Caving 2026 – A van As, D Cumming-Potvin & J Wesseloo (eds)

doi:10.36487/ACG_repo/2645_35

Automating block caves: learning from the past

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Abstract

Load-haul-dump (LHD) automation can be a key control to minimising risk during mid- to late-stage block cave production where there is an increase in fines and elevated inrush risk. However, in early stages of design and implementation there is a clear tension between cave establishment, ramp-up, productivity and capital cost, and the installation and use of automation. Mobile fleet automation systems have been installed at several high-profile operations across the globe – despite this, block caving production remains predominantly manual, even those operations that have seen historical deployments of large-scale autonomous solutions.

The impetus to transition to a remotely operated fleet has often been a result of operational needs – mature caves pose a heightened inrush risk to personnel and this increased risk becomes unacceptable over time. Even though some mines have promoted the productivity, efficiency or other safety benefits that may come with automation, the autonomous system is often implemented based on an ad hoc trigger late in the life of the cave. These mines are not set up to operate effectively using remote equipment and have an operational culture that is not prepared for, or even hostile to, the change in approach.

Designing for eventual automation is crucial to the late stages of a block cave and should be examined in the early stages of study work. Establishing practices to prepare the operation for a transition to remote production is essential for a modern block cave. How this can be done well and how it has been unsuccessful are both critical learnings from past and active operations.

Keywords: *block caving, automation, remote, teleremote, risk, controls, inrush, mud rush, productivity, efficiency, safety, implementation, ramp-up, TARP*

1 Introduction

Block caving is a prime candidate for automation of the mining process. The static operating footprint, repeatability of the mining sequence and the presence of mining hazards to the workforce all combine to produce an environment that is amenable to automation. While fixed materials handling systems (MHS) across the underground mining industry have largely moved to computerised control, the application of automation to the mobile fleet remains inconsistent or even absent. This paper focuses on the latter, narrowing a lens on the application of load–haul–dump (LHD) units on the production footprint of block caves.

The first generation of guided mobile vehicles (Roberts et al. 2000) roughly coincided with the introduction of LHD units into the underground mining industry in the 1960s (Weston 2022). However, it was not until the 1980s that a campaign of development to introduce remote tramming capability for these 'new' LHD units commenced. These early years leading towards commercialisation in the 2000s were fraught with failures and novel approaches that are no longer seen in the industry (Roberts & Corke 1997; Corke et al. 1998).

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Commercialisation of these systems took hold at the turn of the millennium, with Caterpillar's Minegem (now Underground Command) system being built from the Dynamic Automated Systems (DAS) project, and Sandvik's AutoMine® finding success. Subsequent systems from original equipment manufacturers (OEMs) such as Epiroc (historically Atlas Copco Wagner) and independent third-party companies (RCT, Hardline and Nautilus) also entered the market. Though these third-party systems found great success in underground stoping operations, adoption of OEM-based fleet automation systems was largely the target of block caving operations, with published automation systems in trial or in full-scale adoption described in Table 1 based on the authors' knowledge.

Table 1 Snapshot of block caving automation systems

Mine	System	Status	Further commentary
Finsch (South Africa)	Sandvik AutoMine	Commissioned in 2005	Only applied to trucks, full load–haul–dump (LHD) fleet deployment not successful, system decommissioned with completion of block
Northparkes (Australia)	Various	Trials from 1998, full footprint automation 2015	CSIRO DAS which developed into Caterpillar Minegem initially trialled before subsequent deployments of Sandvik AutoMine for later block caves
Cadia (Australia)	Various	Trials from mid-2000s, full footprint automation in late 2010s	Initial Caterpillar trials on Ridgeway sublevel cave transfer level led to repeated attempts to fully automate Ridgeway Deeps block cave with a Sandvik system Epiroc Automation system deployed in Cadia East
PTFI (Indonesia)	Various	Limited adoption from 1990s, widespread application from mid-2010s	Early adoption of RCT system, before use of Caterpillar system in late 2000s including full footprint application at deep ore zone, current trials of Sandvik AutoMine
El Teniente (Chile)	Sandvik AutoMine	Initial trials in 2004, wider adoption in early 2020s	Development of the Sandvik AutoMine LHD system commenced in 2004, with sporadic application across blocks in the years since
New Afton (Canada)	Sandvik AutoMine	Deployment from 2017	AutoMine system replaced line-of-sight teleremote systems and has continued to be operated at subsequent blocks

Deployment of these systems was driven by a combination of productivity, efficiency or safety requirements. Because business improvement programs often find alternative methods to delivering productivity and efficiency gains, safety is typically the driver for deployment of an autonomous system. The mining hazards present not only pose a risk to the operational workforce, but also to the integrity of the operation itself, and with the scale of capital associated with large block caves potentially at risk, the additional cost associated with automation is therefore lower than the revenue gained from increased production. By adding automation or telepresence, it is possible to remove the risk to people and improve business outcomes (Cronin 2017).

Because of the assumed value of automation in block caving, studies often promote automation as part of their production plan – both Carrapateena (OZ Minerals 2020) and Red Chris (Newcrest Mining Limited 2021) block caves show plans for automated production in their respective studies, though there is some hedging in the plan to allow for the transition to occur during steady-state operations. This optimism is often lost during execution; where autonomous infrastructure is delayed and deferred, readiness programs do not account for a remote transition, trials replace implementation and instead, LHD automation programs are deployed in a haphazard manner as a response to unsafe conditions, particularly to maximise reserve recovery. The operations discussed within this paper displayed many of these patterns.

2 Understanding automation implementation

Block caving has continued a trend of increasing block heights (van As et al. 2011) and the risk profile associated with these caves is changing. The depth, stress, seismicity and likelihood of inrush increasing with those block heights is matched by a desire to fully recover all the material within the caving column – even in the face of these more challenging conditions. A growing emphasis on minimising vehicle interactions within the mining industry also supports alternative engineering controls in the production space. Finally, hazardous atmospheres remain a constant concern, with tightening of exposure limits for key contaminants (silica, diesel particulates and nitrogen oxide (NOx) family gases) and key caving deposits dealing with hazardous SO_2 and radon levels.

Automation therefore is often marketed as a simple solution to these challenges (Moss et al. 2024). It is evident that adopting technology such as this occurs with resistance – the additional cost, cultural change and required support structures are not well scoped and are key reasons for delay in implementation. Only when the problem becomes a crisis, the workforce may rally behind the technology required, but the challenge remains in enacting change before the risk event occurs. The expected automation strategy should be a core pillar in the mining plan from the outset and commitment to keeping it as a component throughout the entire study, implementation, development and production sequence is critical – too often automation targets are reduced from full implementation to transition implementations, as required, or worse, entirely omitted in later study stages. The opposite problem – where automation is identified as a need for the business only after the rest of the operating model is established – also sees substantial challenges, as the ability to pivot becomes more difficult and the cost to change the operation increases (Figure 1).

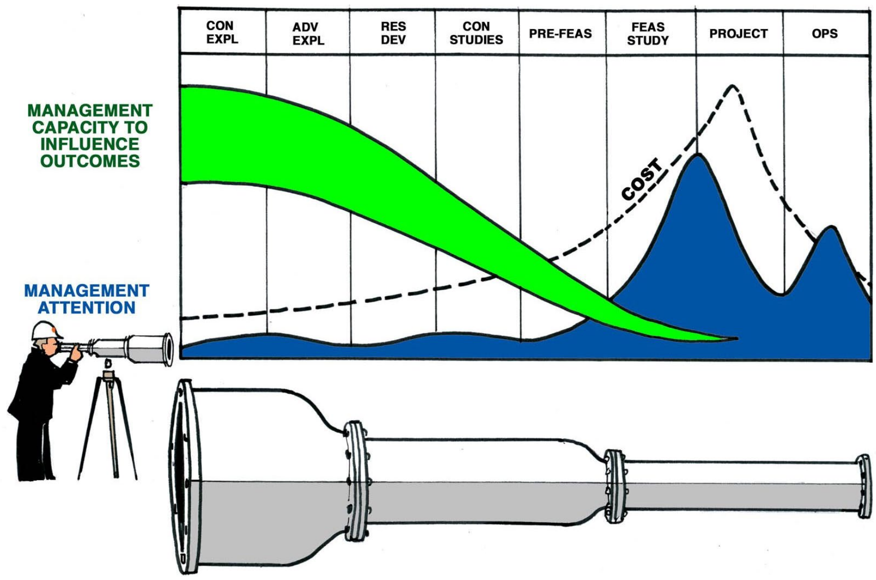

Figure 1 Capacity to influence outcomes during study staging from (Logan 2025)

Where automation finds itself addressing other issues, a thorough investigation of the inputs and expected outputs is required. Reduction of operational staff may provide an operational expenditure reduction, but this may not be realised until the automation system is fully implemented and operating at scale. Continuity of production over shift changes is often more easily achieved by sites adopting continuous hot-seating and staggered shift approaches but this is at odds with a headcount reduction. Even productivity gains are difficult to achieve outside of these additional operating hours as manual operators still consistently outperform the control systems onboard even the most modern LHD units.

3 Designing for (optimal) automation

Taking inspiration from the military – prior to commencement of any program, the current operating state as well as the envisaged future operating state should be established. To undertake this activity, the ISA95

Framework and GMG Mining Automation Maturity Model can be used to inform and guide the levels that activities are graded. Mapping these states against each other should then inform the focus of the work and a technology readiness level (TRL) index applied to potential solutions to achieve the state uplift.

OEM automation systems have continued to mature in the market and now have so many features that selection of an autonomous system should no longer be a driver for implementation success. Instead, the fundamental systems that underlie the automation solution instead provide a clearer avenue for improvement. This bottom-up approach to technology selection focuses on culture, mine design, schedule and enabling systems to ensure that the final implementation is successful.

3.1 Culture

Transitioning to an automated operation requires the workforce to be engaged and aligned with the vision for the mine. Planning for success of the system requires staff to be upskilled and trained in these styles of operations – from the engineers designing the system who require exposure of other operations where success has been seen, to the operational staff who may fear their role is being taken from them. This upskilling is not always practical – some systems have no established training packages and development with vendors is essential – but existing training systems should be leveraged rather than treating technology as a bespoke portion of the business.

As a part of this process, the team needs to appreciate that autonomous mining results in a workforce transition. Mining teams change from actively undertaking tasks and are responsible for their execution, through an intermediary step of isolated responsibility for only select key tasks in the process, before finally becoming a supervisory workforce that monitors equipment that operates within an engineered profile. Some positions (particularly support and maintenance functions) see little change other than additional scope, whereas traditional mining roles can be completely disconnected from their original function.

Adoption of many of the technology layers along this process is not always a successful proposition – it requires workforce resilience and an understanding that repeated attempts to establish new ways of working will be needed. Even once systems are operable, providing opportunity for the team to use them in anger prior to their function becoming necessary is important in ironing out concerns and issues.

3.2 Mine design

Accounting for best practice autonomous solutions should be made at the earliest stage of study work to capture the total requirements of all systems involved, understanding their implementation practicalities prior to mine designs being rigidly fixed which can be to the detriment of the technology. Some key operating paradigms that should be considered through this process are discussed below.

Current underground automation systems are modelled on an exclusion principle, enforced by barrier systems. Until this approach changes (such as the adoption of a mixed-traffic safety system), designing for the practicalities of this fundamental architecture is necessary. Barriers are often placed wherever space remains, rather than being included in the design as a core component of the level geometry. Likewise, an autonomous LHD unit does not have the same performance characteristics as a manually operated machine, and this should be considered prior to implementation. These considerations, among many others (Table 2), should be addressed prior to implementation.

When retrofitting autonomous systems, sites often aim to deliver the same tonnage profile through the same existing site bottlenecks. This paradigm does not account for the changing dynamic of autonomous productivity – a reduced, individual LHD instantaneous rate is observed from an automation system, but it is often overcome with a continuous, steady operation model across the fleet. As a result, a lack of surge capacity in the interface between the systems can result in downstream production stoppages that cannot be immediately rectified by 'bogging harder' as the system has a lower peak production rate. Designing the downstream systems to have increased tolerance for these outages and overspecifying the autonomous system to maintain downstream bottlenecks is therefore critical. The cost of additional capital for more autonomous LHD units than their manual counterparts and a flexible, feature-rich system may be warranted if the benefit is the continued delivery of the site production plan.

Table 2 Brief design considerations for automation

Consideration	Commentary
Barriers	
Location and distance	The distance between each of the detecting devices in a barrier set should be defined by the stopping distance of operating machinery. Consider using a functional safety standard (e.g. IEC61508/62061) to inform estimations. Barriers should be located away from drawpoints, with sufficient room for vehicles to navigate in front of the barrier without interacting with the barrier itself.
Barrier protection	Barriers should be recessed in bespoke cuddies mined during development or in stripped areas.
Inrush run-out	If automation is used an inrush control, the run-out of a typical event will be contained within the barriers.
Machine transition	Introduction and removal of equipment from the system should be carried out in a safe access area.
Spurious trips	Personnel should not need to pass through or work/park-up adjacent to the autonomous area.
Zoning	
Area segregation	Division between crusher tipples/shared perimeter sections/other logical connections should be enforced by traversable barriers that can be dynamically muted/activated.
Minimal zone size	Dividing active work areas should be done wherever practicable to allow manual activities.
Machine performance	
Cornering	The control loop of all current market solutions is not as effective as a human operator. This is especially pronounced around corners where sharper corners cause remote equipment to slow down proportionally more.
Speed	High-speed tramming is possible in straight drives and is comparable to manual. Avoid corners.
Tunnel geometry	Positioning of equipment in a GPS-denied environment becomes more challenging when accounting for sub-300 mm clearances that are commonplace. Consider wider drives without increasing the size of the LHD units.
Bucket fill	Bucket fill is assumed to be up to 20% less, with increased volumes of spillage.
Bunding	Producing an effective, large bund is impractical remotely. Bunding causes significant damage to drawpoint backs and sidewalls as well as services located at the drawpoint.
Roadways	
Concrete surface	Historically a necessity, and still the preferred surface to maximise high-speed operations. A higher-performing surface in manual operations also results in autonomous improvements.
Maintenance	Modern systems handle damaged roadways and can dynamically adjust speed to account for damage.
Materials handling systems interface	
Dumping	Remote dumping remains slower than manual tipping, even in idealised run-of-mine bin configurations. Some tipping configurations require teleremote intervention and should be avoided.
Surge capacity	The recovery time associated with rectifying issues in automation necessitates greater surge capacity.
Direct loading	Direct truck loading should always be avoided. Fixed infrastructure and surge capacity should be used.

The elements from Table 2 have been incorporated into an idealised footprint design shown in Figure 2. This design is based on an on-footprint crushing configuration for a relatively small, single block cave and would not be applicable for all deployments when considering nuances of each site.

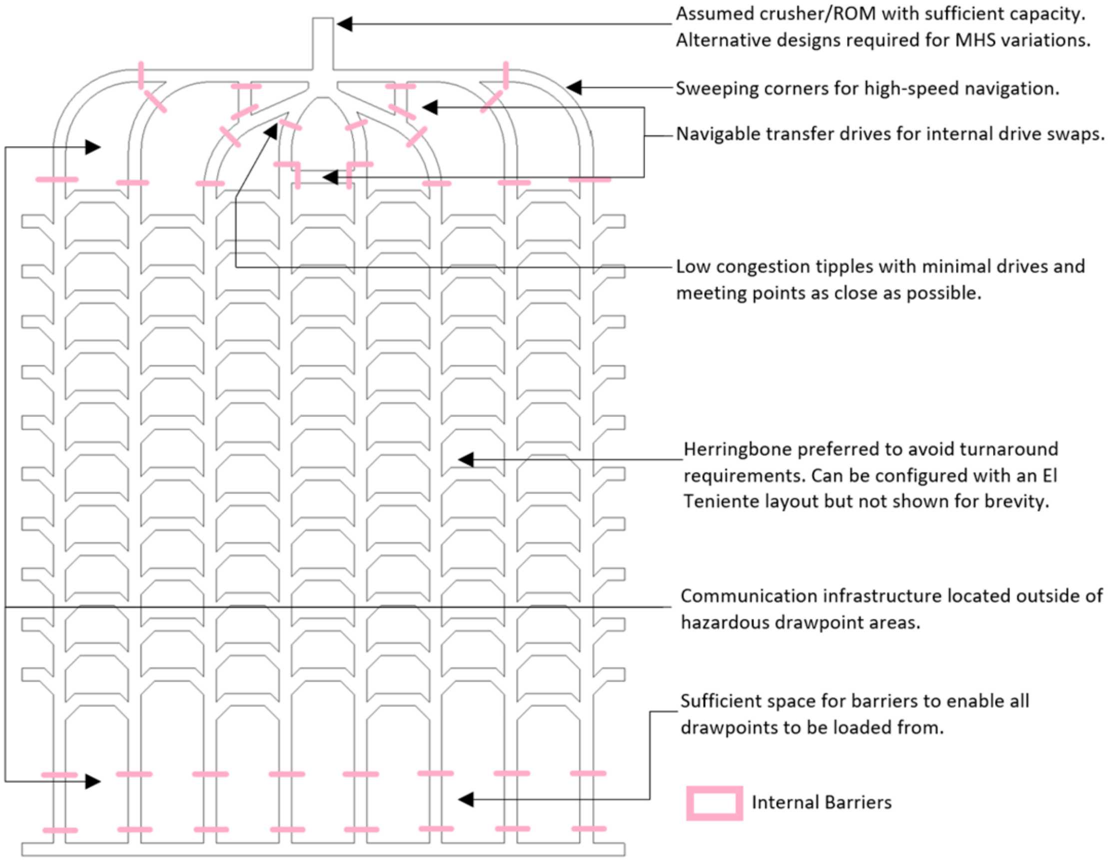

Figure 2 Idealised autonomous footprint level layout. Not to scale, and without any geotechnical or site-specific considerations

3.3 Schedule

Without incorporating automation into the mining schedule, delays in its implementation are expected, and production interruptions are likely as the system comes online. Most importantly, a good understanding of the timing requirements of automation driven by the exposure profile of the operation should be incorporated into the broader mining schedule. Some sites use a certain height of draw as an analogue for fine fragmentation and increased inrush risk, others use particle flow modelling to indicate mud and fines dilution, but most commonly, the system is only adopted reactively when certain conditions are met and the threshold for safe manual operation is exceeded. This latter approach should be avoided, even if it is substituted with a coarse, imperfect trigger.

Once an implementation timing is scheduled, the ramifications on the production profile, system dependencies and change management can be better defined and understood. Realistic deployment timeframes can be produced – at Northparkes for example, it took from 2011 to 2015 for the entirety of the E48 block cave to operate autonomously at nameplate rates (Cronin 2017). Beyond the production ramp-up of the autonomous system, the workforce requires upskilling and familiarisation. The existing LHD operators are largely responsible for single machine operation on the footprint, and navigating the transition to a remote, computer-based, multi-machine skillset where the emphasis is on monitoring and bucket loading exclusively is not a trivial task.

Regardless of implementation timing, there are activities that are effectively time independent. There is no simple method to retrofit an autonomous system to a mine design that does not account for its eventual adoption, so its inclusion during all design stages is paramount. Similarly, late-stage construction of barrier cuddies and infrastructure locations is disruptive. This can be resolved by excavating them at the same time as initial development.

Committing too early in the process also has detrimental effects. Aggressively automating during cave establishment can lead to competing interests, and early over-commitment to automated loading with potentially high secondary break requirements can limit production rates. Manually operated equipment fitted with the additional automation hardware can result in additional costs and downtime prior to commissioning and should be avoided.

3.4 Enabling technology

To meet the needs of the business, an autonomous solution requires effective supporting technology. Three key enabling technologies form the backbone of any autonomous deployment – communications, an operations centre and a dispatch system.

Wi-Fi has been the dominant communications solution for high-performance autonomous deployments over the preceding two decades, but the introduction of private cellular networks in the underground space brings numerous improvements. Cellular systems have superior long-distance propagation of wireless signals, reducing the infrastructure requirements in hazardous areas. Ideally, communications infrastructure is situated outside of drawpoint areas, which is difficult to achieve with Wi-Fi in long drives. Handover between cellular arrays is considerably more seamless than most proprietary Wi-Fi roaming solutions; this minimises interruptions and safety stops due to dropouts. Additionally, cellular networks with robust mobile quality of service enable prioritisation of digital traffic (especially safety data) that cannot be achieved with Wi-Fi.

Controlling the system is best undertaken in a purpose-built remote operations centre. Care should be taken to design centres for human factors rather than simply locating remote operator stations in a spare office. Personnel can be further removed from the mining hazards using robust, wired networks back to these centres rather than an equivalent underground or 'tele-hut' configuration. Consolidation of remote activities can improve the effectiveness of such a control room, incorporating fixed plant control among others. Relocation of control centres off-site enables alternative rosters and employment strategies to be considered, and in some cases, even aggregation of multiple operations into an integrated centre. However, because these centres remove a significant portion of the workforce from the underground workings, they introduce concerns regarding the ability to respond to system outages and emergency response, the latter of which requires careful consideration for each operation. Where operations commit to total autonomous production, consideration must be given to whether it is acceptable to revert to manual operation following an outage.

The ability for autonomous systems to execute and report progress on work incentivises the use of dispatch systems. Rather than traditional paper-based and bucket-counting strategies, a real-time dispatch system can continually optimise the production profile, accounting for tonnages, geotechnical constraints, downtimes, predicted grade, and other requirements. Additionally, the systems can enforce compliance to the directed instructions and reliably flag deviations made by operators.

4 Case studies: Northparkes and Cadia

Putting these concepts into action can be understood in their application at two well-known operations with automation programs – Northparkes and Cadia Valley Operations. Both operations had multiple block caves with automation programs, some of which were publicly successful, though neither have had permanent, continued success with complete automation deployments.

4.1 Northparkes

Northparkes was an early development location for many LHD systems, with E26 Lift 1 being a significant prototype testbed (Roberts et al. 2000), E26 Lift 2 continuing this research and undertaking large-scale trials before E48 Lift 1 was fully automated with the Sandvik AutoMine product. E26 Lift 1 North (L1N) is the current operating block cave and has continued this commercial adoption. E48 and LN1 form the basis of this case study.

4.1.1 E48

E48 achieved full production automation in 2015, approximately 5 years after deployment in 2011 (Cronin 2017) following initial cave establishment in late 2008/early 2009. Tethered Sandvik LH514Es formed the backbone of the production fleet. A staged deployment was employed (Figure 3), progressing across the cave footprint from Zone 4 through to Zone 1. A final zone, the extraction level access (ELA), was also automated to address drawpoints that could not otherwise be loaded from as the LHD unit would breach the originally installed barriers. This approach allowed for incremental deployment without impacting manual production in adjacent areas due to the independent tipple configuration. This system resulted in up to 20% higher daily production per LHD unit at 76% of the cost of the manual equivalent (Cronin 2017).

Figure 3 Final E48 Lift 1 zoning, after (Snyman et al. 2016)

The success of this system has been discussed at length. A surface level comparison of the positives of the E48 mine with constraints impacting the automation deployment, based on the authors' understanding from literature and review of the physical layout, is presented in Table 3.

Table 3 E48 automation qualities comparison

Positives	Constraints
Herringbone layout minimises total cornering required, with no turnarounds	Load–haul–dump (LHD) clean-ups require active intervention by manual operators because of the herringbone orientation
Sweeping corners enable fourth gear navigation even in automation and sufficient space for internal barriers to segregate each drive	Secondary break was undertaken manually and required drives to be entirely removed from automation
Relatively low congestion tipples, with minimal traffic in Zone 2 and 3	Later extensions (Zones 1 and 4) increased traffic significantly
A 'broad' footprint resulted in more drives available for use, with total lengths limited by trailing cable (430 m)	Ventilation direction in-line with tramming route, causing dust after loading to impact LiDAR navigation
MHS bottleneck limited productivity dependency on LHD units	Initial barrier locations required ELA zone to enable complete full auto-production
Program supported by a legacy of innovation culture and years of remote system development at Northparkes	–
Program was initiated after cave was established and manual nameplate rates were subsequently achieved in 2010	–

4.1.2 L1N

There is considerably less published information about the automation system in the subsequent block cave at Northparkes, L1N, beyond noting that the layout has required a rethink of how zoning is undertaken (Teet et al. 2024) and that the level is now fully automated (Evolution Mining 2025). This lack of public information may reflect a change in publishing priorities (given the operation has changed owners twice since E48) but could also reflect that the system is no longer novel or that it is not an industry exception as E48 was. Nonetheless, it is understood that the system is approximately operated as shown in Figure 4. With the presence of clay in the existing E26 cave column (Evolution Mining 2023), the system likely forms a key control to addressing the inrush risk on the extraction level.

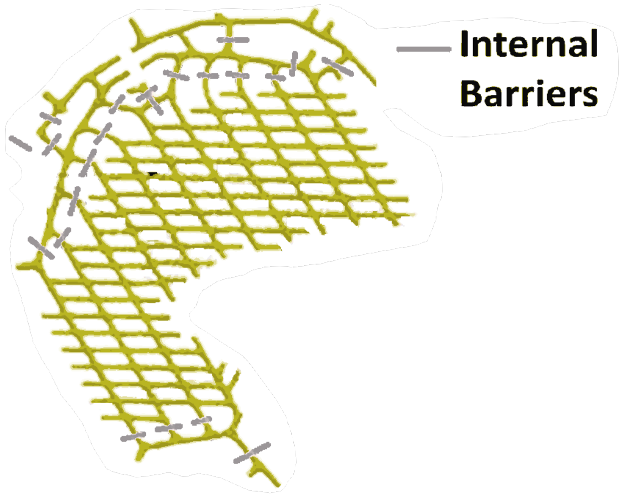

Figure 4 L1N barrier configuration, after Teet et al. (2024)

The unique design associated with this footprint means the discrete zoning approach at E48 would not be possible. Instead, E48 requires access through the shared twin tipple access drives, leading the system to be at most divided into two massive zones. With this significant restriction in place, a comparison of the automation configuration is presented in Table 4.

Table 4 L1N automation qualities comparison

Positives	Constraints
Barrier spacing was a known requirement based on E48 learnings	El Teniente layout requires multiple 90° turns by load–haul–dump units
Program supported by a legacy of innovation culture at Northparkes	Twin tipples leading to a congested perimeter No dedicated turnaround bays, resulting in traffic turning on the perimeter directly
–	Greater than 90° corners are present as part of the change from a herringbone to El Teniente layout during execution stages
–	Dead-end drives result in secondary ventilation ducting being present
–	Personnel access and manual activities in drives must traverse autonomous tipple accesses, resulting in major production interruption
–	E48 production completion and commissioning timing of L1N system indicate a likely gap in remote operator continuity

Even with the significant legacy of automation at Northparkes, the L1N design actively works against an effective automation implementation. Still, Northparkes appears to be aware of these challenges, noting that the next block cave, E22, returns to a four-way tipping configuration (Evolution Mining 2026).

4.2 Cadia Valley Operations

Cadia Valley Operations had numerous block caves with automation implementations, starting with a significant deployment at Ridgeway Deeps and then subsequently implemented in PC1 and PC2 at Cadia East.

4.2.1 Ridgeway Deeps

The automation program at Ridgeway Deeps is well summarised (Dunstan 2016), and highlights some of the alternative challenges associated with automation systems compared to those described with the Northparkes implementation. Many of the zoning, equipment and geometrical considerations (Figure 5) were consistent between Ridgeway Deeps and the E48 solution, such as the presence of a herringbone layout and four tipples. Here, the continued success of the manual operation outperformed the autonomous system, and while the system exceeded the original design nameplate requirements, it fell short by less than 5% of the revised system production requirement.

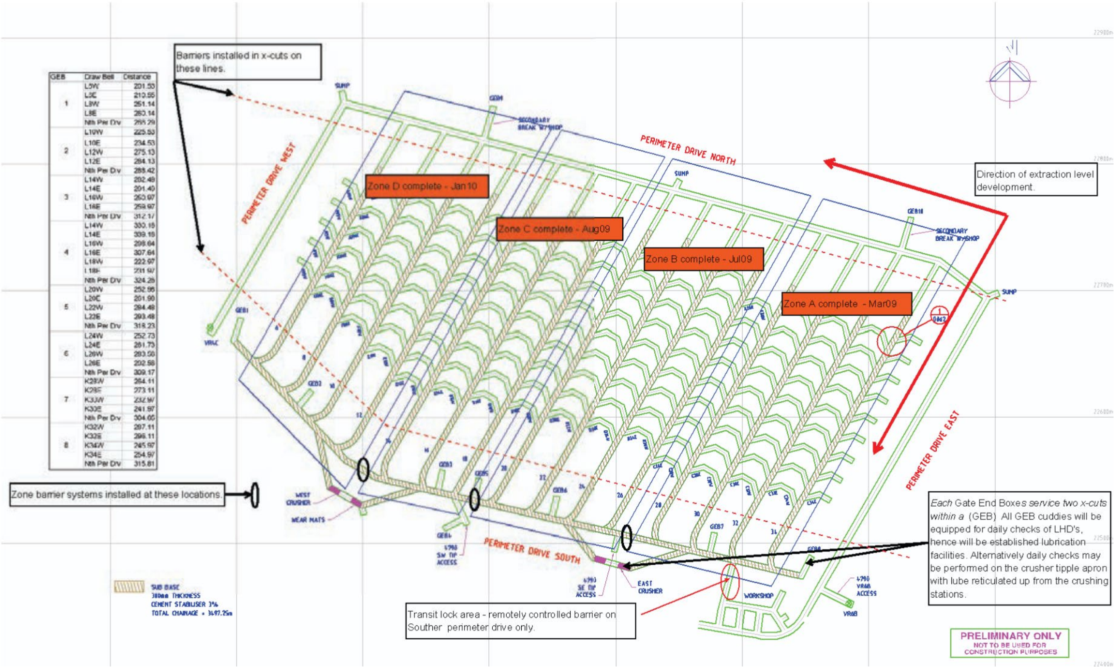

Figure 5 Ridgeway Deeps automation zoning from (Dunstan 2016)

An overview of the qualities of the automation system at Ridgeway Deeps is presented in Table 5.

Table 5 Ridgeway Deeps automation qualities comparison

Positives	Constraints
One load–haul–dump unit per tipple, minimising traffic	Zone and barrier configuration operationally complex (Dunstan 2016)
Chamfered corners and consistent approach minimised turnaround impact	Herringbone layout orientation required an autonomous turnaround every cycle, minimising potential speed on tipple approach
Generous spacing to install barriers	Manual outperformance (including continuous shift change operation) and over-nameplate materials handling systems

4.2.2 Cadia East PC1

PC1 at Cadia was the subject of a targeted program to implement fully remote operations to reduce exposure to inrush risk (Epiroc 2025). As part of this, integration of other equipment from other vendors was critical to the delivery of the solution so that there was a unified approach to accessing the area and minimising production interruption with an ad hoc, multiple remote system configuration. Without this fully remote system in place, PC1 would not be continuing to operate as a conventional operation. The inrush conditions at PC1 resulted in a reduction in bogging rate for this cave (Osorio 2025) so the performance requirements of the automation system are not known. In addition, this was an Epiroc solution, rather than a Sandvik system – a marked change from the previous deployment on the same site at Ridgeway Deeps. The footprint is shown in Figure 6.

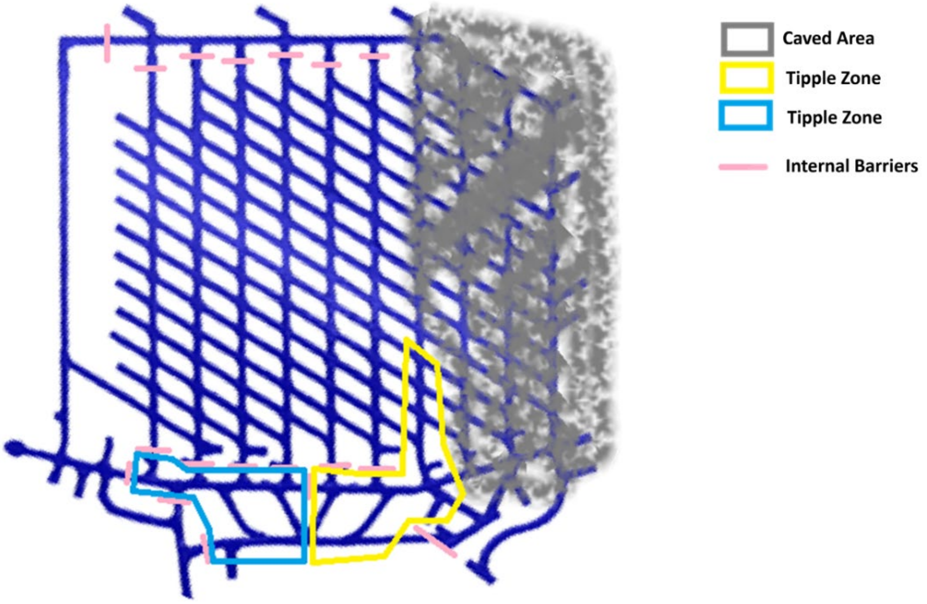

Figure 6 PC1 automation zoning, adapted using information present in (Epiroc 2025), after (Lett 2024)

Unlike the E48 and Ridgeway Deeps layouts that had four-way tipples and clear traffic flows, the PC1 design features a shared perimeter, limiting the ability to install barriers to cleanly divide the area, effectively resulting in two large, shared tipple zones. Additionally, not all drives have dedicated turnaround bays, resulting in further congestion on the perimeter. Cadia has highlighted that making improvements to the production rate of this system was a site initiative (Newmont 2024), indicating potential further gains to be made from this design and that it may not be meeting even the expected reduced bogging rate associated with the inrush conditions. A comparison of the automation qualities for this site is presented in Table 6.

Table 6 Cadia East PC1 automation qualities comparison

Positives	Constraints
Four interconnected tipples technically allow for flexibility in traffic flows	Shared perimeter results in congestion
Integrated system means production is not interrupted by secondary break or other activities as they are also remotely undertaken within the same area	El Teniente layout requires LHD units to turn around, some on the shared perimeter
'Burning platform' for implementation, with the level not operational without such a system	Insufficient space for barriers results in suboptimal tipple zoning and additional perimeter zone to enable full footprint remote loading
–	Hard 90° corners present on almost all drives onto perimeter

4.2.3 Cadia East PC2

No public statement has been made on whether an automation system is active within PC2 at Cadia. Still, there are some clear upsides to the mine design (Figure 7) that would support an autonomous deployment (Table 7) while also enabling very high manual production rates.

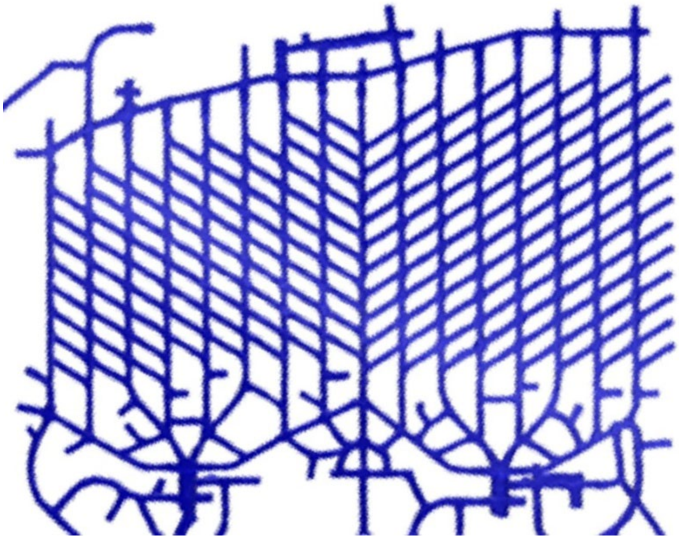

Figure 7 PC2 footprint, after Lett (2024)

When accounting for the estimated high productivity of over 25 mtpa demanded from the PC2 footprint (Newcrest Mining Limited 2019), it is unclear whether any autonomous system would be capable of meeting this high benchmark rate. It is therefore anticipated that an automation system at PC2 would likely only be used as a reactive tool, rather than during steady-state, safe operation.

Table 7 Cadia East PC2 automation qualities comparison

Positives	Constraints
Independent tipples with no more than two drives per tipple	El Teniente layout requires load–haul–dump units to turn around
Wide sweeping corners	Exceedingly high productivity requirements
Dedicated turnaround bays per drive	Sufficient spacing for barriers may not be available to load from all drawpoints if not accounted for in the original design

4.3 Case study learnings

Other than the E48 production level, it is apparent that mines continue to deploy automation systems only when necessary, rather than designing holistically for an optimised, remote solution. Both Ridgeway and PC1 have highlighted that system performance not meeting site expectations led to either the decommissioning or use of the system only as a last resort.

Fortunately, Evolution's description of the tipples at the E22 block cave at Northparkes and Newmont's PC2 footprint indicate that thought into design improvements that help facilitate autonomous systems has been made – the focus is therefore increasingly likely on the ability for these autonomous systems to deliver the required tonnes when a more optimal starting platform is provided.

5 Conclusion

An industry that continues to design operations for manual mining, with little regard given to the eventual adoption of a remote and autonomous solution will continue to see subpar results when those systems are deployed. There have been notable successes in this environment, such as the E48 implementation noted in this paper, but they are the result of careful consideration throughout the entire planning process, and a holistic mining, technology and cultural adoption of the autonomous platform in its deployment. Learning from these successes, as well as avoiding the pitfalls present within other key deployments is a crucial path forward for any caving operation.

Once this is understood, the direction then shifts to ensuring these systems meet expected production profiles. Where production rates outstrip current autonomous system capability, development and investment in those solutions, as well as accounting for any uplift requirements in the original mine design and carrying that through to execution, should be promoted.

The industry should still adopt autonomous solutions as they enable production in contexts that would be unacceptable for personnel to be exposed to. This paper has aimed to provide a brief understanding of the reasons and ways these systems could be implemented more effectively.

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