

# Three case studies on the implementation of new technology in the mining industry

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## ABSTRACT

There is significant value at stake in the mining industry from the implementation of new technologies that support the enhanced profitability and sustainability of mines. However, in order to realise this value, new technology must be implemented in a way that is both effective and sustainable. The industry has a mixed history for technology implementation that provides fertile ground for understanding what is necessary for innovation to deliver value. This paper describes early stage research investigating why this is so, with the aim of improving how to deliver value. Several case studies are provided covering both successful and unsuccessful technology interventions. The paper identifies the common factors that emerge from the case studies, and offers a path forward for further research in this area.

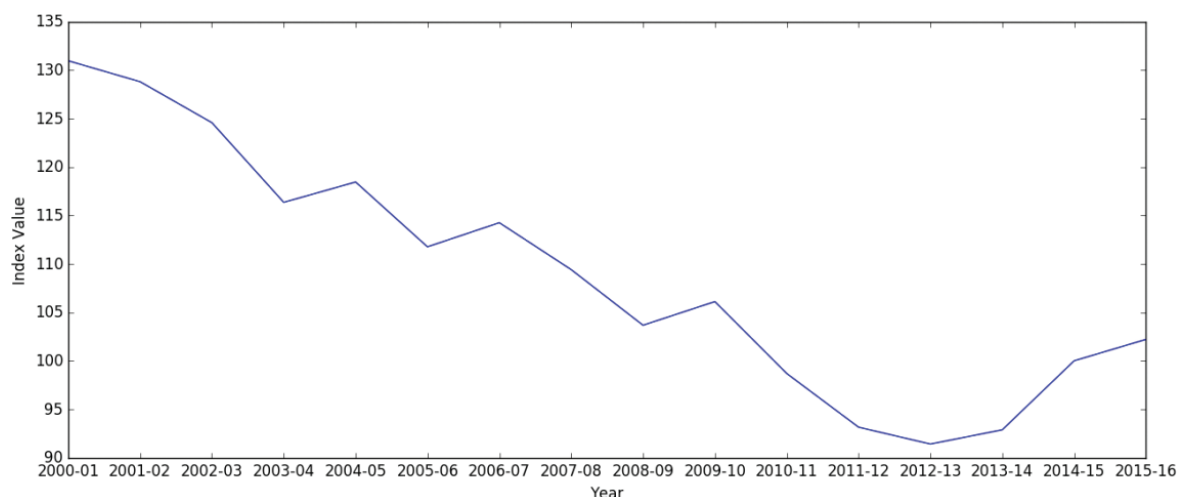
## INTRODUCTION

### Background

The performance of mining operations globally, in general, have not improved over the last decade. Industry-wide return on capital employed (ROCE) trended down from 20 per cent in 2007 to just four per cent in 2015 (O'Callaghan, Burkitt and McKenna, 2016). Similarly, global mining productivity declined, on average, by 3.5 per cent/a, from 2004 to 2013 (Lala *et al*, 2015). This trend is further highlighted by the Australian Bureau of Statistics (ABS) multi factor productivity (MFP) index, see Figure 1. The impact on the sustainability

of the industry from this poor performance is potentially significant. It is important to consider what actions need to be taken within mining operations in order to counter these trends and deliver enhanced industry value.

A range of metrics can be applied to measure enhanced industry value at mining operations: profit, free cash flow (FCF), capital expenditure (capex), ROCE and net present value (NPV) among others. The ability to positively influence these metrics is a complex challenge exacerbated by the often



**FIG 1** – Multi factor productivity (MFP) of the Australian mining industry, from the Australian Bureau of Statistics (ABS, 2016). The MFP index accounts for both the use of capital and labour inputs. As shown in the graphic, while there has been some index recovery in the period from 2014–2016, the general trend is still one of declining performance.

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inverse relationship between these metrics. For example, a focus on short-term (within one financial year) FCF may negatively impact on the mines life-of-mine NPV ( $NPV_{LOM}$ ). This challenge is further complicated by competing business priorities. For example, a mine operator may seek to deliver a suboptimal profit level, if it means that a safer or lower risk and more sustainable mine can be delivered over the long-term. Equally, a mine operator may take less interest in long-term sustainability if instead short-term cash flow is a critical priority for the mine's immediate survival.

However, within this complex dynamic, we argue that over the long-run, it is ultimately the maximisation of the mines  $NPV_{LOM}$  that every mine operator should seek to deliver. This focus on an all-encompassing  $NPV_{LOM}$  takes into account factors including cost minimisation and recovery maximisation. This approach, at least in theory, results in the highest level of value being achieved (Whittle, 2009).

To maximise  $NPV_{LOM}$  there are a broad range of strategies that can be applied to a mining operation. These strategies can be complex and multifaceted. However, the authors argue that any strategy implemented can be categorised into one of four general strategy types (see Table 1).

Within these four strategy types, we exclude from our scope any further consideration of enhancing value through economies of scope or through improving the resource quality. These strategies are excluded as a result of the limited ability that a mining operation has to implement these strategies. Limiting ourselves to the strategies that are site controllable leaves two strategy types for further consideration. Either a mining operation can deliver enhanced  $NPV_{LOM}$  through realising economies of scale or, for a fixed scale, a mining operation can seek to reduce costs and improve productivity.

In relation to delivering increased economies of scale, we observe that the opportunities for increasing the size of equipment are diminishing owing to the physical geometry of ore reserves. Additionally, the opportunity to engineer progressively larger mining equipment is also decreasing. This view is supported by Bartos (2007) who observed that the relatively easy financial gains from economies of scale would not be available for the mining industry in the medium to the long-term.

With this in mind, the remaining site controllable strategy is to reduce costs and improve productivity. These type of strategies to enhance  $NPV_{LOM}$  can further be categorised into two subtypes. The first of these is often referred to as 'sweating-the-asset': utilising existing resources, people and equipment in a more efficient way. This is generally achieved through management intervention and monitoring, eg ensuring that

shift change times are minimised for the existing workforce and the equipment operates for the most hours possible in any given 24-hour period. These productivity and efficiency interventions are the most obvious to implement once economies of scale opportunities have been exploited.

The second substrategy that supports the reduction of costs and improvement of productivities is through the implementation of technological innovations. The achievement of value through technological innovation, however, is also not straightforward. Indeed, this is an avenue that has proven problematic at all scales of investment. Jordaan and Hendricks (2009) highlighted a number of general challenges with technology adoption within the mining industry and Dudley and McAree (2013) highlighted five key obstacles that would need to be addressed for mining automation initiatives to be effective. These obstacles that impact on a mining operation's ability to implement technology are real and ubiquitous across the mining sector. As noted by Hopwood and Chopra (2016), 'despite the dizzying array of technologies available, many miners remain at the early stage of the adoption curve'.

Nevertheless, and given the limited opportunities for enhancing value through other strategies, the implementation of technological change may be the best way for a mining operation to generate increased value. For example, Durrant-Whyte *et al* (2015) estimated that there was \$370 B of value at stake for the mining industry. This value at stake could be delivered through the application of digital technologies that are either available now, or likely to be available in the near future. They identified five areas for digitisation that exist for the creation of this \$370 B of value. These value creation areas identified were:

1. a deeper understanding of the resource base
2. the optimisation of material and equipment flow
3. an improved ability to anticipate failures
4. increased mechanisation through automation
5. the monitoring of real-time performance to plan.

## Do we need to do anything differently?

There is an argument that technological innovation is already highly progressed in the mining industry and that many of these new digital technology options will be implemented as they fulfil fit-for-purpose quality requirements for mining operations. In fact, Bladier (2016) suggested that the mining industry in Australia should be the role model for technological innovation. This perspective is complemented by the notion that implementation of technological innovations in the mining industry is difficult, compared to say, the semi-conductor industry (Bartos, 2007). This difficulty

TABLE 1

The four key strategy types that can be applied to enhance a mining operation's  $NPV_{LOM}$ . Note that the most common types of strategies encountered in a mining operation are either delivering economies of scale (increase volume output), or by productivity and efficiency improvements.

Strategy type	Key substrategy types	Operationally controllable
Economies of scale	<ul style="list-style-type: none"> <li>• Install larger sized/capacity equipment.</li> <li>• Increase the number of operating production equipment fleets.</li> <li>• Reduce overheads or implement other operational synergies.</li> </ul>	Yes
Economies of scope	<ul style="list-style-type: none"> <li>• Downstream value-added to commodities.</li> <li>• Marketing of complementary products or multiple land uses.</li> </ul>	Limited, due to the complexity of change required.
Productivity and efficiency improvements	<ul style="list-style-type: none"> <li>• Maximising the operating performance of existing capital and labour.</li> <li>• Implementation of new technology.</li> </ul>	Yes
Quality of resource improvements	<ul style="list-style-type: none"> <li>• Increase the size of the resource base.</li> <li>• Discover low depth of cover reserves.</li> <li>• Identify ore that improves recovery/grade.</li> </ul>	Limited, as this is largely a function of the geology of the deposit.

lies in unique challenges faced in the mining industry (Fisher and Schnittger, 2012). These unique challenges include, among others, geographic spread of mines, remote locations, harsh environments, access to labour and challenging safety environments.

These highlighted challenges are further compounded by the relative, rather than absolute nature of competition between producers. This relative nature of competition is something best understood by contrasting the different positions of profitable and marginal producers to technological innovation. For profitable producers, the cost imperative does not exist to innovate technologically. In contradistinction, marginal producers often cannot afford to take the risk of innovation. This dynamic has the consequence that innovation occurs predominantly by individual choice, or in response to a competitor's individual action.

The above mentioned points often lead to the conclusion that the industry is delivering as much as practical. Thus, there is only limited scope for enhancement of technology implementation practices. However, while it is acknowledged that there is some merit in the above points, it does not mean that there is only limited opportunity for change.

Instead, we contend quite the opposite is true. Nowadays there are fewer opportunities to achieve a lower unit cost by simply delivering economies of scale. Accordingly, the competition for a position on the lowest part of cost curve within the mining industry stands to get more complex and challenging. *Rather than doing nothing, a significant technological and cost advantage awaits the producer who has the ability to navigate these unique challenges.* This technological advantage will be the key to a mining operations future success or failure.

## How can this innovation value be realised?

To what extent this technological advantage can be realised, is largely dependent on the ability to understand the challenges that restrict this value from being delivered. To understand these challenges comprehensively we are conducting a research program comprising five phases:

1. a desktop review of selected case studies
2. detailed and comprehensive review of new technology deployments, including field research and validation
3. development and categorisation of contributing factors
4. development of response strategies to mitigate these contributing factors
5. field testing of the effectiveness of these response strategies.

This paper shares and summarises the work-to-date of the first stage of this research program: a desktop review of several case studies. While much remains to be done, we are sharing our early thoughts on this problem to open discussion on how to achieve value from technological innovation.

## PHASE 1 – PRELIMINARY CASE STUDIES

Within the described context and research framework, there is fertile ground for extensive research. The range of technological innovations that exist within the industry are too broad to mention. They span all facets of mining, from dispatching systems, to blasting products, to modelling and optimisation software. However, for the purposes of this paper three desktop case studies are considered. In order to select appropriate cases, selection criteria are applied. The technology must:

- be applicable to Australian open cut mines
- address a known industry gap or opportunity

- have been commercially available for at least five years.

From the scope of technology innovations in mining, the above mentioned criteria inform a short-list of 21 potential case studies. Of these, three are selected for detailed investigation and review:

1. application of unmanned aerial vehicles (UAV) for surveying support
2. collision avoidance systems (CAS) to reduce the risk of vehicle-to-vehicle collision
3. the use of autonomous and semi-autonomous production blasthole drills.

The further selection of the three chosen case studies is on the basis of the following additional observations.

Firstly, the selection of UAV is considered timely, given the potential ubiquitous opportunity that UAV currently present. Also, UAV technology is relatively low cost, with a high ease of deployment (Uysal, Toprak and Polat, 2015), and addresses a known gap of surveying in remote or poorly accessible areas. Additionally, there is a deep market for UAV in Australia.

CAS is selected predominantly owing to its proposed highly beneficial safety case. Fatalities from vehicle-to-vehicle collisions are a significant risk in the open cut mining industry. CAS was recommended as a control from a fatal incident investigation in New South Wales (Mine Safety New South Wales, 2015).

Autonomous and semi-autonomous production blasthole drills are selected given the relatively high potential for deployment and high potential safety, productivity and cost improvements (Matysek and Fisher, 2016). There is also a clear trend to automation within the industry. As time progresses, automation technology (for the mining industry) is becoming a mature technology (Fraser, 2015). For each of the selected case studies, a brief summary of the key observations is now provided.

## Summary of case study 1 – unmanned aerial vehicles

The rise in application of UAV has progressed quickly when compared to many other technologies. There are many current applications for UAV in photogrammetry and remote sensing, and that the current trend in increasing demand for UAV geospatial systems appears unstoppable (see Colomina and Molina, 2014). The growth in demand will likely be further compounded by the development of technology that support increasing degrees of autonomous operation (Bemis *et al*, 2014). One such autonomous example is the use of UAV for autonomous cut-fill profiling remotely, and in high precision (Siebert and Teizer, 2014). Thus, from the relatively recent introduction of UAV to mine sites, interest has grown, and now the use is widespread (McConnon and Diss, 2015), and likely to continue.

One of the explanations offered as to why there has been such a rapid and effective take-up of UAV was offered in an interview by Fitzgerald (2016), where it was noted that one of the key advantages of this technology is that it does not need to integrate with equipment in the pits. This seems to be a distinct advantage in the ease of implementation. Traditionally, interoperability in surface mines has posed a large barrier to the implementation of new technology (Farrelly and Ballantyne, 2016).

The ability to operate modern UAV and relevant computing equipment is, relative to other equipment in the mining industry, safe and straightforward. Figure 2 provides an image of a typical UAV that is commercially available in the mining industry. This example quad-copter type UAV provides





**FIG 2** – An example of the capabilities of current unmanned aerial vehicle systems. This particular system, easily carried by hand (see left), is used to develop high accuracy digital terrain maps and high quality visual imagery (see right). This particular mission, at a coalmine in Australia, was to provide daily volumetric reconciliations of waste material moved. The mission could be completed in 30 minutes, with minimal survey support required for installation and maintenance of reference targets on the ground.

a stable platform with sufficient payload to accommodate imaging system suitable for survey work. To learn to safely operate commercial UAV, Civil Aviation Safety Authority (CASA) certification is required. Many training providers in Australia offer CASA UAV pilot certification course for less than A\$4000 and a duration of five days.

Also, mining safety legislation is limited in its scope of operation applied to UAV technology. For example, Section 10(2)(a) of the *Coal Mine Safety and Health Act* for Queensland, states that on-site activities do not include airborne geophysical surveys. Thus, it can be argued that this legislation has no jurisdiction over the implementation of UAV for survey work. In reality, the mines queried about the application of UAV on their site still follow rigorous standards in order to ensure their safety, however, the burden of integrating with existing safety management systems is reduced. Similarly, CASA compliance requirements are relatively prescriptive, when compared to mining safety legislation. This makes the cognitive effort required to achieve compliance lower than for mining compliance.

The measurement and tracking of UAV value delivered is also relatively easy at a mine. UAV generally are low cost (Uysal, Toprak and Polat, 2015) compared to other mining equipment. For example, a UAV such as the one shown in Figure 2, can be purchased for under A\$5000 and would for most mine sites be seen as a minor expenditure. Compare this with the purchase of a new surveying vehicle an order of magnitude 20 times greater than the UAV. Software to extract terrain maps from images acquired by the UAV using photogrammetric principles is readily available as a direct purchase or through fee-for-service internet portals at reasonable prices. Thus, the financial risk of a UAV purchase and operation is negligible for a typical mining operation.

This UAV purchase cost is also significantly less than the surveyor labour savings benefit that are able to be realised. In one example, a mine site purchased a UAV purely for post-blast surveying. The justification for the purchase was the removal surveyors from risk (post-blast fume and uneven terrain). At that particular mine there was, on average a

blast every second day of the year. This task was able to be completed by one UAV operator in 30 minutes per blast. The equivalent task was previously taking two surveyors two hours to complete. Thus, a direct labour saving of 548 h/a was possible. At an assumed surveyor labour rate of A\$95/h, a measured labour saving of A\$52 013/a was achievable. This saving was an order of magnitude ten times higher than the initial purchase price of the UAV. This implementation also resulted in a lower risk of harm to the site surveyors.

The introduction of UAV to mine sites also provides another, more discrete advantage. As previously noted, the ability for an integrated information system is critical to future automation success (see Nebot, 2007). In other words, as much by accident as by plan, the use of UAV in mines is a strategic enabling priority that has emerged with low barriers to effective implementation. This ability to obtain more information, in real-time, integrated to existing information systems is an important enabler for a mines strategic technology plan.

## Summary of case study 2 – collision avoidance systems

The concept of collision avoidance in open cut mining has been developed over many years. There is a strong safety case for any such system that reduces the likelihood of a vehicle-to-vehicle collision on a mine site. As a result of this safety case, the mining industry has generally prioritised the development and implementation of this technology. Thus, there are now multiple products offered by various original equipment manufacturers (OEM) and technology suppliers. These systems can be installed as part of an initial equipment deployment or as an after-market fitment to an existing fleet. As an example of the safety case for CAS, the Burton SafeMine CAS reduced collisions from 14 (for the 12 months prior to implementation), to just two incidents in the 24 month's post-implementation (McAlary, 2014).

Obviously the financial benefit of this type of improvement is hard to quantify, and is not normally the motivation for a decision to implement a CAS. However, if we assume that the Burton case is indicative of the type of improvement possible then generic analysis is possible. If, taking the collision data, we assume that a typical collision consists of two items of heavy mobile equipment, travelling at relatively low speeds (dig face or dump) and that this collision results in no personal harm but A\$10 000 damage to each machine (eg handrails or access ladders) and each event cause operations an opportunity loss of 2000 t of ore at a 75 per cent yield and A\$20/t gross margin, due to the scene being preserved for accident investigation purposes. Then, each event has an attributable cost of A\$50 000. At a reduction of 13 events/a this translates to a financial benefit of A\$650 000/a.

While there appears to be financial benefit, as well as risk reduction from this type of technology, the path to implementation has been paved with many challenges. Discussions with mine managers at various open cut mines in Central Queensland have shown a similar pattern of implementation. The challenges faced by mines implementing CAS include, OEM support (lack of), interoperability (lack of), understanding of how system is to be properly applied (lack of), and spurious alarms.

On further review of the example sites, there was a number of unplanned events, such as poorly understood resourcing model, meaning that sometimes maintenance was available to fix a defective system, sometimes not, and it was not always clear how those types of priorities were resolved. This type

of event left miners with a degree of frustration with their embedded CAS.

In another example, a mine site bought a particular technology, however, post-implementation, found what they considered was a superior product. The mine site though could not change suppliers as they had 'bought into the system'. As it transpired, there was no opportunity to integrate the better performing technology in a gradual or staged approach. The hidden costs of stopping operations once the system was embedded, along with the direct costs of refitting the whole fleet was not identified during the tender process, and if it had been identified, it could not have been managed differently. The only opportunity would have been to 'do nothing' until the site was certain with their technology choice. This would not have been an acceptable option for that site owing to an immediate need to deliver a reduction in the risk of vehicle-to-vehicle collision.

Additionally, and unlike the UAV example, the ability to positively monitor value delivered against the original value proposition is very hard to achieve. As exemplified by McAlary (2014), the demonstration of effectiveness was a lagging indicator of 'incidents not had'. This type of indicator is very hard to positively measure and monitor.

Strategically, there has been a great deal of debate among industry participants as to whether mines should to progress to CAS or instead move to full autonomous haulage systems as fleets approach the end of their useful life. Thus, the question of strategic alignment is also not as clear as the case for UAV.

### Summary of case study 3 – blasthole drill automation

The mining industry is on the verge of explosive growth in automation (Matysek and Fisher, 2016; Pratt, 2015). One such growth area is in the ability to automate production drills. Drilling automation technology has been in the market now for many years. There are a number of suppliers offering various commercial products, indicating either full automation, automation ready or semi-autonomous options (Joy Global, 2016; CAT, 2016; Atlas Copco, 2014; Sandvik, 2016). However, Rio Tinto West Angeles is currently the only mine in the world operating its whole production drilling fleet autonomously (Committee for the Economic Development of Australia (CEDA), 2015).

In terms of historical development for the Rio Tinto autonomous system, a cabless drill was implemented in 2012 and autonomous drilling system in 2014 (Rio Tinto, 2014). The reward for this development was a reduction in total operational costs, net of increases from the implementation of that technology. This operational cost saving was confirmed by Andrew Harding (in an interview with *The Australian* in

December 2015) as delivering an eight per cent operational cost saving for Rio Tinto Iron Ore (Matchett, 2015).

So, while there appears to be a good case for the implementation of autonomous drills, industry wide adoption has not been achieved. Some of the factors that appear to have impacted on sites decisions to not implement automation in this area include: the stage of development of the technology (too risky), site systems not set-up for implementation, interoperability and interaction with non-autonomous system components, value proposition not strong enough to implement, high time cost and capital cost to implement (relative to proven technology), direct labour savings not compelling enough to make a change, and the sites industrial environment.

Technically, many of the autonomous drilling technology challenges have been largely resolved, with most of the development work now in enhancing performance beyond a 'base case' system. However, ongoing automation challenges exist for sites not correctly set-up with an appropriate data/information communication system for remote operations (Dadhich, Bodin and Andersson, 2016). This was previously highlighted as a challenge by Nebot (2007) who said that 'Automation technologies [in mining] will flourish after the evolution of real-time, whole-of-mine, information systems take's place'.

While the challenges have been significant for autonomous drills, particularly in terms of having the requisite operating environment for success, mines are still pursuing the concept. We observe that this interest in autonomous drills makes strategic sense, as the whole industry continues to move towards fully autonomous operations.

## DISCUSSION

From the information gathered during the research of the case studies, a simple table of related factors are constructed. This table, as shown in Table 2, highlights that of the factors considered, CAS scored the lowest result in each category. The case study for UAV demonstrated the most favourable response to the factors.

The first factor evident from the three case studies is that a clear definition of intent of the technology, in terms of its ability to enhance operational performance is needed. As highlighted in the blasthole drill case study, one of the key factors that has limited the introduction of the drills on a widespread basis appears to be the lack of understanding of the value proposition for the technology. Without clear metrics for performance that management can monitor easily, the technology implementation risks derailing at the first set-back. This need for clear modelling, mapped to the complexities of an operation is also evident in the CAS case study. In part, the potential value of CAS was eroded in early implementations owing to a lack of clarity around the inter-

TABLE 2

A summary of selected factors that were observed from the case studies. It is evident from this limited sample set that the technology with the most favourable set of factors is most likely to succeed. These case studies all demonstrated a degree of alignment to a broader site automation strategy; however, for the collision avoidance systems case study that strategic alignment was not clearly understood by all participants.

Case study	Strategic alignment	Value easily definable	Performance easily monitored	Ease of decision to implement	Ease of system modelling
UAV	High	High	High	High	High
CAS	Medium	Low	Low	Low	Low
Drills	High	Medium	Medium	Medium	Medium

UAV – unmanned aerial vehicles; CAS – collision avoidance systems.

relationships of the key system factors. This lack of complex system understanding caused, in many cases, mining operations to commit to technology that was not easily interoperable with other parts of the system and additionally hard to reconfigure as needed.

Contrasting this, the UAV case study shows that the ability to be able to interoperate the technology with various parts of the system and effectively achieve a 'plug-and-play' approach limits the risk exposure. This advantage of UAV coupled with their low cost of implementation proved to be a decisive advantage for the technology to be adopted.

One factor that appeared in all three cases was the need for a consistent methodology for making a decision to implement a change. The case studies all showed that basic 'change management' checklists that ultimately evolved from a safety management framework are not effective in supporting the full complex decision of implementing a technology. These change management tools, when correctly applied, appear to add significant safety value to the mine, however, they do little for the extraction of full operational efficiency. So while the delivery of a safe outcome is controlled and effective, the delivery of operational efficiency appears less so.

In addition to the identification of full value prior to making a decision, a mapping of relevant policies, procedures, people and equipment is required for implementing and sustaining the change. As shown in the production drilling case study, the lack of clarity around the impact of the decision on the industrial agreements, safety management system components and ancillary services limits the interest in technology adoption. This case study shows that the linear value chain model is too basic to map important system complexities and interactions that may occur and detract from performance. The CAS case study also showed that a clear lack of training for both system users and maintainers was not well defined prior to implementing the technology. This lack of definition ultimately negatively impacted the total system cost and reliability. Ultimately the complexity of the CAS implementation is significantly higher than that of the UAV. However, comparing the two provides an interesting observation. In the case of UAV, there were no negative impacts on other parts of the operation. However, in the case of CAS, there were negative impacts across the operation, many of which were not correctly planned for prior to implementation.

Interestingly, in each case study the strategic framework for which the decision to implement the technology was different. The production drilling case study showed that a clear strategic decision was made prior to implementation, however, this strategic alignment alone was not enough to ensure success. Instead, the strategic alignment ensures that when the project does not perform there is a clear mandate to continue to persevere with the technology as there is a long-term goal at stake.

## CONCLUSIONS

Mining industry performance has declined significantly over the last decade. Opportunities for generating performance and profitability improvements through economies of scale are also diminishing. Thus, a significant way for mining operations to generate value in any stage of the commodity price cycle is to implement technological innovations. These technological innovations can deliver reduced cost structures and therefore greater profits and greater sustainability of operations. The mining operation's that overcome the challenges of implementation of technological innovation will be best placed for long-term success.

This desktop review shows that of these broad range of technologies that could be applied to the mining industry, there appears to be some common factors that lead successful widespread implementation. It is recommended that this research be expanded to a detailed and comprehensive review of technology deployment, including field research in targeted technology deployments.

Additionally, it is observed that, from the desktop research conducted, access to relevant information was difficult. Thus, it is apparent that the industry would benefit from a more comprehensive approach to cataloguing the opportunities, successes and failures of technological innovations.

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