RFC Ambrian

New Technology & Innovation

Report 1 - Mining 4.0 and Corporate Strategy

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Contents

Executive Summary

Innovation and new technology

Innovation and new technology are not new concepts and have been a constant throughout history whether it has been incremental, step-change, or disruptive. However, these words have been used with increasing frequency over the past decade with the expansion of digitalisation and the step in to the fourth industrial revolution. This is particularly true within the mining industry and you will find an increasing number of authoritative reports examining 'new technology and innovation in mining' from management consultancy firms, original equipment manufacturers, mining companies, and professional bodies. These range from the theoretical, concept, and management guidance point of view, through to the development from the implementation of new products.

RFC Ambrian has a 40-year track record of providing independent corporate advisory and investment services to the global mining industry, from both a technical and financial perspective. This report is the first in a series of reports that will be published by RFC Ambrian on new technology and innovation. In this report we touch on some of the concepts being discussed, but following reports aim to highlight new innovations and analyse the practical side of new technology in the mining industry. We will present the top initiatives under development which are making, or are about to make, a meaningful impact on mine economics and safety.

The Fourth Industrial Revolution

The first industrial revolution saw innovations in steam power drive work from hand to machine. The second revolution was largely powered by electrification, with telephone lines and light bulbs connecting and illuminating people across the globe. A century later, the third began the process of digitising the world, with the spread of PCs, the internet, and sophisticated IT.

Industry commentators now believe the fourth industrial revolution (4.0) is here. It is difficult to isolate it to one predominant technological breakthrough; but it appears that three technological megatrends are the principal drivers: connectivity, intelligence and flexible automation, linked by the common thread of digitalisation. Digitalisation is the process of employing digital technologies and information to transform business operations. Mobile devices, cloud computing, analytics, sensors, advanced robotics, virtual reality, and artificial intelligence are all digital technologies that have quickly influenced and changed conventional business models.

Mining 4.0

Many people talk about the transition to the digital mine. The use of digitalisation in the mining industry has started and is becoming more pervasive. The technology is improving but it is only just beginning to be integrated across the value chain. We believe that success for mining companies won't just be about adopting the latest applications and technologies, but also the embedding of digital and innovative thinking into the heart of their business strategy.

Our assessment of the current status of the digital mine is that the mining industry is only at the early stages of digital transformation, but it is taking place at what appears to be an accelerating pace. This is because much of the technology is now robust enough and significantly developed and trialled to allow implementation in the production process. The steps may be small and incremental, but mining executives are now starting to realise the productivity benefits through the visualisation of data across the entire value chain and the implementation of the new technology.

Corporate Approach to Innovation

Mining companies are slowly adjusting their strategies and business models to include innovation and new technology as a cornerstone to their policies. The incentive for management is the ever-constant pressure to maintain or improve profitability and to improve safety. These benefits are starting to be captured by the early movers, although the results are not fully transparent. Today we appear to be at a tipping point where investors now expect companies to be embracing innovation through digitalisation as they witness the positive early results.

The front runners will capture the initial competitive advantage that will move them down the cost curve and give them an advantage over their competitors in terms of likely higher profits and potentially higher market ratings. Arguably, in time, the whole industry will gravitate to the 'Mine of the Future' and digitalisation will become another cost reduction factor that moves the whole industry's cost curve down and eventually helps keep commodity prices lower.

Obviously, the key for mining companies with a long-term view will be to constantly stay ahead in innovation. Notably though, the accessibility of digitalisation is open to all sizes of company or operation, as well as SMEs and is not exclusive to developed economies. This increases the risk of digital technologies lowering the barriers to entry and making it harder for incumbents, although in the mining sector owning and operating the top-quality assets remains important.

How Successful Have Corporates Been?

This is a very hard questions to answer as corporates are reluctant to fully reveal this type of information and likely many do not have a full grasp of all the data themselves. Innovation is certainly a difficult concept to integrate in to an organisation and even harder to articulate and numerate to shareholders. It is also raising tensions between mining companies and OEMs about who ultimately owns the IP as it is developed.

Some companies are clearly succeeding and making real progress on the path to digitalisation and creating the 'mine of the future'. However, others are struggling to varying degrees, with some needing more time to determine and implement a real strategy, while some remain mired in the historical conservatism of the mining industry.

Positive benefits can be seen and there remains a lot of enthusiasm in the industry, although we suspect that some new technologies are proving harder to implement and are less cost effective than some initially expected. While we think that benefits will continue to materialise from innovation, we believe the path will not be straightforward and the rewards variable.

The Fourth Industrial Revolution

Introduction

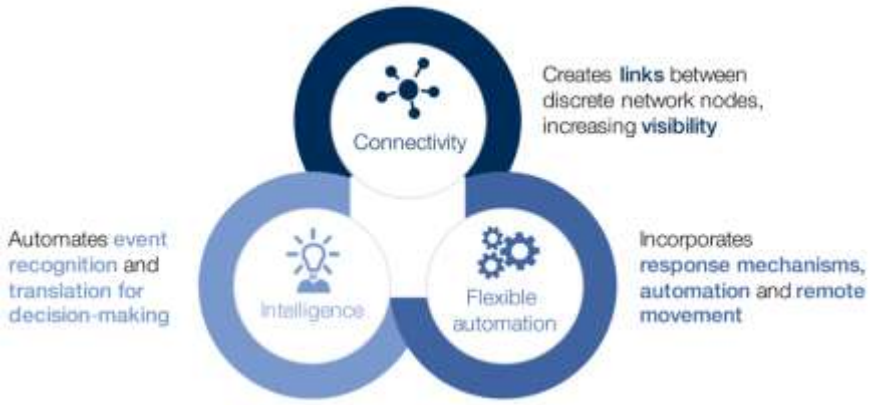
The first industrial revolution saw innovations in steam power drive work from hand to machine. The second revolution was largely powered by electrification, with telephone lines and light bulbs connecting and illuminating people across the globe. A century later, the third began the process of digitising the world, with the spread of PCs, the internet, and sophisticated IT.

Industry commentators now believe the fourth industrial revolution (4.0) is here, although it is difficult to isolate it to one predominant technological breakthrough. McKinsey [(1)] suggests artificial intelligence (AI), robotics, the Internet of Things (IoT), autonomous vehicles, 3D printing, nanotechnology, biotechnology, materials science, energy storage, and quantum computing as the key factors. All of these have the potential to completely upend traditional manufacturing, blurring the lines among physical, digital, and biological spheres. However, three technological megatrends are the principal drivers of this transformation in production: connectivity, intelligence and flexible automation.

Many companies are piloting Fourth Industrial Revolution initiatives in manufacturing, but few have managed to integrate Fourth Industrial Revolution technologies at scale to realise significant economic and financial benefits. These manufacturers of the future have adapted the connectivity, intelligence, and flexible automation potential of their operations. The successful businesses of 4.0 have emerged not through wholesale replacement but by transforming existing structures.

The Fourth Industrial Revolution in manufacturing remains a top priority for many leaders of private and public organisations. It is having an enormous disruptive impact on value chains, industries and business models. It presents the next engine of economic growth, ushering in opportunities to learn and embed values in a way that past revolutions could not. McKinsey states that the adoption of technology, guided by an inclusive vision for a better world, can yield a stronger, cleaner, global society.

Figure 1: Key technology megatrends transforming production



Source: McKinsey

The Digital Revolution

As we know, the current boom in innovation is not just occurring in the mining industry but in other industries globally and the common thread is digitalisation. There is a lot of different terminology associated with digitalisation, but it is essentially about the increased gathering and processing of real-time data from all aspects of today's world.

This is being achieved through increasing processing power, stronger and faster networks, better sensors (including the application of GPS, radar, and LiDAR), and improving software and algorithms. This enables analysis and insight in to the data and then allows feedback within a system, either manually, through automation, or through artificial intelligence. The business is then able to visualise, control, and optimise the operation immediately if necessary, using real-time data. This is applicable to nearly every aspect of operation in a producing mine.

Many believe that the barrier to digital transformation is no longer technology but the organisation's ability to adapt to an increasingly advanced and changing environment and sometimes cost. The incentive for management to embrace digitalisation is the ever-constant pressure to maintain or improve profitability and to improve safety. For the mining equipment, technology, and service industry to succeed in its role of selling and implementing the digital technology, the innovation must be robust, consistent, and cost effective. The interface with the management must also be practical and appealing and appear to lack complexity. A vast difference can already be seen across mining and metals companies in terms of testing, adoption, and benefits.

In November 2015, McKinsey [(2)] estimated that the potential economic impact of mine digitalisation could be US$370bn by 2025 through increasing productivity, reducing waste, and improving safety. The largest impact (US$250bn) was forecast to come from deeper understanding of the resource base, optimisation of material and equipment flow, increased mechanisation through automation, and monitoring of real-time performance against plan.

The World Economic Forum study in January 2017 (in collaboration with Accenture) [(3)] suggested that the industry could achieve savings of $428bn by 2025. The biggest source of this saving ($106bn) is forecast to come from integrated sourcing, data exchange and commerce. This is followed by the connected worker ($85bn), remote operation centres ($84bn) and autonomous operations and robotics ($56bn). It also believed that it would result in a loss of nearly 5% of the workforce.

Looking even further forward, Accenture [(4)] believes that a cognitive network is the next generation of technology being deployed across industries around the world. The ability for machines to think and act like humans through the analysis of unstructured data will drive true transformation across the mining value chain. The use of artificial intelligence will provide a way for people to interact with technology and create an environment that is self-improving, self-learning, self-healing, and self-controlling. This is the goal for the 'mine of the future'.

Mining 4.0

Recent decades have seen very few major breakthroughs in technology in the mining industry. In mineral processing, the major breakthroughs took place over 100 years ago (flotation) and 50 years ago (solvent extraction). In mining, the revolutionary developments include, the invention of dynamite, the introduction of tungsten carbide drills, the adoption of underground mass mining methods, and the scaling up of surface mining equipment.

Despite the lack of major breakthroughs, mining is now much safer, more efficient and environmentally friendly than it was 25 years ago as a result of incremental changes in the production system. Major trends have included: continued mechanisation in the mine; development of maintenance, administration, and supply systems; geological and engineering technical optimisation software; an increase in the scale of mines and mineral processing plants; and the extensive use of IT for process control, not least in connection with mineral processing. However, The Fourth Industrial Revolution in mining and processing differs from the continuous improvement efforts that have characterised operations for decades. It is not incremental; rather, it involves a step change and it is resetting benchmarks.

The Mine of the Future

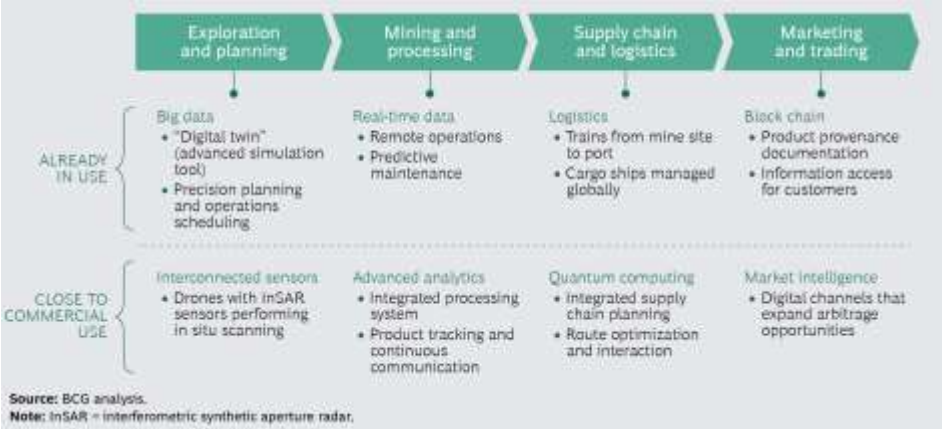
Many people talk about the transition to the digital mine. The transition has started but the goal is still some way off, although trends suggest that it could become a reality sometime in the future. The use of digitalisation has been taking place in mines to varying degrees, in various situations, for some time. Its use is becoming more pervasive and the technology is improving but it is only just beginning to be integrated across the value chain. We believe that success for mining companies won't just be about adopting the latest applications and technologies, but also the embedding of digital and innovative thinking into the heart of their business strategy.

In Deloitte's 'Tracking the trends 2019' [(5)] which looks at the top issues shaping the mining industry, it states that technology and artificial intelligence will play a key role, not only in helping companies envision future scenarios, but in identifying risks at an enterprise level and transforming the supply chain. Moreover, advances in finance platforms, sensor technology, autonomous vehicles, cloud-based solutions, and analytics are paving the way for the design of a digital mine.

One of the early movers from the mining industry was Rio Tinto with its 'Mine of the Future' programme [(6)] launched in 2008. It is about finding advanced ways to extract minerals deep within the earth while reducing environmental impacts and further improving safety. In 2010, Boliden, KGHM and LKAB, along with several major global suppliers and academia launched a concept study for a common vision of the mine of the future by 2030 [(7)]. In 2018, Anglo American launched its 'FutureSmart Mining' programme [(8)] and many other mining companies have less-formal initiatives and programmes. We discuss the approach taken to innovation by the large mining companies further in the report.

Nick Holland, CEO of Gold Fields has been talking about the mine of the future for a number of years and in mid-2018 [9] talked about mining companies needing to embrace technology because finding and developing a mine is becoming more difficult and taking longer and grades are declining. He believes that innovation and technology is like a tsunami coming at the industry, you either ride the wave or get washed away. Gold Fields goal is to have a surface or underground mine that is completely remote by 2028. He believes that working with technology companies to provide solutions is a key part of this effort.

Figure 2: Examples of New and Emerging Technologies



Source: Boston Consulting Group

One of today's 'mines of the future' is Resolute Mining's highly automated Syama underground gold mine in Mali [10], which commenced production in December 2018. The mine has been designed to ensure it is able to accommodate the best available technology for mining, haulage and processing. Underground development costs include provision for a high capacity fibre optic system, which will be installed throughout the mine. This will allow the operation to install sophisticated mobile equipment monitoring and guidance systems, which will in turn improve safety and productivity in the mine. As these technologies develop their use will be progressively incorporated into the operation of the mine.

ABB has an interesting video showing its ideas of a concept mine of the future [11] including a digital twin. It has a new Collaborative Operations Centre in Vasteras, Sweden where ABB plans to develop its digital technologies for the future of mining. Its mission to deliver the benefits of digital technologies via its unified, cross-industry digital offering. GE Digital [12] also sells its view of a digital mine to market with its Predix platform for the industrial internet, which connects all mining assets to reduce unplanned downtime, optimise operations and enable proactive processes.

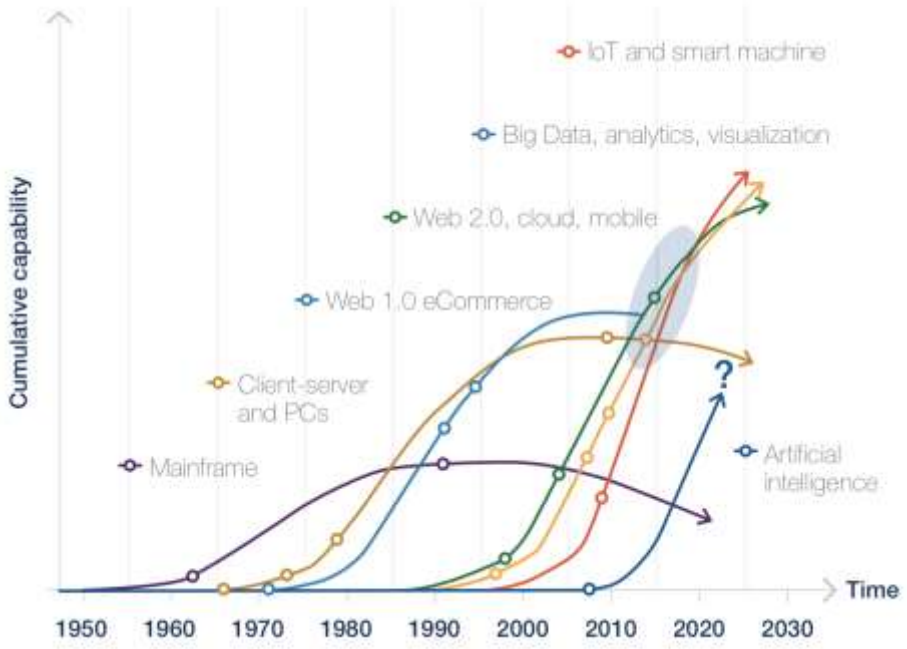
Rio Tinto has introduced digital twinning at its Koodaideri mine in Western Australia which involves building a replica digital plant that collects all the data on the plant from design, build, commissioning and operation, to improve real time decision making.

Accenture's view of the digital mine [4] states that it leverages the best of digital technology, Internet of Things (IoT), and cloud or on-premise platforms to connect the

mining value chain from mine to market and from sensor to boardroom. Data is consolidated from siloed databases such as fleet management, dispatch, historians and ERP solutions. Once consolidated, powerful analytics can be run to provide operational intelligence and trend analysis, all visualised on tablets, smart devices, desktops and in operation centres. This enables users to better understand the operation and embed productivity improvements through dynamic planning and scheduling, dynamic dispatch, and blending, based on customer order and market economics.

Our assessment of the current status of the digital mine is that the mining industry is only at the early stages of digital transformation. This possibly reflects the historical conservatism attributed to the industry, but it is taking place at what appears to be an accelerating pace. This is because much of the technology is now robust enough and significantly developed and trialled to allow implementation in the production process. The steps may be small and incremental, but mining executives are now starting to realise the productivity benefits through the visualisation of data across the entire value chain and the implementation of the new technology.

Figure 3: The increasing capability of digital technologies



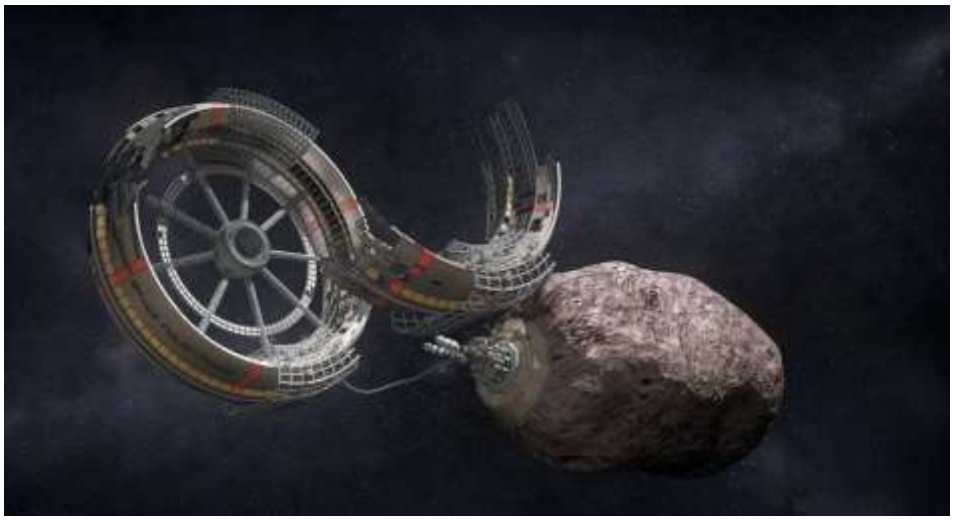
Source: World Economic Forum/Accenture analysis

Digital Implementation and Disruption

The World Economic Forum report [3] states that the major difference between disruption today and in the past is the accelerating pace and pervasiveness of change. When analysing core digital technologies and the evolution of their capabilities over time, the speed of capability improvement, adoption and displacement by new technologies has quickened. Much of this acceleration has been generated by the falling cost of technology. Moreover, when these digital technologies are used in combination, they significantly increase the overall capability of these technologies.

Industry experts also point out that 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 [13]. Also, innovation is about a deep appreciation of process at the fundamental level, combined with a vision of the final goal. In between is brilliance, perseverance, focus, a sense of proportion, being able to deal with people and knowing deep down that failure can be expected all too often and is simply a part of learning [14].

Figure 4: Concept of asteroid mining



Source: Bradford Space

Jean-Sebastian Jacque, CEO of Rio Tinto [15], states that he has absolutely no doubt that digitalisation will be the fundamental game changer in the mining industry. New digital technologies from AI to the Internet of Things, and new biotech, will force managements to be more imaginative. In marketing and trading, digital and big data will play a big role with blockchain helping customers, from governments to consumers, to check the ethics and value of all products, as well as their environmental credentials.

Finally, Boston Consulting Group [16] believes that further development of emerging digital technologies, promise to revolutionise the industry in almost unimaginable ways. Among them: drones that perform in situ scanning, genetically manipulated bacteria or nanobots that mine at the molecular level, deep-sea robots that mine underwater, big data and algorithms that enable end-to-end tracking and communications as well as real-time supply and demand management, water-neutral processing that eliminates the need for water and slurry ponds. Some far-sighted commentators also talk about the mining of asteroids.

These new technologies may still be some way off; however, they have the potential to disrupt both existing business models and the traditional roles and relationships among mining companies and their customers, suppliers, and even competitors. Companies like Planetary Resources have already assembled asteroid mission profiles.

Corporate Approach to Innovation

Mining companies are slowly adjusting their strategies and business models to include innovation and new technology as a cornerstone to their policies. As we have stated, the incentive for management is the ever-constant pressure to maintain or improve profitability and to improve safety. The current key innovation enabler to a step change in operating performance from new technology is the adoption of digitalisation.

Some companies have been talking about the 'Mine of the Future' for over ten years and have developed, trialled, and implemented new digital technology. These are the early movers. Many others have been slower and content to be second movers, waiting for the technology to become proven commercially and offered by third party providers. Some are still just sitting back and observing and only making incremental changes to their business model during their normal capital cycle.

Technological Tipping Point?

Today we appear to be at a tipping point where investors now expect companies to be embracing innovation through digitalisation as they witness the benefits achieved by the early adopters. The increases in productivity, cost savings, and improvements in safety are starting to be captured by the early movers, although the results are not fully transparent. McKinsey [(1)] analysis suggests that AI adoption in industry by front runners can anticipate a cumulative 122% cashflow change, while the followers will see a significantly lower impact of only 10% cashflow change.

The front runners will capture the initial competitive advantage that will move them down the cost curve and give them an advantage over their competitors in terms of likely higher profits and potentially higher market ratings. Arguably, in time, the whole industry will gravitate to the 'Mine of the Future' and digitalisation will become another cost reduction factor that moves the whole industry's cost curve down and eventually helps keep commodity prices down.

Obviously, the key for mining companies with a long-term view will be to constantly stay ahead in innovation. Notably though, the accessibility of digitalisation is open to all sizes of company or operation, as well as SMEs and is not exclusive to developed economies. This increases the risk of digital technologies lowering the barriers to entry and making it harder for incumbents, although in the mining sector owning and operating the top-quality assets remains important.

The Best Way To Predict The Future Is To Create It

One of the early movers in the mining industry has been **Rio Tinto** and its 'Mine of the Future' programme [(6)] launched in 2008. Its strategy has been to find advanced ways to extract minerals while reducing environmental impacts and further improving safety. This sounds somewhat generic, but it has been a leader in innovation and new technology in recent years with a focus in four areas: autonomous truck haulage systems, automated drill systems, AutoHaul (autonomous rail haulage from the mine to the port), and its remote operations centre in Perth, Australia. It has also been involved with a range of other new technologies at the same time. The company finally

commissioned its first network of driverless trains at the end of 2018 and as a result has now achieved its goals in these four areas. It can continue to roll out this technology to other mines within its portfolio but could also present a refreshed strategic direction to the market. Chris Salisbury, chief executive Iron Ore, recently highlighted that Rio Tinto has just launched a pioneering laboratory in Brisbane to come up with big, blue sky ideas that will help Rio Tinto 4.0, and ultimately, the industry, to be better, faster, and more efficient.

Figure 5: Rio Tinto's Iron Ore Operations Centre, Perth

Source: Rio Tinto

In 2018, **Anglo American** launched its 'FutureSmart Mining' programme [8] which aims to apply innovative thinking and technological advances to address mining's major challenges. It has developed four aspirational concepts that it is working to achieve:

- The concentrated mine - maximising mine output (the ratio of metal to ore) while minimising operating and capital costs and its environmental footprint.
- The modern mine - automated and continuous rock cutting vehicles to safely extract the targeted ore deep underground without the need for explosive blasting.
- The intelligent mine - a truly smart mine, transforming vast quantities of data into predictive intelligence (from sensor to boardroom).
- The waterless mine - eliminating fresh water from its mining processes, especially in the separation and transportation of ore and waste (tailings).

With its concentrated mine concept, Anglo American is integrating three technologies: advanced fragmentation, bulk sorting, and coarse particle recovery [17]. Together these have the potential to deliver a step-change increase in the operations output, without a step change in operating and capital costs while reducing energy and water use.

With its modern mine concept, Anglo American is developing and testing automated and continuous rock cutting vehicles to safely extract the targeted ore deep underground without the need for explosive blasting, thereby creating far greater rock stability and far less variance in the quality of the ore extracted. Such safety and

productivity innovations make it possible for the company to mine lower grade ores and complex mineralogy, creating a safer environment, lower operating costs while enhancing the value of the mineral resource in the ground [18].

With its intelligent mine concept, Anglo American's latest work is concerned with identifying mineral and material properties using analytics for real-time drilling analysis, hyperspectral core imaging, and geological modelling software using 3D and virtual reality to generate and interpret predictive data models. It is also developing customised learning algorithms to predict control parameters required by its plants. Another important application is condition monitoring and predictive maintenance [19].

With its waterless mine concept, Anglo American is already making inroads into its water challenge through an ambitious closed loop approach to water dependency. This sealed system approach aims to deliver greater water efficiencies through direct water recycle and reuse. As part of this, the company is focusing its innovation efforts in two areas: evaporation measurement and dry tailings (waste) disposal [20].

Figure 6: Anglo American's Rapid Mine Development System

Source: Anglo American

Less Formal Approaches

BHP has not announced a formal programme to shareholders, but the centrepiece of its technology strategy is integration [21]. It has stated that integration is the capability that connects everything, building a bridge between the present and the future and lays a foundation for fully integrated and highly automated operations by 2025.

BHP has globalised its technology function, which now spans research and development, program delivery, and technology operations along the value chain. It is applying a 'systems engineering' approach with its assets to analyse mine life cycles, identify constraints and prioritise investments. This facilitates rapid replication of best practices across its operations. BHP has a portfolio of ongoing projects to integrate and automate across its business and is trying to instil a digital mindset and culture of innovation across its organisation.

A vital pillar to its technology strategy is building an ecosystem of partners with established and new companies, many from the OEMs. These partnerships give it access to leading technology and outside talent to help it find solutions to complex problems. BHP is also investing in relationships with universities and has contributed US$3m as part of an alliance with the University of Melbourne, Stanford and Cambridge to raise global awareness of CO_2 storage and support the development of large-scale carbon capture and storage projects in the future.

In February 2019, within its half year results [22] BHP presented a slide giving its broad overview of its technology programme and systems approach to the integration and automation of its value chain (Figure 7).

Figure 7: BHP – The transformative power of technology

Source: BHP

In Canada, **Teck** has four Research and Development hubs covering diverse technology and innovation initiatives. This includes assessing the effectiveness of current technologies as well as developing new breakthroughs. Teck's approach to innovation and technology is focused on four key pillars: Safety, Sustainability, Productivity, and Growth. Teck believes that these pillars have the greatest potential to contribute to its business and deliver the greatest value for its employees, the company, its communities and society. These pillars are supported by the ongoing digitalisation of its operations and activities.

Teck has been working closely with companies locally and globally on strategic partnerships to develop and implement ground-breaking technologies, such as an open-source fleet management system, the first electric semi-autonomous drill systems, a virtual-reality mine and the first shovel-mounted ore sorting technology which uses sensors to separate valuable ore from waste. Teck also participates and funds over 25 different research and development consortia, including research chairs for the Natural Sciences and Engineering Research Council of Canada (NSERC) and university research initiatives.

Teck maintains a dedicated team to scan and facilitate action around new technologies and innovative opportunities. Multi-disciplinary teams help drive analysis on the benefits of new technology and plan for testing, trials and pilots.

Gold Fields started the implementation of a new innovation and technology strategy in 2017. The thrust of the strategy has been to modernise, integrate and optimise existing systems and processes. Once this has been embedded the company will consider a more comprehensive drive towards full mine automation. The ultimate goal of the strategy is to work towards the 'Gold Fields Mine of the Future', which is premised on automation, an integrated digital data platform, remote machine operation, virtual reality and reduced mining waste. In addition, partnerships with IT companies and OEMs that are leaders in the field will be integral to successful implementation of the strategy.

Figure 8: Solar Facility That Supplies Power to Quebrada Blanca Operations

Source: Teck

Newmont Mining initiated a targeted approach to technology and innovation through investments in people and systems in early 2018. It is developing a 5-10 year enterprise technology and innovation strategy. Its approach to digital integration focuses on advancing responsible mining practices that maximise sustainable value. Specialised teams target strategic digital opportunities across the portfolio. This includes integrated architecture of informational and operational technology and infrastructure through connected, streamlined and analysis-rich operations. Mine monitoring and control teams focus on wearable technology for operational efficiency and safety, while machine control and automation crews improve equipment performance, safety and consistency through artificial intelligence and other tools.

Goldcorp states that its 'ticket to play' in the digital transformation is in its portfolio of young mines, equipped with a strong, reliable technological backbone enabling digital expansion. A case in point is the deployment of a single multiservice IP network at its Éléonore underground mine, providing secure wireless communications to improve safety, reduce maintenance and operating costs. As part of Goldcorp's digital transformation strategy, it is targeting new technological opportunities in six areas that are ripe for innovation, covering every stage of the mining life cycle, from exploration and development to operations and reclamation: Big Data and Machine Learning, The Connected Miner, Autonomous Mining Operations, More sustainable mines with smaller environmental footprints, Operations and Reclamation, and Safety and Environmental Re-Engineering.

Goldcorp is the leader and one of the founding partners of the #DisruptMining [23] initiative, a mining innovation contest. It is an annual challenge showcased during the annual Prospectors and Developers Association of Canada conference. It offers innovators and entrepreneurs a platform to bring disruptive and exponential technologies to the mining sector. A panel of industry leaders awards one of the finalists the opportunity to negotiate a $1m investment in its technology, company, or idea. Since the launch of #DisruptMining in 2017, Goldcorp has invested over C$10m in a range of new technologies and companies identified through the innovation accelerator. This funding has supported companies through the start-up phase into growth and scale-up.

Innovation Testing Sites

In Europe, **KGHM**, **Boliden**, and **LKAB** in Sweden have been working with several major global suppliers and the academia since 2010 [7] to develop a common vision for future mining by 2030. It has seven principle features: one control room, no human presence in the production areas, continuous mechanical excavation, pre-concentration of ore, maximisation of the inherent values in the rock, systems to describe the rock with its structures to aid process control, and production and sustainability of final products at the mine site. R&D projects have taken place and data has been collected from LKAB's Kiruna mine and its concentrator, from the Boliden Kristineberg mine and its share of the concentrator situated in Boliden, and from the KGHM Lubin, Polkowice and Rudna mines including their concentrators.

In Canada, the NORCAT Underground Centre [24], located in Sudbury, Ontario, is an underground operating mine that serves as both an innovation and training centre providing technology development, testing and demonstration as well as hands-on training and development. The NORCAT innovation centre has an operating mine designed to enable start-ups, small-medium enterprises, and international companies to develop, test, and demonstrate innovative and emerging technologies in an operating mine environment. On an annual basis, the centre supports approximately 50 mining technology projects and hosts nearly 50 global mining companies that tour the mine to see the latest developments in the mining industry.

In Australia, CRC ORE [25] operates the Kalgoorlie-Boulder Mining Innovation Hub to harnesses the development and deployment of new mining technology. CRC ORE is a not for profit organisation funded by the Australian Federal Government and the global minerals industry. CRC ORE facilitates the development of innovative solutions through a global consortium of Mining companies, Mining Equipment and Technology and Services (METS) companies and research institutions. CRC ORE commenced in mid-2010 and after its initial 5-year funding term, was awarded a further 6-years of funding until July 2021.

A country in which government has put a particular effort into seeking to promote collaborative innovation in the mining sector is Chile. The focus of these initiatives, the most recent of which is the Alta Ley programme [26] launched in 2015, is the bringing together of all those with a part to play in the innovation process, whether these be miners and policy-makers with problems to be solved or METS companies and research bodies (including universities) with solutions to offer.

How Successful Have Corporates Been?

This is a very hard questions to answer as corporates are reluctant to fully reveal this type of information and likely many do not have a full grasp of all the data themselves. Innovation is certainly a difficult concept to integrate in to an organisation and even harder to articulate and numerate to shareholders. Some companies are clearly succeeding and other are struggling to varying degrees. In November 2017, BHP acknowledged that it had been viewed as a fast follower rather than a technology leader, but its goal was to attain a leadership position.

We are now seeing an increasing number of mining executives with titles like 'Head of Innovation' and 'Chief Technology Officer' and an increasing number of new technology charts in presentations. For some, this is likely a sign of real progress on the path to digitalisation and the 'mine of the future', for others they are possibly just steps to buy more time to determine and implement a real strategy.

Positive benefits can be seen and there remains a lot of enthusiasm in the industry, although we suspect that some new technologies are proving harder to implement and are less cost effective than some initially expected. Understandably, when things do not go according to plan it is not in management's or the OEM's interest to highlight problems and issues, especially if significant capital has been invested in a project. While we think that benefits will continue to materialise from innovation, we believe the path will not be straightforward and the rewards variable.

The AHS Experience

One example of this is Autonomous Haulage Systems (AHS), which we cover in our next research report on innovation and new technology. Outlining the potential benefits of AHS is straightforward but finding hard data to support it is more difficult. The companies have made suggestions about the scale of improvement, but they are light on detail, definitions are not clear, and the data varies between companies. Suggested improvements in productivity have come from Caterpillar (15-20%), Fortescue Metals (30%), Komatsu (15%), and Rio Tinto (15%). These improvements are still meaningful, and corporates would argue that every mine is different and that the mining companies and OEMs that have so far implemented AHS have the right to guard this proprietary information and hold on to the competitive advantage.

Slow Pace of Implementation

At the same time, despite the acclaimed success and the relative level of maturity of the technology, the wider implementation of AHS does not appear to be happening very fast. The systems of both the two main suppliers (Caterpillar and Komatsu) are well proven and have delivered positive results, although according to consultants both systems also have examples of less-than-expected performance. Nevertheless, the technical issues appear relatively minor and there is interest right across the industry, but there is little explanation of why more mines are not now using AHS.

There are a number of likely reasons for this and one of the most important is a lack of skilled personnel. We believe there is a lack of in-depth knowledge of the technology and limited personnel with the requisite experience, skills, and training

throughout the industry's hierarchy. Further, there is a shortage of skilled autonomous operators, developers, and consultants, some of who are moving to the autonomous auto market. Important factors in the success of AHS appear to be the level of management commitment, planning, and focus in the implementation, with the best results reported from well-operated mining sites.

Another factor is likely to be limitations on equipment supply from OEMs for new equipment and truck conversions, either due to manufacturing backlogs or maybe market caution limiting investment. This is allowing the OEMs to be more selective in their customers. However, if the existing suppliers do not develop additional capacity quick enough this could create opportunities for additional entrants in to the market.

Capital availability in the mining industry could also be an issue (although it is less tight than it has been in recent years). Certainly, some lower margin operations might struggle to finance the capital, although the uplift in relative profitability could be transformational, with relatively quick paybacks.

Finally, the historical conservatism of the mining industry is also likely to be a factor. There is still a natural reluctance within the industry to adopt new or unproven technology due to the high capital cost involved and the potential operational and reputational risks involved. This will be compounded if the organisation has limited experience and limited access to the technology.

Whose Truck Is It Anyway?

Other issues with new innovation include how to develop it and how to capture the ultimate benefit. Although there are no stated strategies, we see the major mining companies approach development in a number of ways including: working directly with OEMs; in-house development; and joint ventures, partnerships and funding relationships with government bodies and universities. Smaller mining companies must mostly accept existing technology available in the market. However, most mining companies remain relatively secretive about their actual strategy and the projects they are working on.

One potential problem with working with OEMs is determining how the benefits of the intellectual property are shared. Both Caterpillar and Komatsu were both strategic and fortunate that they were able to partner with mining companies to develop AHS. Fortescue, BHP, and Rio Tinto played a significant role in developing the autonomous truck fleets for the two dominant suppliers. While both the mining companies and the OEMs have gained significant knowledge and experience, we suspect it is the OEMs that have gained the largest share of the intellectual property. Unless meticulous contract negotiations took place at the start of and during the trials, we suspect that the OEMs now hold the upper hand in pricing power with their existing clients. Further, they are able to transfer this knowledge right across the industry at a likely premium price.

It is interesting that Rio Tinto, which trialled AHS with Komatsu haul trucks, is now also retrofitting Caterpillar haul trucks with AHS technology. It may be wanting to trial both systems for technical and practical reasons, but it may also be looking to recover some pricing power.

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