, and bottlenecks or areas of concern on the footprint were identified.

2 Methodology

This paper explains the process that was followed to undertake a review of the block cave footprint proposed in the PFS, and the assessment of alternative footprint design options and operating strategies. The requirement for this analysis has been triggered by the establishment of a Decarbonisation Roadmap by OZ Minerals, to be applied to all of its current operating assets.

The review process involved a staged approach, which first required the assessment of the predicted throughput of the current (base case) footprint design utilising a battery electric loader fleet (as opposed to a diesel loader fleet). Once operational performance for the base case was evaluated, a number of concept level designs were developed, and a strengths, weaknesses, opportunities, threats (SWOT) analysis of each of these designs was completed. For each of the designs, the main aspects that contrasted were as follows:

- Location of underground crushing station/tipples relative to footprint.
- Orientation of extraction drives (EXTs).
- Inclusion of trucking loop.
- Herringbone versus El Teniente drawpoint design.
- Inclusion of orepasses.

A variety of factors were considered in the assessment of alternative concept designs including:

- Development metres.
- Simplicity of design concept.
- Location of tipples.
- Proximity to geotechnically unfavourable structures.
- Caveability.
- Ventilation.

The SWOT analysis reduced the extensive suite of concept level design options to three designs, which were then progressed for further refinement and operations analysis.

The refinement stage considered the level designs more from an operational lens, with a focus on vehicle interaction, traffic flow and ventilation impacts, among other things, for each of the designs. This ensured that the level designs and operational strategies that were progressed were executional from a high-level perspective.

The final designs were provided to Polymathian, along with equipment and operational assumptions which were to be used as inputs for the simulation model. Input assumptions were related primarily to the operational efficiency of battery electric mobile equipment fleet, obtained from historical performance data available to OZ Minerals as well as specifications from original equipment manufacturers (OEMs). The input assumptions were a critical part of the process, as the accuracy of these assumptions affects the validity of the results produced by the simulation model. These assumptions are explained in more detail in Section 2.1.

2.1 Model input assumptions

To ensure that the simulation model operations provided an accurate representation of actual production level operations, input assumptions were developed by OZ Minerals based on historical performance data and as provided by OEMs to incorporate into the simulation logic, as summarised in Table 1.

Table 1 Summary of key put assumptions provided for the simulation model

Assumption	Purpose
Drive availability	Incorporate estimation for unavailability of EXT due to drawpoint secondary breakages, services/ventilation repair, roadworks, etc.
Operating hours per day	Consideration for shift changeover, personnel breaks.
Bucket size and bucket factor	Varying bucket sizes of existing battery electric loaders considered, with a conservative fill factor for mid-cave operations.
Vehicle dynamics	Maximum speed of loaders and trucks and acceleration/deceleration on entry and exit for drawpoints, intersections or tipples.
Loader load and discharge times	Average and range for time taken load the bucket from drawpoint and discharge at a tipple or load into a truck.
Truck capacity and discharge times	Truck capacities for a range of existing battery electric trucks considered.
Materials handling system rate	Nominal rate and availability of the underground crusher, considering various outages (tramp metal, high bin, etc.). Materials handling system control system based on bin level.
Battery life	Intervals for battery changeouts and changeout time for existing technology.

2.2 Operations simulation logic

The simulation model provides a detailed representation of all production equipment operations on the footprint, as well as interfaces with (upstream) drawcall requirements and drawpoint availability and (downstream) materials handling system (MHS) availability. The model representation extends on earlier analysis of the Carrapateena sublevel cave (Hronsky et al. 2020) for the common MHS and block cave (Eustace et al. 2020) to support assessment of multiple alternative design layouts and operating strategies.

Scheduling activities and detailed equipment movement for secondary break activities are not modelled. Instead, drawpoint hang-up and oversize events are modelled together with a sampled duration for secondary break activities to occur to obtain a realistic level of availability for drawpoints (Castro & Cuello 2018; Vargas et al. 2015).

2.2.1 Drawpoint demand and availability

The relative tonnes drawn from each drawpoint is based on mine plan draw profile inputs from cave modelling software. The draw profile has been refined from the PFS to provide relatively even draw across the production level. However, a reduced number of drawpoints and draw targets in outer EXTs can limit capacity for operating strategies where loader access to EXTs is limited.

A ratio bogging methodology is used to determine the sequence for bogging drawpoints (DP) and the tonnes to be drawn. This approach maintains the relative tonnes drawn from each drawpoint (DP) to within a specified number of orders of the relative draw (percentage of the total cave) which is specified by draw profile model inputs. Figure 1 provides a snapshot of relative draw targets for each drawpoint at peak production. Ratio bogging constraints prevent excessive bogging from individual DPs by aligning order priorities with the draw profile. The constraints also prevent excessive bogging in EXTs with lower draw targets. This can manifest as lost throughput if all DPs for the current EXTs have reached their limit and the loader can't be redeployed to another EXT.

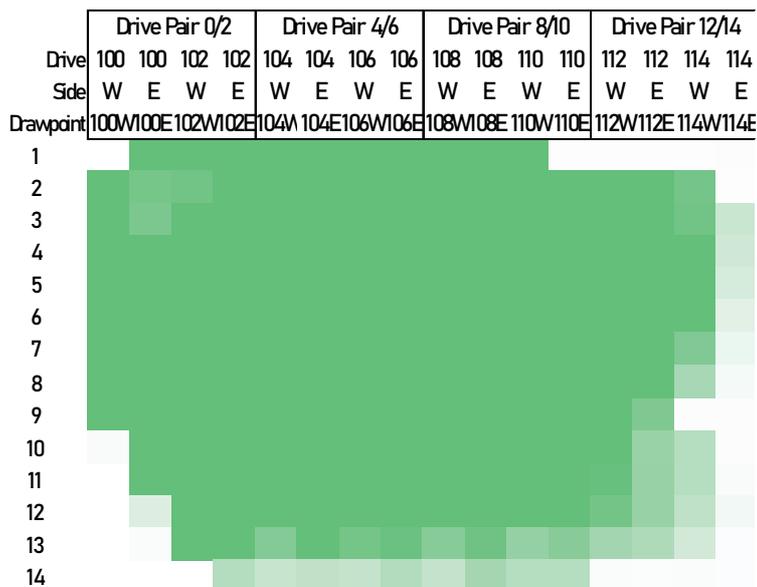


Figure 1 Relative drawcall as the block cave reaches full production for 8 EXT design (darker green represents higher drawcall targets)

EXT closures are modelled to provide a representative level of EXT availability for secondary break and road panel works and configured to be consistent with similar existing operations. EXT closures are implemented with a rolling program of 24hr closures with concurrent closure of 2 EXTs (75% EXT availability for the 8EXT layout configurations, ~78% availability for the 9EXT layout configurations) and staggered to suit each operating methodology. Figure 2 shows an example of EXT closures (greyed EXTs on the lefthand side) for the 9EXT layout configuration for BC1 (undeveloped EXTs for BC2 are also greyed on the righthand side of the figure).

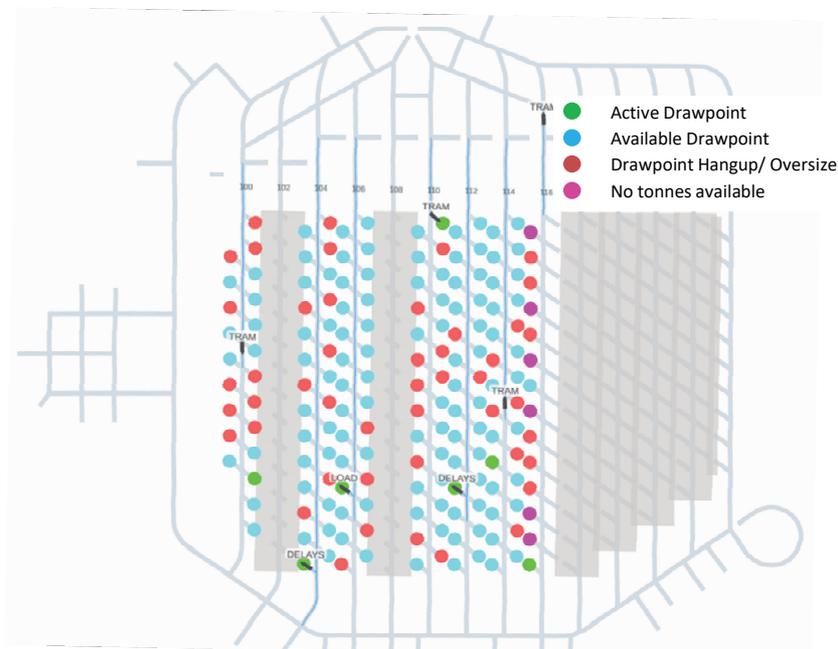


Figure 2 Representation of drive closures (greyed EXTs)

2.2.2 *Load–haul–dump and haul truck movements and interactions*

All movements for production equipment are represented in detail to enable an accurate assessment of the effect of vehicle interactions and associated delays on overall performance. Production level operations are based on a path network representation of EXTs, access to drawpoints, tipples and turnaround points. A load–haul–dump (LHD) requests and occupies and releases path segments from its origin to destination. Occupation of paths in the production level network is managed to prevent interactions between LHDs and network lockups. To continue running cycles between an allocated drawpoint and a tipple (or truck), an LHD must have both access to a drawpoint and a green light at the tipple.

The movement logic consists of several different layers:

- A fundamental movement layer to manage route finding (including vehicle facing direction) and vehicle dynamics. Vehicle performance including acceleration, deceleration, tramming speed is based on data from equipment providers and historical performance data where possible.
- Additional movement logic applied for each of the operating strategies as required to manage specific passing manoeuvres and coordination between multiple loaders operating in the same EXT or EXT-pair.
- Coordination between movement constraints and planning objectives, such as decisions for reallocation of loaders to other EXTs to align production with the draw profile, or to reallocate a group of loaders from loading on the Eastern to Western side of an EXT.

Battery changeovers are explicitly represented in the model. Allowances for shift changes, personnel breaks planned maintenance and unplanned failures for the MHS are included in throughput results. Other ancillary activities that impact the number of available production loaders from a given total fleet (such as interval maintenance and unplanned loader failures) have been excluded from the model for the purposes of this study.

2.2.3 *MHS material flow, control system, availability and reliability*

The crushing station for the MHS is modelled to provide a representation of MHS outages on the production level. The representation includes the ROM bin capacity, crusher rate, crushed ore bin (COB) capacity and control levels and belt feeder rate. Red lights cause delays to loaders and trucks at the tipple when the COB reaches the upper tolerance for the working range. Unplanned outages are applied to the MHS with time between failure (TBF) and time to repair (TTR) distributions such that the total time and number of unplanned outages per unit period is aligned with the MHS reliability used for engineering design calculations. Production operations are assumed to cease during longer planned maintenance periods. Outages and planned maintenance are configured to achieve and overall availability for the MHS of 88%.

2.3 **Operating strategy**

Several alternative operating strategies have been developed and analysed with the objective of reliably achieving the production target of 12Mtpa with an electrified mining fleet. The alternative operating strategies are focused on addressing constraints identified for the reference operating strategy that limit achievable throughput.

Relative performance of alternative operating strategies are a function of the size and orientation of the production level footprint, proximity of the crushing station, draw call and production targets. The specific conditions for production level operations for the Carrapateena block cave require consideration of alternative operating strategies and detailed simulation analysis to quantify relative performance. Similar studies have considered alternative approaches for increasing production capacity for block cave mines including extracting ore to ore passes at both ends of the layout (Shelswell et al. 2018) and continuous ore production systems (Morrison 2020). This study considers extraction of ore to a single crushing station on one side of the production level using LHDs only or LHDs and trucks operating on the single production level.

A limited number of 8 EXTs are available to achieve the production target for the BC1 footprint. This poses a challenge for a typical DP to tippie shuttle operating strategy, which can only operate a single loader in each available EXT.

2.3.1 Consideration of operating strategy changes in electrification of caving operations

Electrification of the production fleet for a block cave operation has a number of impacts on mine design and ultimate performance. Some of the operational changes include:

- The requirement for battery swaps and associated impacts on equipment availability or a need to have additional standby equipment.
- Reduced ventilation requirements for diesel particulates, potentially creating the possibility of operating more equipment on the production level, without incurring excessive ventilation costs.
- Potentially smaller equipment (bucket size), which reduces production output for a given fleet size and operating strategy.
- Changes in performance and cycle times.

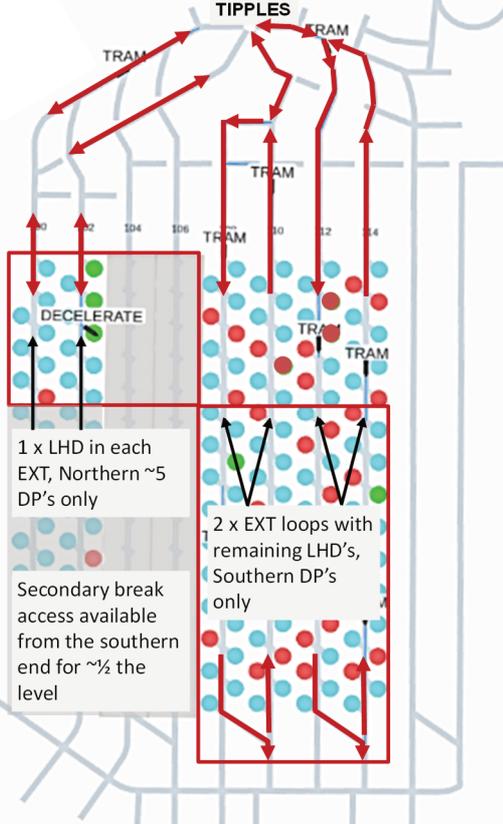
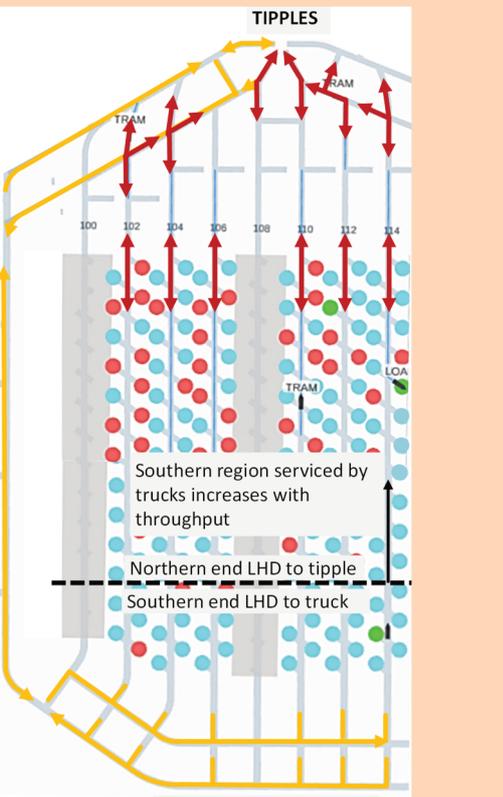
More significant impacts are likely to be realised from electrification when changes in constraints enable changing of operating strategies. Option 1 in Table 2 presents a reference scenario, which is based on a typical block cave operating strategy with a single LHD operating in each available EXT and shuttling between the drawpoints and the tippie. The reference operating strategy is only marginally capable of meeting production targets for the footprint with large capacity diesel loaders (and therefore no time for battery swaps) and an additional EXT, beyond the preferred footprint for the phase 1 mining operations.

The operating strategy falls well short of production targets with smaller capacity electric LHDs operating on the preferred phase 1 footprint. Remaining strategies presented in the table have been developed to achieve the production target on an 8EXT footprint with smaller capacity electric loaders.

Table 2 Description of alternative operating strategies assessed

Operating strategy	Schematic	Description
(Legend)		Production level network layout LHD path/direction of travel Truck path/direction of travel Active drawpoint Available drawpoint Drawpoint hang-up/oversize Secondary break closure

Operating strategy	Schematic	Description
<p>Option 1:</p> <p>(Reference)</p> <p>Drawpoint to tibble shuttle operation</p> <p>Layout: 9 EXT footprint</p>		<p>Operational characteristics</p> <p>Drawpoint to tibble shuttle operation for a single LHD operating in each available EXT.</p> <p>Minimises weighted average LHD cycle from drawpoint to tibble, with some interactions for LHDs in adjacent EXTs accessing the same tibble.</p> <p>Suited to lower throughput production levels and/or wide and shallow footprints with a higher number of EXTs relative to throughput.</p> <p>Throughput limitations</p> <p>Throughput for this type of operation is ultimately limited by availability of a critical EXT/s and performance for a single LHD operating in the EXT.</p> <p>Draw profile requirements constrain throughput for remaining EXTs to be proportional to the critical EXT.</p> <p>Mitigation measures</p> <p>A second LHD can be added to each EXT providing a marginal throughput improvement, but most of the potential benefits are lost to complex passing manoeuvres.</p> <p>Variants evaluated</p> <p>9 EXT Layout (shown)/8 EXT Layout (excluding the RHS EXT).</p> <p>1 LHD per drive/2 LHDs per drive.</p>
<p>Option 2:</p> <p>EXT loop with shuttle to tibble</p> <p>Layout: 8 EXT footprint</p>		<p>Operational characteristics</p> <p>Single-directional LHD loop operating on paired EXTs, bi-directional shuttle to tibble.</p> <p>Minimises interactions between multiple LHDs operating currently in each available EXT and provides regular LHD presentation at each tibble.</p> <p>Suited to higher throughput production levels and/or long narrow footprints with a lower number of EXTs relative to throughput. Inefficient at lower throughput levels (longer cycles).</p> <p>Throughput limitations</p> <p>Throughput continues to scale linearly with the number of LHDs but is ultimately limited by the tibble shuttle (at ~2 x reference case throughput)</p> <p>Mitigation measures</p> <p>Layout not refined to suit this operating strategy – reduce loop to tibble distance to further increase throughput.</p> <p>Variants evaluated</p> <p>12 Mtpa target/max throughput.</p> <p>Lower speeds, 2 x EXT loops.</p>

Operating strategy	Schematic	Description
<p>Option 1/2 Hybrid Strategy:</p> <p>Drawpoint to tipples shuttle operation for northern DPs only</p> <p>EXT loop with shuttle to tipples for southern DPs</p> <p>Layout: 8 EXT footprint</p>	 <p>TIPPLES</p> <p>TRAM</p> <p>DECELERATE</p> <p>1 x LHD in each EXT, Northern ~5 DP's only</p> <p>2 x EXT loops with remaining LHD's, Southern DP's only</p> <p>Secondary break access available from the southern end for ~½ the level</p>	<p>Operational characteristics</p> <p>Drawpoint to tipples shuttle operation for northern DPs (Option 1), EXT loop with shuttle to tipples for southern DPs.</p> <p>More efficient than either Option 1 or 2 at the target throughput level and improved access to DPs for secondary break relative to option 2.</p> <p>Throughput limitations</p> <p>Throughput can be scaled by reducing the number of northern DPs serviced by a single LHD operating in EXT northern ends and increasing the number of LHDs operating in each EXT loop, but ultimate capacity is less than for Option 2.</p>
<p>Option 3:</p> <p>Drawpoint to tipples shuttle operation for northern DPs</p> <p>Loader to truck for southern DPs and southern trucking loop to tipples</p> <p>Layout: 8 EXT footprint</p>	 <p>TIPPLES</p> <p>TRAM</p> <p>LOA</p> <p>Southern region serviced by trucks increases with throughput</p> <p>Northern end LHD to tipples</p> <p>Southern end LHD to truck</p> <p>Southern Trucking Loop</p>	<p>Operational characteristics</p> <p>Drawpoint to tipples shuttle operation for northern DPs (as for Option 1), LHD to truck for southern DPs and southern trucking loop to tipples.</p> <p>Weighted average cycle time and throughput target for northern end DPs to tipples is reduced allowing the overall production target to be achieved. Remaining DPs at the southern end are serviced by a small loader/truck fleet. The relative size of the region serviced by trucks increases with the throughput target.</p> <p>Requires more operating equipment to achieve the same throughput as Option1/Option 2.</p> <p>Throughput limitations</p> <p>Relatively high achievable capacity, ultimately limited by the capacity of a single loader to service ~half of each EXT, interactions between trucks and loaders on the eastern side of the layout and between loaders at the tipples.</p> <p>Variants evaluated</p> <p>Relative throughput for N/S footprint.</p> <p>Truck-LHD ratios.</p>

Operating strategy	Schematic	Description
<p>Option 4:</p> <p>LHD to truck and trucking loop to tipples for both Northern DPs and southern DPs</p> <p>Layout: 8 EXT footprint</p>		<p>Operational characteristics</p> <p>LHD to truck and trucking loop to tipples for both northern DPs and southern DPs.</p> <p>Capable of achieving high production level throughput but requires more equipment to achieve the same throughput as other operating strategies. Better suited to layouts where the tipples is distant from the production level footprint.</p> <p>Throughput limitations</p> <p>Capacity is limited by the critical (highest drawcall) EXT with one LHD operating at each end. Truck interactions also cause some delays at high throughput levels.</p> <p>Variants evaluated</p> <p>Relative throughput for N/S footprint.</p> <p>Truck-LHD ratios.</p>

3 Results

Each of the operating strategies described in Table 2 has been analysed using the simulation model. Analysis was focused on identifying options that are capable of reliably delivering the 12 Mtpa production target with an electric production mining fleet. Configuration details have been refined for each option, to achieve the most efficient operation at the target production rate (e.g. minimum number of LHDs and trucks required to reach production targets are presented for each operating strategy).

Some of the operating strategies are extendable to throughput levels significantly higher than the production target of 12 Mtpa, by continuing to increase the size of the production fleet. Capacities for specific configurations are provided, although a comparison of the ultimate capacity for each option was not a focus for the present study. A full assessment of the MHS and surface processing design would need to occur prior to properly considering scenarios which predict a throughput of greater than 12 Mtpa.

Operational characteristics and performance for each operating strategy are provided in Table 3. The relative performance of alternative operating strategies is specific to the production level layout, draw profile and other characteristics of the Carrapateena block cave mine. Relative performance of the different operating strategies is particularly affected by the production target, size and shape of the footprint and proximity of the crushing station and will vary for different operations.

Table 3 Key findings for alternative operating strategies

Operating strategy	Key findings
Option 1: Drawpoint to tippie shuttle operation	<ul style="list-style-type: none"> A drawpoint to tippie LHD shuttle operating strategy is just capable of reaching the 12 Mtpa production target (12.1 Mtpa) with a 9th EXT and 7 × large capacity 21t diesel LHDs. Use of a 9th EXT for BC1 is undesirable as it compromises the viability of the second phase of the block cave (BC2). The operation is ultimately constrained by EXT availability (75%) with one loader only per EXT and the draw profile (the EXT with the highest draw requirement limits the overall throughput for the cave). 18 t electric LHDs fall well short of the production target (9.8 Mtpa), due to the smaller bucket size and battery change requirements. An extension of the Option 1 operating strategy to allow a second LHD into some EXTs (with passing manoeuvres at the turning bay) allows the production target to be reached. However, a second LHD in EXTs introduce significant passing delays for this operating strategy, resulting in a relatively inefficient operation, with 11 LHDs required to reach the 12 Mtpa production target.
Option 2: EXT loop with shuttle to tippie	<ul style="list-style-type: none"> Achieves 12.1 Mtpa with 10 × 18 t electric LHDs or 13 × 14 t electric LHDs on an 8-EXT layout (with 75% EXT availability). 3 × concurrent EXT loops (6 EXTs) are required to reach the production target. Also capable of achieving production targets when maximum loading speeds are reduced (4 m/s) with additional LHDs. Ultimately constrained by tippie capacity at ~16.2 Mtpa for 18 t BeVs and ~12.6 Mtpa for 14 t BeVs for the reference tippie design but could be increased further with refinements to the layout to suit the operating strategy.
Option 1/2 hybrid	<ul style="list-style-type: none"> Achieves the production target with 9 × 18 t electric LHDs through improved productivity (relative to Option 2) for LHDs shuttling between northern DPs in the tippie. Also provides improved accessibility for secondary break.
Option 3 Drawpoint to tippie shuttle operation for northern DPs Loader to truck for southern DPs and southern trucking loop to tippie	<ul style="list-style-type: none"> Production targets can be achieved with 5–6 × 18 t electric LHDs operating in the northern end of the production level and 2 × 18 t electric LHDs operating in the Southern end of the production level, supported by 3 × 42 t haul trucks, which access the tippie at the northern end via a truck loop on the Eastern side of the production level. Use of a small LHD and truck operation on the southern end of the layout is effective in both reducing the throughput target from the northern end to be achievable using a DP to shuttle type operation and reducing the average tramping distance and cycle time on the northern end. Capacity is ultimately limited by interactions between trucks and loaders on the western side of the layout and between empty and loaded trucks on the single carriageway between northern and southern truck loops.
Option 4 LHD to truck and trucking loop to tippie for both northern DPs and southern DPs	<ul style="list-style-type: none"> A northern truck loop reduces LHD cycles between DPs and the end of the EXT (truck loading location), increasing the throughput able to be achieved with 6 × 18 t electric loaders (and 5 × 42 t haul trucks) at the Northern end to 10.5 Mtpa. The throughput requirement for the Southern end is reduced to 1.5 Mtpa, which can be achieved using 1 × 18 t electric loaders and 2 × 42 t haul trucks. This operating strategy is capable of achieving the production target but requires a significantly larger production fleet than alternative operating strategies for an equivalent throughput.

A relative comparison of operating efficiency is shown in Figure 3 for each of the operating strategies. For the purposes of the comparison, production operational fleet size is shown in terms of total number of loaders and trucks in operation to achieve the indicated throughput. The results show that a hybrid (Option 1/2) operating strategy provides the most efficient operation at the 12 Mtpa production target, in terms of the fleet size required to achieve the target. Option 2 and Option 3 are also capable of reaching production targets with a slightly larger fleet size. The hybrid (Option 1/2) and Option 2 provide a more efficient

operation at higher throughput levels as both Options 3 and 4 require additional trucks and loaders as throughput is increased. Operating efficiency together with other considerations such as development metres required for each option, access for secondary break and EXT maintenance and ventilation will form the basis for the choice of operating strategy.

A number of factors that affect the performance for each operating strategy come into play at different points as the throughput target and production fleet size is increased. These influences affect the relative performance of each operating strategy shown in Figure 3 over the throughput range shown and include:

- LHD interactions at the EXT turning bay (Option 1 – 2 × LHD /EXT variant).
- LHD interactions at the tipple (for Option 1 and 3, for Option 2 as it approaches maximum throughput).
- Draw call constraints (which affect EXT usage for outer EXTs, the plateau in fleet size for Option 1 – 2 × LHD /EXT variant and change in inclination in fleet size for options 3 and 4).
- Truck interactions (Option 3 and Option 4).

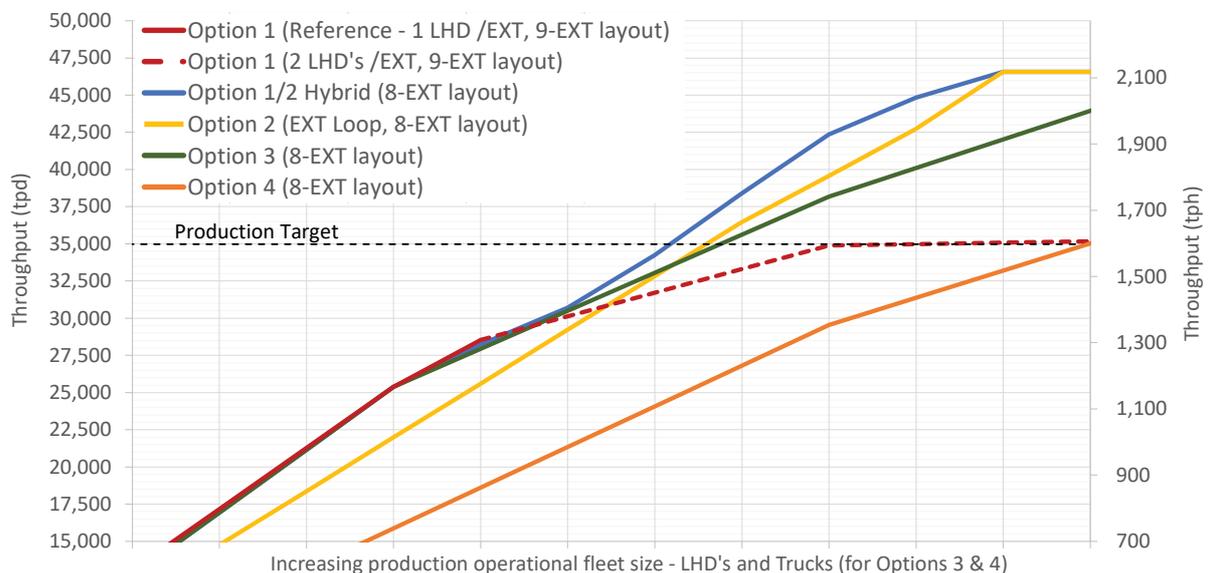


Figure 3 Comparison of efficiency for alternative operating strategies

3.1 Additional considerations for results

Ancillary operations other than battery swaps for electric LHDs and trucks are not explicitly represented in the version of the simulation model used for this study. An allowance of two hours per day was used to approximate impacts of shift changes and personnel breaks. Equipment fleet numbers are operating' vehicles only and do not include consideration for equipment availability and utilisation. Some operating strategies are likely to be affected more by variability over time in the number of vehicles available for production than others.

The analysis presented is focused on a peak production period for the BC1 phase of the mining operation. Relative performance of alternative operating strategies will be different for other production phases.

3.2 Relationship between the required number of trucks and LHDs

The relationship between number of operating trucks and LHDs was assessed as part of the evaluation of operating strategy Options 3 and 4. Figure 4 shows the effect on throughput of increasing the number of trucks servicing six LHDs operating at the northern end of the production level. Diminishing returns for additional trucks are observed for truck fleets larger than five as the LHD cycle time typically provides sufficient time for the next truck to present at the EXT.

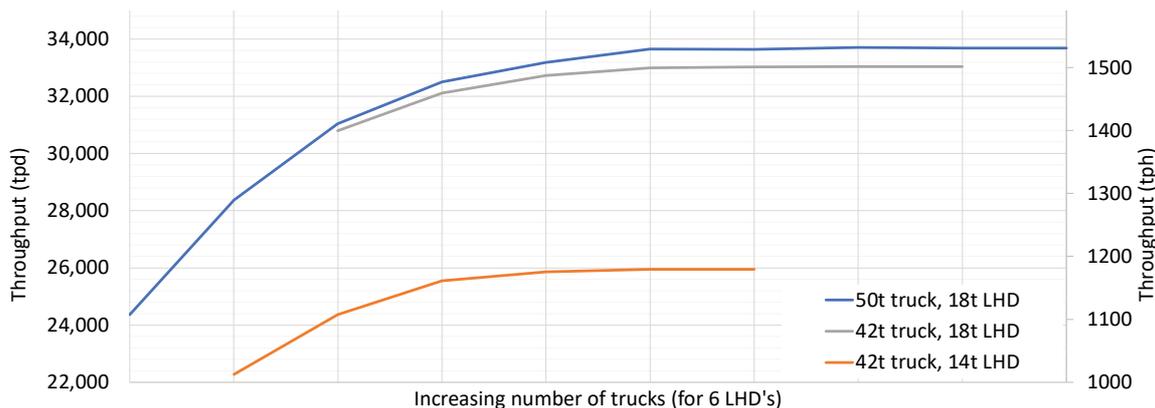
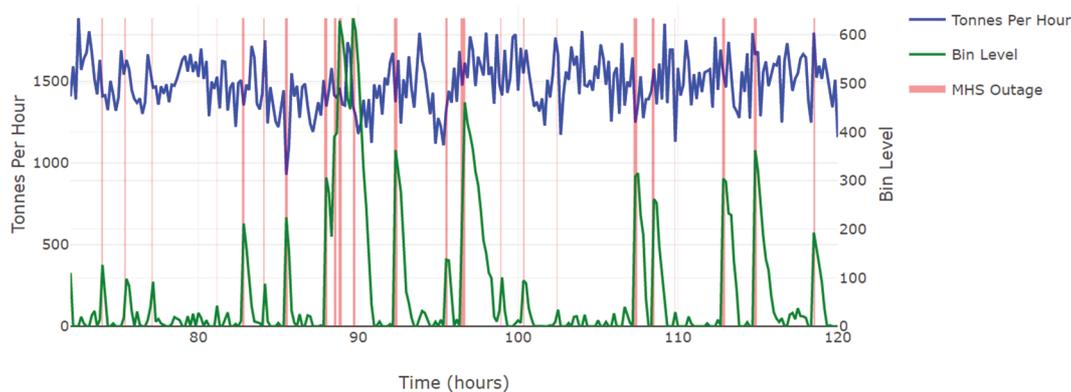


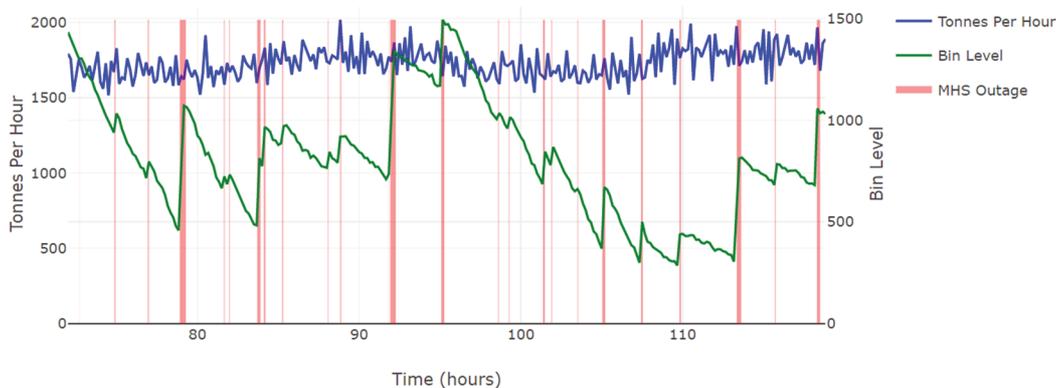
Figure 4 Relationship between the number of LHDs and required number of trucks

4.3 Tipple presentation uniformity and interface with MHS

The choice of operating strategy also has an impact on the uniformity of presentation of LHDs and trucks at the tipple and therefore variability in production rate. This affects the interface with and requirements for the MHS system (such as the working capacity of the crusher ore bin). Figure 5 shows the difference between variability in rate of presentation at the tipple for Option 1 (top) and Option 2 (bottom). Option 1 produces irregular LHD presentation frequency as a result of changes in the active DP, which affect the LHD cycle time and production rate. In contrast, LHD presentation rate at the tipple for Option 2 is only affected by the side of the EXT accessed and remains relatively constant regardless of the assigned DP. This has the potential to reduce production rate variability and crushing station buffering requirements.



(a)



(b)

Figure 5 Comparison of LHD presentation rates (tph) at the tipple for (a) Option 1; (b) Option 2

4 Conclusion

The results of the simulation comparison have shown that there are several alternative combinations capable of meeting a throughput of 12 Mtpa for the Carrapateena block cave with a battery electric equipment fleet. The alternative footprint designs, operational strategies and equipment fleet combinations show potential for meeting the decarbonisation of footprint activities objective while maintaining production at target levels. Based on the set of operating parameters for the Carrapateena block cave, in terms of footprint dimensions, tipple locations etc., several of these design options outperform a typical loader to tipple operational methodology that is often employed in a block cave mining operation.

Despite the increase in overall tramming distance, Option 2 provides a sound solution in meeting the 12 Mtpa throughput, without the requirement for a significant increase in additional development expenditure when compared to the base case design, which may result in a negative impact to schedule or a noticeable increase in mobile fleet size. Additionally, this option provides an efficient means for increasing throughput beyond production targets notwithstanding other potential system constraints such as the capacity of the underground crushing station. The Option 2 design also allows the optionality to start with and/or return to a more conventional loader to tipple configuration. Alternatively, a combination of both the EXT loop operating strategy (Option 2) and the conventional drawpoint to tipple operating strategy (Option 1), could be implemented (the Option 1/2 hybrid scenario), subject to the prevailing operating parameters over the life of the operation.

Further work is required to ensure the chosen footprint design option can be supported from a ventilation, scheduling, ground support, etc. point of view, as well as a consideration for the impact of interaction with ancillary equipment on the footprint.

The operating strategies developed and tested for the study have shown the potential to provide significantly increased throughput for both existing block caving operations and future developments, particularly where the width of the orebody limits the number of EXTs. In some cases, throughput increases may be able to be achieved by increasing the LHD fleet without changes to the extraction level network. In addition to increased throughput, operational flexibility is afforded by allowing more equipment to operate effectively in an area of focus on the production level. Refinements to the operating strategies tested may enable additional capacity increases, such as refining the tipple layout to minimise LHD interactions or developing a variant with ore passes at each end of the extraction level.

It is important to note that the accuracy of the results of the simulation are highly dependent on the accuracy of the input assumptions, and an appropriate amount of rigour should be applied when confirming these assumptions prior to input into a simulation model. It is also worth noting that different operating strategies may be more effective at different stages of the life of a block cave operation.

This paper has demonstrated the importance of considering the performance of a range of footprint design options and alternative operating strategies when developing a block cave mine and how simulations are an effective tool to complete this analysis.

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