CREATING A TECHNOLOGY MAP TO FACILITATE THE PROCESS OF MODERNISATION THROUGHOUT THE MINING CYCLE

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DEPARTMENT OF MINING ENGINEERING

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Year: 2016

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ABSTRACT

The global mining industry is currently under pressure. The industry is in the midst of the largest mining super cycle since the Second World War. Mining companies face increasing challenges to profitability due to unfavourable commodity prices as well as increasingly tougher mining conditions, rising pressure from various stakeholders and numerous other mining challenges. Incremental improvements are no longer sufficient enough to sustain the mining sector, which explains why many leading organisations are rallying behind the innovation imperative that calls for major transformation. This is especially true with the impending technological revolution, where innovation will be the key to survival. This not only holds true for the mining industry, but for nearly all companies, businesses, organisations and governments worldwide.

In the upcoming technological age, the line distinguishing different businesses and operations will become increasingly unclear. It is therefore vital to approach innovation from a holistic point of view. One driver to improve the innovation efforts of an organisation is to look at technology trends across various industries. Many technologies exist, or are in development, that may be applied to be used (or be modified and applied) in the mining industry. With the rapid rate of technological advancement world-wide, it is also important for the mining industry to remain aware of cross-sectorial innovations that may have an impact in future. This is especially true when it comes to exponential and disruptive technologies.

Operational performance excellence relies on the innovative use of such technologies and to remain abreast with developments that may add value to a given component within the mining cycle. As a result, the mining industry will be increasingly focused on integrating all activities across the value chain. This includes the continued introduction and development of Integrated Remote Operating Centres, mechanisation and automation. Such technological advances and implementations in mining form part of the modernisation drive currently taking place in the South African mining industry. However, in order to accomplish such value-added end-goals the constituent technologies need to be evaluated in detail. From these and many other technologies, mining operations can also achieve multiple other benefits and “quick wins”.

While investigating these technological trends it was found that many different organisations, businesses, institutions and individuals conduct great amounts of research to identify technologies that are applicable, or potentially relevant, to mining. Often these studies complete the same research for the initial phases, prior to focussing in more depth on specific technologies. As a result, a need was identified for research in technologies that may add value to mining. By identifying starting points for further studies and R&D into specific technological solutions, many of these initial research phases may potentially be eliminated or reduced.

The greater part of the mining industry is often not aware of emerging technologies that could potentially add value to their operations, or which may disrupt aspects of their business or even their daily lives. The impact or benefit of technologies has to be assessed in order to gain an understanding of how opportunities could be exploited or detrimental impacts negated. In doing so, an organisation may work towards enhancing its operational risk management strategies, minimise negative consequences from external technological factors, and identify potential improvements to an operation or the organisation as a whole.

It is therefore vital for companies and individual operations to have access to a platform that can provide technology related information which needs to be accounted for. For this reason, a Technology Map was created that highlights technologies that may further be analysed in order to identify those technologies with sufficient potential to add value. The structure of the Technology Map was developed to include the main value drivers within the entire mining cycle, covering the exploration-, mine evaluation-, mine design-, operations-, and mine closure to post-closure mining phases. Various technologies, ranging from physical to digital technologies, were analysed. Those with potential to add value, or which need to be accounted for in order to avoid detrimental impacts, were slotted into the sub-categories, processes, activities, focus areas or specific challenges beneath the applicable value drivers throughout the mining cycle.

CREATING A TECHNOLOGY MAP TO FACILITATE THE PROCESS OF MODERNISATION THROUGHOUT THE MINING CYCLE

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LIST OF SYMBOLS

3D	Three dimensions/Three dimensional
APP	Computer Program/Application
AR	Augmented Reality
BBSEE	Broad-Based Socio-Economic Empowerment
CAPEX	Capital Expenditure
CIO	Chief Information Officer
DMR	Department of Mineral Resources
DNA	Deoxyribonucleic Acid
FoG	Fall of Ground
GDP	Gross Domestic Product
GPS	Global Positioning System
HMD	Head Mounted Display
HUD	Head-Up Display
IT	Information Technology
ICT	Information and Communications Technology
IoT	Internet of Things
LNG	Liquid Natural Gas
MEMS	Microelectromechanical systems
MPRDA	Mineral and Petroleum Resources Development Act
MTOE	Million Tonnes of Oil Equivalent
NGO	Non-Governmental Organisation
NIHL	Noise Induced Hearing Loss
OECD	Organisation for Economic Co-operation and Development
OEE	Overall Equipment Effectiveness
OEM	Original Equipment Manufacturer
Omics	Omics informally refers to a field of study in biology ending in -omics, such as genomics, proteomics or metabolomics
OPEX	Operating Expenditure
PC	Personal Computer
RFID	Radio-Frequency Identification
RDI	Research Development and Innovation
RDO	Rock Drill Operator
SOP	Standard Operating Procedure
TCO	Total Cost of Ownership
TFS	Technical Feasibility Study
ULP	Ultra-Low Profile
XLP	Extra-Low Profile

CHAPTER 1

MOTIVATION FOR THIS STUDY

1.1. The Current status of the Mining Industry Globally

“Mining is not everything, but without mining, everything is nothing.” Unknown.

Mining contributes around 10% of the global economic activity, as measured by the revenues from the commodity mining, quarrying and also the petroleum sectors. Payments to service and support industries constitute another estimated 10% of the world’s economic activity. When the contribution from mining products to the productive capacity of other industries is also added, a global economic contribution estimate is obtained of more than 45% by the mining industry. These include fertilisers for agriculture, fuel for energy and transportation, carbon and iron for steel and manufacturing and other products for construction, all vital to the operations of numerous industries and also economies (Cutifani, 2013).

While achieving this contribution, mining operations disturb less than 1% of the earth’s surface. Mining also produces less than 3% of carbon gases and the industry is further also the key source of products that clean the water we drink and the air we breathe. By considering these facts, it is not an unreasonable claim that mining is the most important industrial activity on the face of the planet. At the same time, mining is also the world’s most vital industry to help ensure the future health of the planet (Cutifani, 2013).

However, the global mining industry is currently under pressure. The industry is in the midst of the largest mining super cycle not seen since the Second World War. There is no denying that this super cycle, which began in 2006, may last for many years and have long-lasting impacts on the mining industry (Bryant, 2011). In the short term, falling commodity prices are clamping down cash flows (Figure 1.1a shows an example on the Commodity Metals Price Index). While looking ahead, many existing mines are maturing, resulting in the extraction of lower ore grades and longer haul distances from the excavation face. Orebody replacement rates are declining and the duration of development for new mines is increasing. Adding to this, worldwide mining operations are as much as 28% less productive today than they were a decade ago (Figure 1.1b), and that is after adjusting for declining ore grades (McKinsey, 2015).

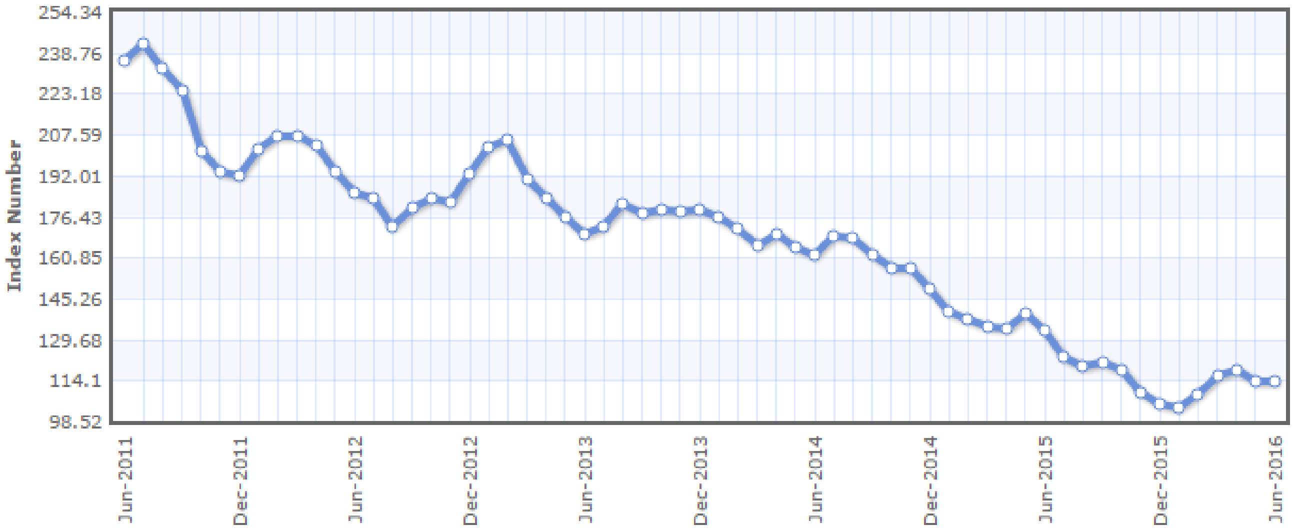


Figure 1.1a: Commodity Metals Price Index (includes Copper, Aluminium, Iron Ore, Tin, Nickel, Zinc, Lead, and Uranium Price Indices) (Indexmundi, 2016)

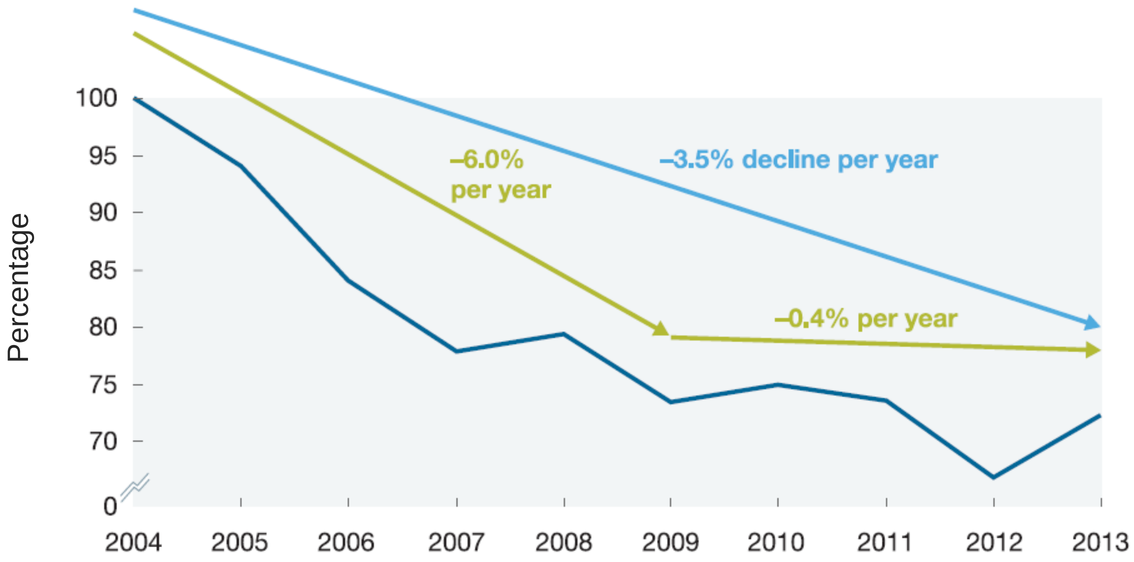


Figure 1.1b: Global Mining Productivity Index (McKinsey, 2015)

Mining companies therefore face increasing challenges to profitability due to unfavourable commodity prices as well as increasingly tougher mining conditions. Even though commodity prices have improved since the lows of 2008, prices mostly still remain stagnant or falling. This limits revenue potential for mining operations and companies in general, and further hampers shareholder returns as shown in Figure 1.1c. Declining ore grades in existing operations also means that companies are required to mine deeper to reach new deposits, which in turn increases costs and results in reduced profits. Since the start of 2000, over 75% of new base metal discoveries have been at depths greater than 300m. Mining at these depths bring additional challenges, such as safety issues, water flooding, gas discharges, seismic events and ventilation problems (Deloite & Touche, 2014). Adding to the fact that mining operations are now deeper and more dangerous, the geology is also more challenging. The result is that continuous improvement alone is no longer sufficient for companies to survive (Mining Indaba & Monitor Deloitte, 2016).

In order to address these challenges, the industry has been rallying behind calls for mechanisation and “modernisation”. These drives further come with their own challenges and the route towards achieving their desired end goals would not be an easy one. The question also needs to be asked as to whether both the route and the end goal would be sufficient to counter the issues that are being faced.

Furthermore, compared to their global counterparts, South African mining companies’ margins are under even greater pressure. Along with the stagnant or falling global commodity prices are rising input costs. This forces companies to make difficult decisions in an attempt to sustain short-term operations, while aligning these decisions with long-term objectives. Labour and energy costs in particular have exceeded inflation, while employee productivity has fallen. Figure 1.1.d shows an example from the South African Gold Mining Sector. These challenges in the operating environment do however not quell the pressure from increasing demands from unions and mine workers, nor the impact from strikes that often follow unfavourable outcomes. Adding to these challenges, there are rising demands by government and civil society as to the role mines should play in society (Deloitte & Touche, 2014).

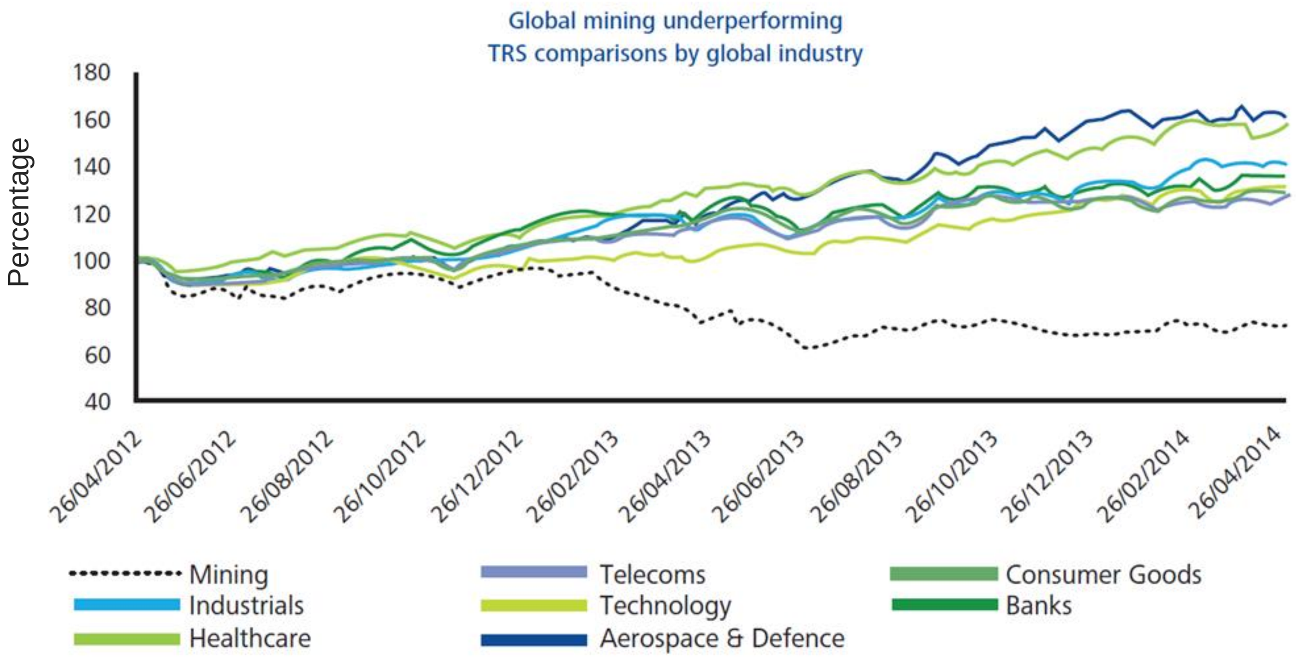


Figure 1.1c: Total Return To Shareholder (TRS), as a percentage, comparisons by global industry (Deloitte Touche Tohmatsu Limited, 2015)

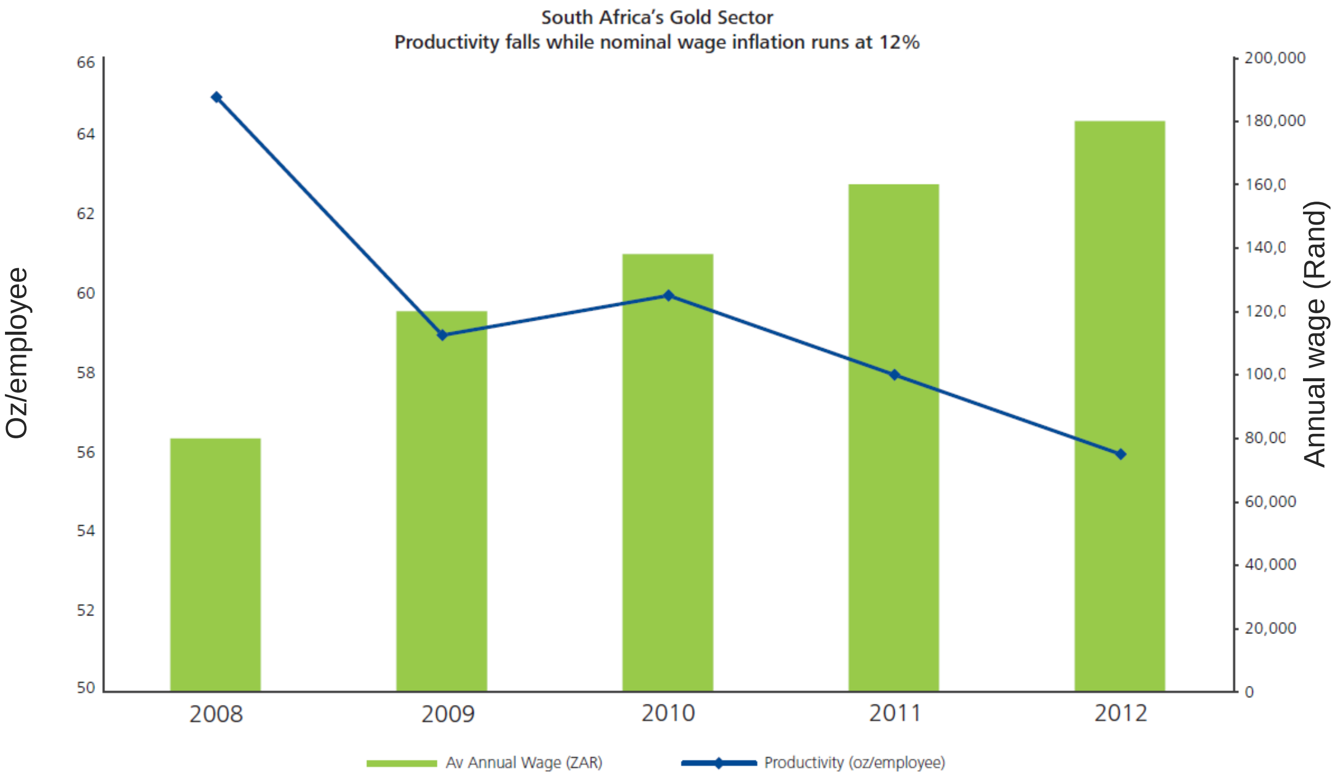


Figure 1.1.d: South Africa's Gold Sector on Employee Productivity (Oz/Employee) vs. Nominal Wage Inflation (Annual wage in ZAR) (Deloitte Touche Tohmatsu Limited, 2015)

In the current mining industry mining companies are struggling to recalibrate. Yet, the industry still faces other unresolved challenges. This includes reduced demand, declining grades, mounting stakeholder expectations, a lack of financing and withdrawing foreign investors. At the same time, the industry has to contend with a range of mutable issues. This includes the innovation imperative, shifting regulatory realities and the rising risks associated with both physical (especially in 3rd world regions) and cyber security (Deloitte Touche Tohmatsu Limited, 2016).

All of these factors led to a strong need to find new ways to deal with mining challenges as well as labour, as the abovementioned drivers are pushing towards upskilling the workforce and implementing increased mechanisation. These efforts are towards an end goal in a “modernised” mining industry. With a goal to improve working conditions, reduce the dependence on large quantities of unskilled labour and to generally mine more efficiently (Deloitte & Touche, 2014).

Global trends relating to 2030 were analysed by the European Strategy and Policy Analysis System (ESPAS). In this it is forecasted that global competition for access to natural resources will continue to intensify. Similarly, the associated risks, in terms of market volatility, geo-political tensions and instability will also increase. Faced with growing demand for raw materials, worldwide mining capacity should however double by 2030, but volatility is likely to increase due to heightened ‘financialisation’ (ESPAS, 2015). Yet, if there’s one constant in the mining industry it is constant change, unpredictability and complexity (IBM, 2009).

The need for this expansion in mining, coupled with the increase in challenges of all sorts faced by the industry, will require new ways in dealing with risks and new approaches in finding solutions to mining problems. The time for taking innovation seriously as a business imperative has come. While talk of this has drummed on for years, often constrained to the boardroom, now is when mining houses will succeed or falter based on whether a successful innovation strategy is brought to life and whether it can be integrated across departments (Mining Indaba & Monitor Deloitte, 2016).

Rajeev Chopra, Global Leader of Energy & Resources from Deloitte Touche Tohmatsu Limited, stated that “Miners can no longer afford to look at mining trends and technologies in isolation. As global economies converge, political, social and technological changes increasingly impinge on how the industry operates. To find solutions, we need to ask the right questions and be willing to consider unexpected answers.” (Deloitte Touche Tohmatsu Limited, 2016).

Without such a redefined approached to mining, existing and arising opportunities will continue to become increasingly more difficult to exploit. As an example, the Arctic region will become gradually more accessible (especially with the development of new technologies such as hybrid airships, which will use a combination of blimp, helicopter and fixed-wing aircraft designs to create a new type of flying machine). This will provide some of the needed expansion opportunities, but will also pose economic, geopolitical, environmental and human challenges (ESPAS, 2015). The Arctic region contains substantial natural resources, with an estimated between 15% and 30% of undiscovered gas reserves as well as mineral resources (such as zinc, nickel and graphite) (US Geological Survey, 2008). Mining in this region would however require innovative approaches to mining and, without the application of the proper and suitable technologies, such a venture may be difficult and even dangerous.

1.2. Definitions Used in this Study

Innovation

The word innovation is often vaguely defined and definitions are diverse. Therefore, the definitions used in this study are that of Mining Indaba & Monitor Deloitte (2016), verbatim:

"The word innovation is the ultimate white label word. It is widely open to interpretation and can be tagged on to anything that successfully changes the status quo or solves a problem in life, whether at a commercial or social level." In short, *"Innovation is the creation of a new, viable business offering."* Or more to the point for this study, *"Innovation [as separate from invention] is the creation of a new [to our market or the world], viable [creating value for both our customers and ourselves] business offering [ideally going beyond products to platforms, business models and customer experiences]*".

As will be discussed in detail in the following section, this study placed greater focus on innovation in the technology sphere. For this study, innovation came into play in identifying technologies of various kinds that could add value in some way to the mining industry.

Modernisation

The term *modernisation* will be used in order to describe the transition of the mining industry, including mining organisations and individual operations, from the current towards a more technologically advanced and innovative industry. This term is a reflection of the drive currently taking place in South Africa to "modernise" the mining industry. The aim of mining modernisation is to extract South Africa's mineral resources in the safest, most efficient, cost-effective and sustainable manner possible; improve the skills, health, quality of life and fulfilment of the people working in the industry; conserve the natural resources, and preserve and restore the environment; contribute to the development of local and labour-sending communities; and, transform and grow the mining industry and nation (COMSA, 2016).

The definition of modernisation, as given by the Chamber of Mines of South Africa in the context of improving the local mining industry, is "*a process of transition and transformation of the mining industry of yesteryear and today to that of tomorrow*" (COMSA, 2016). Within this study, the term *modernisation* then refers to the innovative implementation, adoption and advancement of technologies in order to create value within the mining industry that would facilitate mining modernisation.

Five qualifying criteria was used when assessing technologies in order to determine the potential of a technology to add value and, as such, also have potential to assist with mine modernisation. These five criteria included a technology's potential to:

- Increase production;
- Increase productivity;
- Increase efficiency;
- Improve safety;
- Reduce risk of human error.

Technology Classifications

In the context of this study, the following classification definitions were assigned in order to group different technologies together:

Physical technologies: Any technology that has a physical nature in its use and work output, such as machinery, equipment, or the devices necessary to use data & information technologies.

Digital Technologies: Any technology relating to the sourcing, analysis and application of data or information. This may include the generation of data from sensors or other sources. It may also include the transfer of information, which may range from statistics and forecasts to communications and instructions. It may further also include the analysis and refinement of data to information, to value-adding knowledge or insights. Lastly, any software application will also be classified under this section regardless of what type of role it plays in the usage of either data or information.

Technology Map

The definition of a Technology Map in the context of this study is taken from the following descriptions regarding technology maps and technology roadmapping:

A technology map is a plan that matches short-term and long-term goals with specific technology solutions to help meet those goals (Garcia & Bray, 1997). It is a plan that applies to a new product or process, or to an emerging technology (Phaal *et al*, 2001). It helps reach a consensus about a set of needs and the technologies required to satisfy those needs, it provides a mechanism to help forecast technology developments, and it provides a framework to help plan and coordinate technology developments (Laube & Abele, 2005).

Value Chain and Mining Cycle

Investopedia (2016b), describes a value chain as "*the process by which businesses receive raw materials, add value to the raw materials through various processes to create a finished product, and then sell that end product to customers. Companies conduct value-chain analysis by looking at every production step required to create a product and identifying ways to increase the efficiency of the chain. The overall goal is to deliver maximum value for the least possible total cost*."

In the mining context, the value chain generally encompasses to the progression from exploration and deposit discovery, to evaluation in determining mineral resource and reserve characteristics, followed by extraction, beneficiation and delivery of final product to the market (Britz, 2016). Often mining organisations define the mining value chain as those activities, functions, and business strategies purely within the operations phase of a mining venture (Du Plessis, 2016). Since all of the mining phases may have an impact on each succeeding phase, the value creation within an organisation is inevitably linked to all phases within the mining life cycle.

For this reason and within the context of this research study, the term *mining cycle* will refer to all the mining phases, namely the exploration-, mine evaluation-, mine design-, operations-, mine closure to post-closure mining phases. As such the mining cycle contains the mining value chain and all other phases, sub-phases, processes or activities that make up the entire life cycle of a mining venture.

1.3. Project Background

The mining industry tends to regard itself as a very different and unique industry, unrelated to other industries and how other businesses function. As a result, compared to most other industries, the mining industry has been lagging behind in the innovation sphere (this will become evident in the following section). This is particularly true in terms of technology development and adoption. It then becomes important to take a different approach and to focus on the way other non-mining industries, companies, organisations and any relevant business functions. To compare with their technology strategies, as well as the innovative technological applications, inventions and adoptions they focus on.

In the upcoming technological age, the line distinguishing different businesses and operations will become increasingly unclear. It is therefore important to approach innovation from a holistic point of view and not with a specific solution in mind. "*In order to create a lasting, sustainable advantage, a holistic approach to innovation is required*" (Bryant, 2011). This extends to the technology strategy of a mining organisation, in which it is necessary to also acquire external technologies and innovation knowledge in order to compliment the internal needs of the mining industry.

It was found that many different organisations, businesses, institutions and individuals conduct great amounts of research to identify technologies that are applicable, or potentially relevant, to mining. Often these studies complete the same research for the initial phases, prior to focussing in more depth on specific technologies. As a result a need was identified for research in technologies that may add value to mining. By identifying starting points for further studies and R&D into specific technologies, many of these initial research phases may potentially be eliminated or reduced.

The purpose of this study is to introduce the mining industry to emerging technologies that could potentially add value to their operations and facilitate mine modernisation. Technology ages quickly and new developments emerge at a rapid pace, resulting in studies (and implementations) becoming out-dated and irrelevant. It is therefore vital for companies and individual operations to have access to a platform that can provide technology related information that needs to be considered.

1.3.1. Focus of the Study: Technological Innovation

Incremental improvements are no longer sufficient enough to sustain the mining sector, which explains why many leading organisations are rallying behind the innovation imperative that calls for major transformation (Deloitte & Touche, 2014). The general consensus, in numerous industries and countries, is that innovation is the key to survival. This not only holds true for the mining industry, but for nearly all companies, businesses, organisations and governments worldwide (ESPAS, 2015).

While innovation was perhaps once perceived as a fad, it has become critical to mining. Solutions that were once deemed unviable or inapplicable to the industry continue to be adapted to suit the needs of mining companies (Deloitte Global Services Limited, 2014). However, 90% of innovation efforts fail. There are no shortages of new and brilliant ideas, but finding the right ones and delivering results requires a structured and scientific process (Deloitte & Touche, 2014).

With the rapid rate of technological advancement world-wide, it is important for the mining industry to remain aware of cross-sectorial innovations that may have an impact in future. This is especially true when it comes to exponential technologies. These are technologies that, instead of following a linear adoption curve with a steady rise, they initially remain flat before accelerating dramatically. The result is that exponential technologies often disappoint in their early years before seemingly realising an accelerated adoption. Often companies overlook the value of such technologies when they should have been exploring them in their initial stages (Deloitte Touche Tohmatsu Limited, 2016).

According to Bryant (2015), "*The current point in the mining 'sawtooth' cycle presents tremendous opportunities for innovation. The time is now for the mining industry to embrace technology and business model innovation*." Those that strive to capture the full value of the current super cycle will need to realise important transformations in their business system. These transformations will need to allow rapid and accurate characterisation of ore bodies, faster development of mines, faster extraction, improved recovery rates, improved mine planning and increased use of automation and remote operations (Bryant, 2011).

One of the most notable examples is from Rio Tinto, who recognised the coming of the super cycle in 2006 and invested accordingly in R&D and innovation. The results included extensive increases in iron ore output in Australia, earning the company record profits. Along with the implementation of some of the progressive Mine of the Future initiatives, Rio Tinto has become an industry leader. The company has however been focusing primarily on the necessary areas of optimising and automating current mining methods, rather than developing truly transformational approaches and new processes (Bryant, 2015).

Many respectable leaders are advocating the need for innovation in mining. Another example is Rod Thomas, president of the Prospectors & Developers Association of Canada (PDAC), who stated that *"given the mounting mining challenges, it's time to acknowledge that innovation is no longer a luxury. In fact, innovation is now critical to the survival and sustainability of the mining industry, integral to value creation and adequate returns on investment, and essential to sustaining mining's contributions to the Canadian economy*" (PDAC & Deloitte, 2015). Likewise the same could be said globally.

Glenn Ives, Americas Mining Leader in Deloitte Canada, stated "*It's interesting times in the mining industry; more interesting than many of us expected. China's economic rebalancing is causing exceptional disruption. Commodity prices are taking much longer to recover than anticipated. To my mind, this makes innovation even more imperative. Rather than being optional, being bold may be the prerequisite to survival."* (Deloitte Touche Tohmatsu Limited, 2016). He further also stated that, *"if mining companies hope to emerge from the downward cycle in a stronger position from which they entered it, they need to increase mining intensity and focus on reducing capital, people and energy intensity. This will require them to adopt innovative technologies used in other industries in a measured and risk-intelligent way and increase the use of information technology."* (Deloitte Touche Tohmatsu Limited, 2015).

As mining companies begin to adopt innovative practices on a larger, more all-encompassing scale, they stand to gain significant value. Deloitte & Touche (2014) & Deloitte Touche Tohmatsu Limited (2015), highlighted the adoption of external (to the mining industry) technologies as a way to accelerate the process of applying innovation to the entire mining operational ecosystem, verbatim:

"Leverage emerging technologies*: New technologies hold the promise of vastly altering mining sector fundamentals. 3D visualization tools can help companies track their people, equipment and changing environment at each mine site, in real time. New mineral processing technologies are emerging to reduce the safety hazards associated with gold extraction and to unlock previously uneconomic mineral deposits. Social media is helping companies to facilitate electronic booking at mine sites and enhance employee access to information, no matter where they're located. Some companies have even launched SMS messaging platforms as a way to foster two-way communication with employees, solicit feedback and improve workforce engagement. New production and logistics technologies also promise to reduce both the use of natural resources and emissions. For instance, when up and running, Vale's S11D project's mine and plant in Carajás, Brazil will consume 93% less water, use 77% less fuel and produce 50% less greenhouse gas emissions than a comparable operation using conventional methods."*

It is also not only consultants, service providers or non-direct mining leaders that call for innovation and increased technological advancement as the key to save the current mining industry. The following prominent mining leaders have similar opinions, as will now further be discussed.

At the 2015 Jo'burg Mining Indaba Chris Griffith, CEO of Anglo American Platinum, stated that "*given the magnitude of our extraction challenges, it is quite extraordinary that the global mining industry currently spends so little on innovation and business-improvement programmes. On a revenue-to-revenue basis, the industry spends 80% less on technology and innovation compared with the petroleum sector, for example. Yet our operating costs are increasing three times faster than consumer-inflation rates and are on their way to doubling in less than five years. With industry margins being squeezed on all fronts, we simply have to embrace innovation if we want to find more productive, efficient and sustainable ways of extracting value from the minerals we mine. We can't rely on only small, incremental changes and a business-as-usual philosophy to get us out of this predicament. Major innovation is exactly what our industry needs to solve its critical challenges. In fact, mining needs to leap forward 20 years in the next five…*"

Mark Cutifani, CEO of British multinational mining company Anglo American plc, advises the mining industry to look to other industries, such as petroleum, aviation and manufacturing, for technologies that have been used to address industry needs, including design, mapping, modelling and simulation solutions (Rivard, 2014). Cutifani (2013), also stated that "*the mining industry, is woefully under-spending on innovation and business-improvement programs given the state of extraction challenges. In the context of being the world's most important industrial activity, it would seem to me that we all have a problem… We must step more boldly into a world of aggressive and consultative social, technical and commercial innovation.*"

Rick Howes, CEO of Canada-based Dundee Precious Metals, believes mining's credibility in delivering the business results stakeholders expect is suffering, and that technology may be integral to the industry achieving future success. Howes stated that compared to other industries, mining is decades behind in technology adoption and that operational performance excellence relies on the innovative use of technology (Rivard, 2014).

Michael MacFarlane, former Executive Vice President, Strategy and Business Planning, at AngloGold Ashanti, stated that the focus must be on introducing proven existing technology from other industries combined with the development of new technologies. An impetus should be on improving planning by eliminating much of the guess work in decision making. At the same time, mining companies need to improve the speed and quality of capital allocation by automating the process. The mining industry is starting to look to other industries for new solutions. In particular, there is an interest in the Manufacturing industry's commonplace approach of managing process information in real-time. All of the necessary technologies for the mining industry to adopt the Lean Manufacturing concepts, built on real-time data collection and variances management, already exist (MacFarlane, 2014).

The mining industry will be increasingly focused on integrating all activities across the value stream, including the continued introduction and development of Integrated Remote Operations Centres (IROCs). With real-time data now available, the entire value stream can be fully optimised and managed in a similar fashion to the manufacturing industry (MacFarlane, 2014).

In South Africa the need to innovate, along with prescribed focus areas, is also defined by the Technology Innovation Agency (TIA) of South Africa. Due to the fact that South Africa's economic growth has been and will continue to be closely linked to the fortunes of the mining industry. A strategy was put in place since 2012 to support the development of new technologies and innovation strategies implementation up until 2017. The technology development was urged to be focussed on areas critical to the entire mining value chain, namely exploration, mining, mineral processing, beneficiation, associated health and safety issues and environmental issues. The main thrust of the TIA's strategy is to enhance innovation with the ultimate goal of economic growth through the development of new products, services and companies (TIA, 2012).

Looking forward, mining companies will have critical choices to make about every aspect of business. Companies can either innovate or stagnate. The most fundamental change will be in turning the supply chain on its head, where the goal won't be to push product out of the ground to dump on the market, but to respond nimbly to sophisticated customer relationships and market dynamics. Mining companies will have to lose the rigid and ironclad business models and practices of old and become fluid, flexible and agile enterprises poised to exploit arising opportunities. This, is what IBM believes sets the vision and imperative for envisioning the future of mining (IBM, 2009). The strategic focus areas for the future of mining, as highlighted by IBM (2009) are shown in Figure 1.3.1. These focus areas may all be addressed and/or improved through innovation. These further include innovation in both physical and information technology development and adoption.

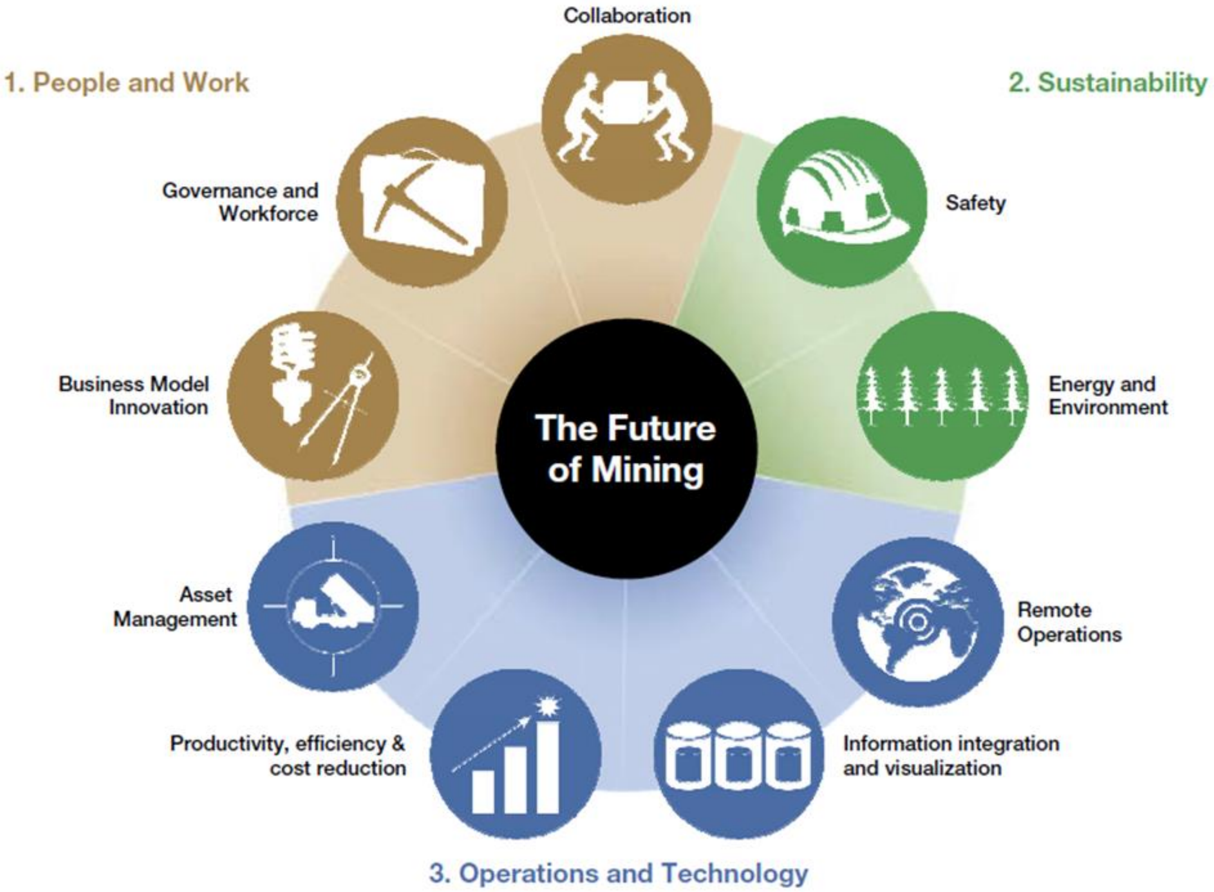


Figure 1.3.1: Strategic Areas of Focus for the Future of Mining (IBM, 2009)

The rapid advances in Information Technology (IT) areas such as big data, cheap massive computer processing, sensors, advanced robotics, nanotechnology and more, have particularly aided in driving down unit cost of production in various areas and raised productivity in almost every industry. This provides the mining industry with the same opportunities when applying these technologies in more advanced manners. IT, and other data and information based innovations, can help transform not only the current approaches but also develop a whole new operating platform and enable a new business model. Taking advantage of new approaches embodied in open innovation and the principles of the lean start-up (as applied by other companies, such as General Electric), combined with a new investment surge could rapidly accelerate this necessary transformation (Bryant, 2015).

Organisations should also think of innovation as much more than research and development (R&D). While exploratory R&D has the power to streamline processes in the future, innovation further revolves around an organisation's current capacity to adapt practical applications that already exist. This includes technologies from other industries, sectors, and organisations that can be modified and applied to fit the needs of mining companies today (Deloitte & Touche, 2014).

At the same time, innovation mandates that companies think in entirely new ways. For instance, traditionally mining operations have focussed on extracting higher grades and reaching faster throughput by optimising production schedules, pit layouts, logistics and fleet matching etc. However, a truly innovative mind-set would be where the industry adopts an entirely new design paradigm that leverages new information, mining and energy technologies in order to maximise value (Deloitte & Touche, 2014).

To date, innovation in the mining industry has been hampered by a historical collective focus on cost reductions as the primary mechanism for business improvement. Also, industry consolidation and cooperative purchasing agreements have enabled the commoditisation of key products and supplies, further hindering innovation efforts. After such a lengthy period of relative stagnation in technological advancement, the mining industry is ready for technological transformation and renewed advancement. Paths of high opportunity include, a shift towards a strategic focus on R&D, collaborative efforts with suppliers, and, as already noted by many prominent figures, technology adoption from outside the mining industry (Bryant, 2015).

1.3.2. Refined Focus of the Study: Categories of Technologies

Over the past few years with the drop in commodity prices (as shown in Figure 1.1a), mining companies have been striving towards finding new productivity initiatives. Productivity is about maximising throughput per unit of time, per unit of quality and per unit of cost. Mining companies then often seek to apply a better use of technology to achieve these goals. Some strategies, involving technology applications, include to (Deloitte Global Services Limited, 2014):

- Seek out innovative technologies that are capable of unlocking deposits and improving productivity on the mine site;
- Use system transformation to address core business drivers (such as operating time and rate);
- Replace disjointed reporting systems with streamlined management dashboards that report on actual operational performance;
- Use production visibility tools to get an automated, real-time visual of mining operations from pit to port.

Another method for improving productivity involves leveraging best practices from other industries. Sam Walsh, the CEO of Rio Tinto, has been drawing parallels between mining and manufacturing since he joined the company from the automotive industry. Years ago, he began advocating the adoption of lean practices into the mining sector, which involves a process aimed at reducing waste and optimising outputs, and Rio Tinto has since capitalised from this approach. The approach was originally pioneered by Toyota Motors and it has helped countless manufacturers boost productivity and reduce costs by eliminating all unnecessary processes from their operations (Deloitte Touche Tohmatsu Limited, 2016).

The automotive industry is a highly-unionised environment, where safety is of paramount concern. Labour and overhead costs account for roughly 80% of operating budgets, compared to 40% to 50% of mining costs that relate to labour (Deloitte Touche Tohmatsu Limited, 2016). The similarities between the automotive and mining industries pose the question as to whether mining can't learn more from the automotive environment. The same can then be said for many other industries and the way they innovate and apply technologies to their processes.

For decades, mining companies have understood the imperative to adopt technologies to accelerate automation and reduce fatalities. Investment in innovation for better technology application, has ranged from automation and enhanced drilling systems to data analytics and mobile technologies. Mining companies that have been embracing innovation are improving mining intensity whilst reducing people capacity, capital requirements and energy intensity (Deloitte Touche Tohmatsu Limited, 2016). This is why leading companies continue to look at new technologies, such as nanomaterials, robotics, 3D printing, modular design, bioengineering and alternative haulage, in an effort to further improve operational performance (Deloitte & Touche, 2014). It is also worth mentioning that Caterpillar and Komatsu have also been working on automation and electric drive vehicles and AngloGold Ashanti has had some successes, notably the use of reef boring technology to dramatically extend the life of many mines (Bryant, 2015).

Similarly, in terms of mineral exploration, technologies such as hyper-spectral imaging and interferometric synthetic aperture radar need to be investigated. These technologies are already in use to monitor ground subsidence, landslides, volcanoes and active faults (TIA, 2012). Mining companies can also leverage techniques like simulation, technical modelling and seismic technologies borrowed from the oil and gas industry, instead of engaging in traditional drilling. This can allow companies to identify mineral-rich deposits more cost effectively, while simultaneously helping the industry to maintain a sustainable discovery pipeline (Deloitte Touche Tohmatsu Limited, 2015).

In the information age value is however measured on more than these physical technologies. In order to improve long-term planning and forecasting, companies must also explore emerging Information Technologies. Examples include cloud computing, sensors, GPS systems, embedded logic, cyber security, big data, 3D visualisation and simulation modelling (Deloitte & Touche, 2014).

A drive in Dundee Precious Metals termed “Taking the Lid Off” involves trying to get real-time production management in an underground mine using the latest technologies available. Some of these technologies include low-cost-off-the-shelf Wi-Fi networks and inexpensive wireless RFID (Radio-Frequency Identification) tagging for vehicle and personnel location tracking. Other non-physical technologies include software systems for mapping, modelling, estimation, design, scheduling, simulation and mine production management reporting. Exploiting these technologies has the potential to fundamentally change the way mining operations are managed (Rivard, 2014). For example in the “Taking the Lid Off” initiative at the Chelopech mine Bulgaria, real-time monitoring technologies were applied on production processes to enable faster decision making in light of changing conditions (MacFarlane, 2014).

To combat the rising energy costs, reduce unwanted emissions and accelerate electrification, companies further also need to investigate energy technologies. Some of these include advanced materials, smart grids, energy storage technologies, renewable energy conversion, superconductivity, non-detonating solutions and high-energy lasers (Deloitte & Touche, 2014). In the energy space alone some operations have achieved 10% to 40% energy savings. This resulted from the investment in renewable energy installations, deploying innovative energy technologies and driving towards more automated mine processes to optimise energy consumption (Deloitte Touche Tohmatsu Limited, 2016).

When refining the focus of innovation to technological innovation, the various technologies and also mining challenges mentioned can be summarised into three main categories, namely Mining Technologies, Information Technologies and Energy Technologies. These categories form an interconnected system that further forms the focus areas for the Innovation Imperative in the Mining Industry, as described by Deloitte & Touche (2014) and shown in Figure 1.3.2a.

These three categories of technologies serve as broad focus areas for this research study, as various technologies will be investigated that could add value to each and/or all three categories. The technologies mentioned above contain good examples of existing technologies from other non-mining industries, that may potentially also add value to mining. Some of these may already be applied to some extent in certain mining operations while lagging behind at others.

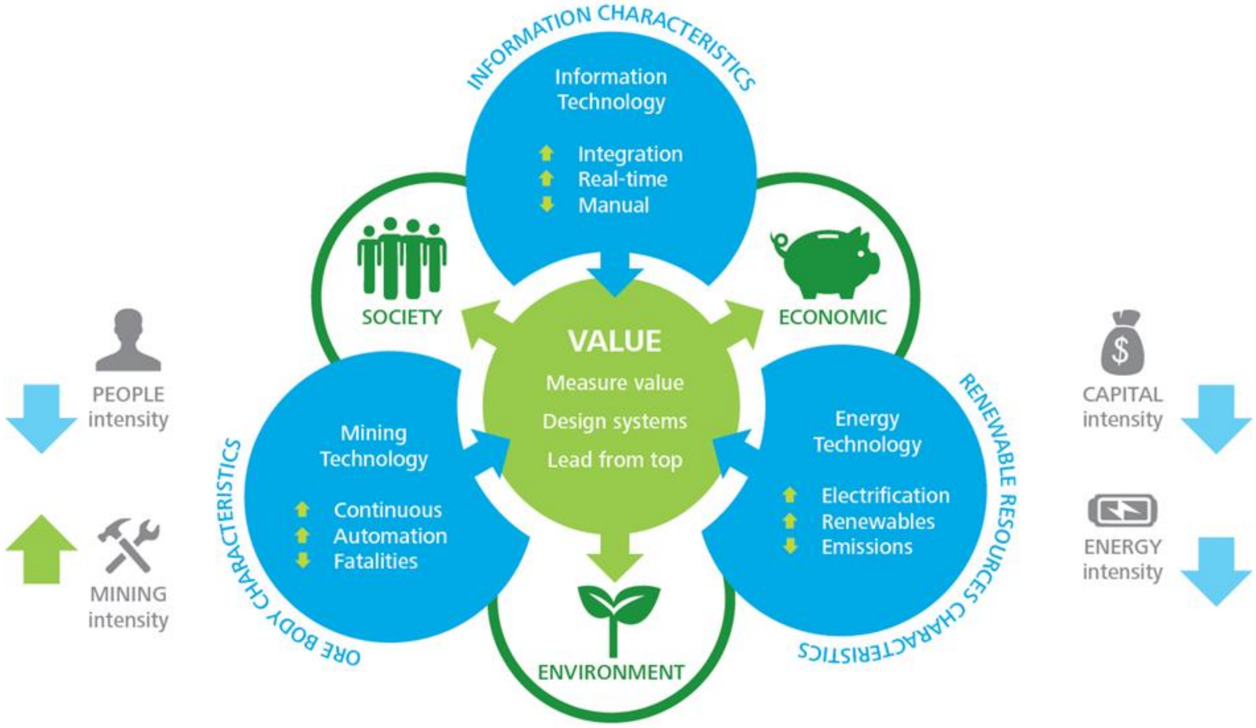


Figure 1.3.2a: Categories of the Innovation Approach to Mining (Deloite & Touche, 2014)

According to Deloite & Touche (2014), when a system has interconnect components and processes it is often easier, less risky and more profitable to solve many problems at the same time. From Figure 1.3.2a, the arrows pointing up indicate an increase and the arrows pointing down indicate a reduction in the associated factor. The description of this system is given as follows, verbatim, (Deloitte & Touche, 2014):

"*By integrating mining, energy and information technology into mine and process design in an innovative way it is possible to achieve radical performance improvement breakthroughs. This approach is applicable to new and operating mines. First create a lean mine and then enable high performance with Information Technology. Integrated system design typically leads to new performance levels that are not possible on an incremental basis. By focusing on maximising value for the environment and society as part of the mine and process design, new levels of improvements in value to shareholders are created in a substantial and sustainable way*."

When put together, these technologies can help companies reduce capital, labour and energy intensity, while increasing mining intensity. By combining these three technology groups into mine and process design in an innovative way, companies can achieve major performance breakthroughs. They can improve safety standards, reduce operating costs, optimise their energy mix and enhance operational performance (Deloitte & Touche. 2014).

This highlights the importance of understanding what technologies already exist, as well as what is in development. As previously discussed, apart from existing technologies in non-mining industries, emerging technologies (across any industry) should also be critically analysed. This is especially true for exponential and potentially disruptive technologies. These technologies have the potential to disrupt industries, businesses, organisations, governments and economies globally, and it is therefore vital to gauge the potential impact that they could also have on mining. In order for companies and organisations to critically evaluate the current applicability of their technology strategy, they need to constantly analyse the potential of a technology (that may hold value) as it advances. This is a continuous process in order to analyse potential applications and impacts that may result from or be created by applying technology. In order to aid companies in achieving breakthroughs from technology, it is necessary to highlight applicable technologies within the abovementioned technology groups.

Emphasis should particularly be placed on the truly disruptive technologies that would potentially have the biggest global impact. The reason for this is firstly due to the fact that these technologies would impact many different sectors, economies and businesses, all of which impacts the mining industry directly or indirectly. The second reason is that these technologies and the change they would bring is so great that it is easier to gauge potential impacts or benefits over the next few years (even decades), as compared to that of smaller technological innovations. The last reason is that disruptive technologies impact the world and the lives and work of large quantities of people, leading to greater ranges of potential impacts that business leaders should account for. Figure 1.3.2b shows a summary from McKinsey (2015), of the estimated potential global economic impact (in US$trillion) of twelve potentially disruptive technologies by 2025. This significant impact will spill over to the mining sector from various points of influence. While the economic impact directly related to mining is currently not estimated, the total global impact clearly indicates that these technologies cannot be ignored.

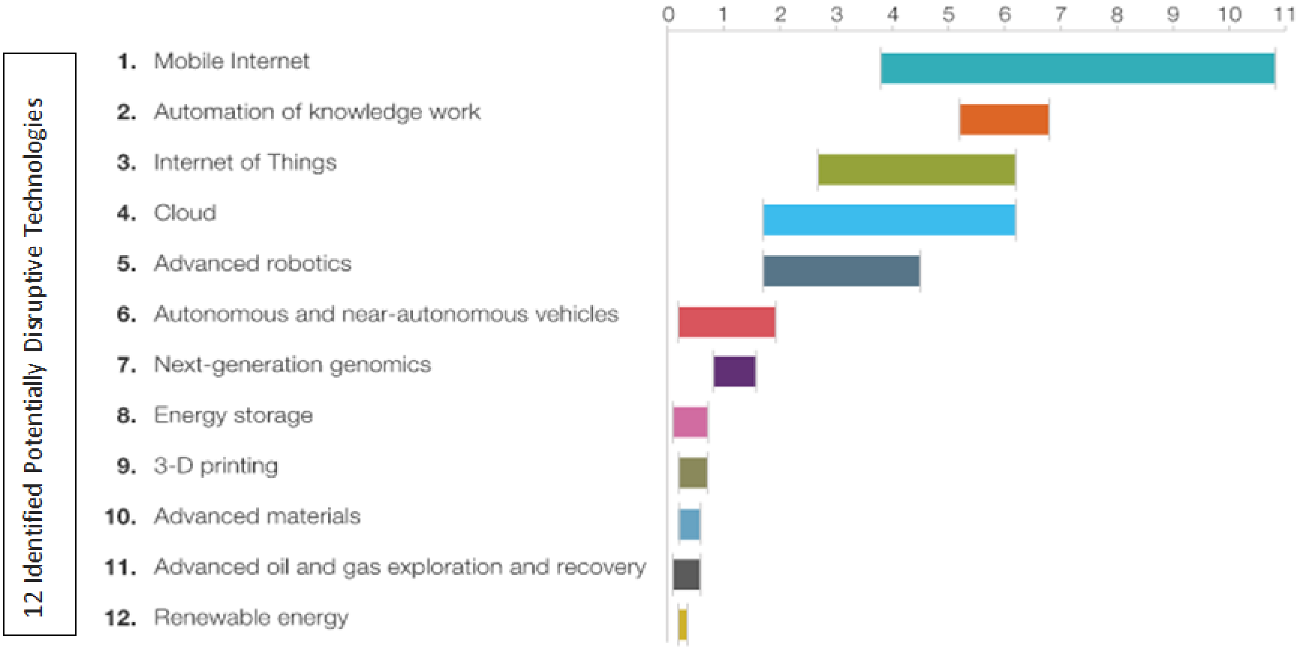


Figure 1.3.2b: Estimated potential economic impact of disruptive technologies across sized applications in 2025 ($ trillion, annual) (McKinsey, 2013)

1.3.3. Emerging Technologies Applicable to the Mining Cycle

It is beneficial to investigate and analyse various technologies that may hold value, pose a threat or have an impact on a mining operation or organisation as a whole. The impact or benefit has to be assessed in order to gain an understanding of how opportunities could be exploited or detrimental impacts negated. In doing so, an organisation will have the opportunity to work towards the modernisation of its mining business, operation(s) and/or entire business value chain.

The way in which these technologies are represented for further assessment is also important. In order to assist a reader with identifying technologies applicable to further investigation, it was recognised that it would be necessary to plot the technologies on a Technology Map. It was also recognised that such a Technology Map would have to be fully representative of the entire mining cycle in order to effectively relate the investigated technologies to the applicable areas of impact.

1.4. Problem Statement

A critical investigation was conducted into new and emerging technologies, both within the mining industry and in non-mining industries. The identified technologies were analysed and those with the potential to either add value or have an impact on mining were plotted onto a technology map. The technology map spanned the entire mining cycle, from exploration to post-closure, as well as the constituent sub-phases, systems, processes, activities and other focus areas that form part of the value drivers within the mining cycle. The ultimate goal of this technology map is to assist with the identification of technologies that may add value and as such contribute towards the modernisation of the mining industry.

1.5. Scope of the Study

During the research phase focus was placed on technologies that were deemed to have the potential to add value to the mining industry. This potential incorporation of various technologies, or the modification thereof to be used in mining, was not only considered for the present but was also judged on potential incorporation in the future.

This study largely approached the mining cycle, mining value chain, and specific problems or focus areas from a South African mining industry perspective. The reason for this was based on the fact that the industry in South Africa faces unique challenges unlike most other countries, especially regarding the labour force, local communities and geology. Therefore, when designing solutions for the South African mining industry, it often encompasses problems of mining operations or companies in other countries and more.

When looking at potentially disruptive and exponential technologies, many of the potential impacts listed were from a holistic point of view and not region or country specific unless otherwise indicated. In addition to this, the technologies that were investigated within this study were not analysed into detail beyond conceptual level applications. Further research and development (R&D), as well as prototype development where applicable, is advised before full-scale implementation is attempted.

It should be noted that the Technology Map was created with a universal mining system in mind and that it is not orebody, commodity type, mining method, region, country or other specific.

Limitations also exist to the extent of technologies that were included in the study. Not all existing technologies were investigated that may potentially be applied to mining, as focus was placed on those technologies that were deemed to offer the most value or largest significant impact. Due to time constraints many technologies had to be ignored and a full-depth analysis did not take part on many that were indeed investigated.

Software solutions and other software packages were not considered in this study. The focus included a broad overview which could incorporate various software systems (existing and otherwise) into some of the mentioned technological application possibilities. In autonomous systems, for example, different software packages could be used to add value to a more all-encompassing autonomous system that extends over an entire operation. During the mine planning, mine design and feasibility study phases, technologies such as augmented reality and virtual reality were mentioned as potential value adding technologies. These applications for example would be in conjunction with various software systems, both existing and as new requirements. Similarly, many of the mentioned technologies (especially under digital technologies) may require full-scale software implementations to complement their application. This requirement was not analysed in depth.

Along with the flagged technologies, an analysis of the potential value or impact that they may bring was also conducted. It should however be noted that a scientific innovation process is required to take a conceptual idea of an application of technologies to a value adding end-result. Such a process did not form part of the focus for this research study.

In order to achieve real positive changes, innovation has to go beyond purely focusing on technology. There are a myriad of ways and areas to innovate and no single innovation can solve the current mining dilemma. The entire system needs to be considered, including the socio-economic system (Deloitte & Touche, 2014). For the purpose of this study the entire mining system was not included in the scope through a full innovation system approach, e.g. business model and strategy innovation. The study did, however, aim to include the entire mining system (as far as reasonably possible within the time limits of the study) but with a technology approach. This approach was to provide solutions and value to the various factors within the entire mining system (or mining cycle). Further, the technologies investigated within this study have the potential to fundamentally alter business strategies and operation. In their application, the broader implementation requirements and potential alterations will have to be assessed by each organisation. It is in these alterations and realigning of company approaches, business models and strategies that a truly innovative change can be pursued.

1.6. Objectives and Methodology

Table 1.6: Objectives and Methodology

Objective		Methodology
1.	Identify the need for innovation in mining.	The need for innovation in relation to the current status of the global mining industry was analysed. This was achieved by evaluating both the current condition of the mining industry and researching the justification for innovation as a solution to the problems that are faced.
2.	Define the scope of the study.	The scope was defined by outlining the focus areas for an innovation in mining study. The focus was placed on technology within the broader context of the mining cycle. The technologies investigated were analysed based on their potential to add value within the mining cycle and as such facilitate mine modernisation. Value addition was judged on optimisation potential, as per the criteria described in section 1.2.2. For the representation of the identified technologies, a Technology Map was identified as a good way of tying in the technologies to the relevant applicable areas in mining.
3.	Investigate technologies applicable to the mining ecosystem: Disruptive Technologies.	Technologies that had the potential to disrupt the status quo of various business and other organisational environments were investigated. The potential impact on the mining ecosystem was then analysed in order to create an understanding of what business leaders need to be aware of. Potential applications were also investigated on a conceptual level for some of these technologies with the potential to add value.
4.	Investigate technologies applicable to the mining ecosystem: Emerging Technologies, in other non-mining industries that may add value to mining.	Technologies, recent and in-development, were investigated in other industries that could potentially be applied in mining to add value. These technologies were analysed both in the context of a direct application, or with the potential to be modified to be applied to the mining environment.
5.	Investigate technologies applicable to the mining ecosystem: Recent technology innovations in the mining industry that may add value to other operations.	Recent technological innovations, new inventions and other technology applications or systems were investigated. The aim of this section was to create awareness of existing, recent technologies that may also be applied to other environments and operations.
6.	Create a platform for the Technology Map.	The analysis of the investigated technologies (from Objectives 3 to 5) indicated various areas of potential application, impact and value creation. This included numerous mining systems, sub-systems, activities, challenges or specific focus areas. These relevant focus areas were tabulated with their

Objective		**Methodology**
		corresponding technologies, as per their relevant positions within the mining cycle. In order to represent this table on a Technology Map, it was first necessary to create a platform upon which the technologies may be represented. This platform further had to embody a framework that is representative of the full mining life cycle. To achieve this, a modified Delphi and mini-Delphi technique was used where structured communication sessions were held with face-to-face discussions. These sessions ranged from mini-workshops with small groups (2-3 experts) to one-on-one interviews. The people taking part in these sessions were all mining experts with qualifications in mining engineering or were industry experts with significant amounts of experience within various aspects of the mining industry or with experience specifically relevant to technology strategies or the creation of Technology Maps. (Refer to the *acknowledgement* section for more information on the experts that contributed towards the creation of the Technology Map.) The process started with identifying the needed value drivers to represent the mining cycle, how these value drivers should be grouped, and how they could be displayed to represent a framework that is familiar to various kinds of mining experts. Once the basic framework was completed, each expert (and additional experts) was consulted individually and asked to evaluate the framework based on the following: • Is the framework for the mining cycle representative of the scope of the study? • Is the framework sufficiently representative of the mining value chain, from the interviewee's experience, but on a wider scale representing the broader mining cycle and with a more universal approach to mining (i.e. that represents mining in general, prior to expanding to specific site, commodity, geological, geographical or other factors)? • Are there any value drivers missing from the framework that are crucial and which need to be added in order to represent the entire mining cycle for all its phases? • Are the value drivers grouped correctly based on the interviewee's experience and opinion? • Does the interviewee agree with the groupings (termed value driving pillars as described in Chapter 3) and how they are named?

Objective		**Methodology**
		• Are there any comments regarding the mining cycle framework for improvements? For example, regarding the layout, structure, classification methods and criteria (as described to each interviewee), number of value driving pillars (groups of value drivers). After each individual interview the interviewee's feedback was worked into the framework to improve upon the previous version and refine it closer to an acceptable standard for the pool of mining experts reviewing the framework. The revised version was then provided to the interviewee for final commentary prior to moving on to the next expert. The flow of contact with each expert was structured in such a way that the level of seniority increased with time. As a result, the seniority of the experts increased in parallel with the refinement of the framework. Seniority was assessed from an academic perspective (moving from Masters in Engineering to PhD's in Engineering) and from an industry perspective (increasing amount of industry experience in terms of quality and number of years, as well as diversity of expertise and seniority in company hierarchy). Once the framework for the mining cycle had been finalised to a satisfactory level where the experts had no further recommended improvements, the process stopped and the framework was seen as the final version. This version was then correlated with the identified focus areas for the investigated technologies, i.e. their potential areas of impact, application and value creation. These areas were then incorporated into the mining cycle's value-driver framework as sub-categories under the applicable value drivers. As such, the original framework for the mining cycle was expanded upon to include additional sub-value drivers.
7.	Create a Technology Map with the potential to add value within the mining cycle and as such facilitate mine modernisation.	The expanded mining cycle' value-driver framework was then populated with the investigated technologies from the literature study in order to create the Technology Map. The resulting Technology Map was then representative of the entire mining life cycle, while displaying various technologies with the potential to enhance the modernisation process.

REFERENCES

Britz, J. 2016. Personal correspondence – CEO of Namane Resources.

Bryant, P. 2015. Clareo: The Case for Innovation in the Mining Industry. [ONLINE] Available at: http://www.ceecthefuture.org/wp-content/uploads/2016/01/Clareo_Case-for-Innovation-in-Mining_20150910_lo.pdf. [Accessed 14 January 2016].

Bryant, P. 2011. The Case for Innovation in the Mining Industry. Clareo Partners, Chicago.

COMSA, 2016. *MODERNISATION: TOWARDS THE MINE OF TOMORROW*. Chamber of Mines of South Africa.

Cutifani, M. 2013. A CRITICAL IMPERATIVE – INNOVATION AND A SUSTAINABLE FUTURE WORLD MINING CONGRESS, MONTREAL CANADA.

Deloitte & Touche. 2014. *The future of mining in South Africa – Innovation Imperative*. Deloitte & Touche a member of Deloitte Touche Tohmatsu Limited. Creative Solutions at Deloitte, Johannesburg.

Deloitte Global Services Limited. 2014. Mining spotlight on: Remaking mining – Exploring the Innovation Imperative [ONLINE] Available at: http://www2.deloitte.com/content/dam/Deloitte/global/Documents/Energy-and-Resources/gx-er-remaking-mining.pdf. [Accessed 26 January 2016].

Deloitte Touche Tohmatsu Limited. 2015. Tracking the trends 2015: The top 10 issues mining companies will face this year. [ONLINE] Available at: https://www2.deloitte.com/content/dam/Deloitte/fpc/Documents/secteurs/energie-et-ressources/deloitte_etude-tracking-the-trends-2015-en.pdf. [Accessed 10 February 2016].

Deloitte Global Services Limited. 2014. Deloitte Global Services Limited, London -*Mining spotlight on: Sliding productivity and spiralling costs*. [ONLINE] Available at: http://bionanouni.wdfiles.com/local--files/teaching-im010-horario-2014i/Deloitte_14-Mining-Spotlight-On_Sliding-Productivity-and-Spiraling-Costs.pdf. [Accessed 29 January 2016].

Deloitte Touche Tohmatsu Limited. 2016. Tracking the trends 2016: The top 10 issues mining companies will face in the coming year. Deloitte Touche Tohmatsu Limited. Annual report. United Kingdom.

Du Plessis, M. 2016. Personal correspondence - Researcher and Innovation Strategy Advisor at the University of Pretoria, previously Group Manager Assurance and Innovation, and, Manager Technical Advisory and Innovation at Exxarro.

ESPAS. 2015. European Strategy and Policy Analysis System (ESPAS): Global Trends to 2030: Can the EU meet the challenges ahead? [ONLINE] Available at: http://europa.eu/espas/pdf/espas-report-2015.pdf. [Accessed 03 April 2016].

Garcia, M.L. and Bray, O.H. 1997. *Fundamentals of Technology Roadmapping*. Strategic Business Development Department Sandia National Laboratories. [ONLINE] Available at: http://prod.sandia.gov/techlib/access-control.cgi/1997/970665.pdf. [Accessed 19 August 2016].

Griffith, C. 2015. Modernisation – a vital step in building a sustainable mining industry in South Africa. Mining Indaba 2015 Speech.

IBM. 2009. *Envisioning the Future of Mining*. [ONLINE] Available at: https://www.ibm.com/smarterplanet/global/files/ca__en_us__oil__smarter_natural_resources_future_of_mining.pdf. [Accessed 17 February 2016].

Indexmundi. 2016. *Commodity Metals Price Index Monthly Price - Index Number.* [ONLINE] Available at: http://www.indexmundi.com/commodities/?commodity=metals-price-index&months=60. [Accessed 18 July 2016].

Investopedia. 2016. *Value Chain*. [ONLINE] Available at: http://www.investopedia.com/terms/v/valuechain.asp. [Accessed 20 August 2016].

Laube, T. and Abele, T. 2005. *Technologie-Roadmap: Strategisches und taktisches Technologiemanagement. Ein Leitfaden*. Fraunhofer-Institut Produktionstechnik und Automatisierung (IPA), Stuttgart, Germany.

MacFarlane, M. 2014. Dassault Systemes GEOVIA: Natural Resources – Special Report on Mining Innovation. [ONLINE] Available at: http://www.geovia.com/sites/default/files/campaigns/GEOVIA_SpecialReportMiningInnovation.pdf. [Accessed 04 March 2016].

McKinsey. 2015. *How digital innovation can improve mining productivity*. [ONLINE] Available at: http://www.mckinsey.com/industries/metals-and-mining/our-insights/how-digital-innovation-can-improve-mining-productivity. [Accessed 11 March 2016].

Mining Indaba & Monitor Deloitte. 2016. *Innovation State of Play | Mining | Deloitte Southern Africa*. [ONLINE] Available at: http://www2.deloitte.com/za/en/pages/energy-and-resources/articles/innovation_in_mining.html. [Accessed 04 May 2016].

PDAC & Deloitte. 2015. *Innovation state of play: Mining edition 2015*. [ONLINE] Available at: https://www2.deloitte.com/content/dam/Deloitte/ca/Documents/energy-resources/Innovation_State_of_Play.PDF. [Accessed 04 February 2016].

Phaal, R., Farrukh, C. and Probert, D. 2001. *Technology Roadmapping: linking technology resources to business objectives*. Centre for Technology Management, University of Cambridge. [ONLINE] Available at: http://www.ifm.eng.cam.ac.uk/resources/techmanworkbooks/roadmapping-for-strategy-and-innovation/. [Accessed 04 February 2016].

Rivard, L. 2014. Dassault Systemes GEOVIA: Special Report on Mining Innovation: Mine owners focus on technology to control costs. [ONLINE] Available at: http://www.geovia.com/sites/default/files/campaigns/GEOVIA_SpecialReportMiningInnovation.pdf. [Accessed 04 March 2016].

TIA. 2012. *The Mining Sector Innovation Strategies Implementation Plan*. [ONLINE] Available at: http://www.tia.org.za/CMS/uploaded_docs/TIA%20Mining%20and%20Minerals%20Innovation%20Strategies%20Implementation%20Plan%20(2012%20-%202016).pdf. [Accessed 04 February 2016].

US Geological Survey. 2008. Circum-Arctic Resource Appraisal: Estimates of undiscovered oil and gas north of the Arctic Circle.

CHAPTER 2

LITERATURE SURVEY

LITERATURE SURVEY

For the literature study a wide variety of technologies were investigated. These included existing technologies and technologies in development. Exponential and disruptive technologies were investigated in particular, with the aim of identifying technologies that would impact the world and result in an impact, whether directly or indirectly, on the mining industry in the near future. Furthermore, recent and emerging technologies from other non-mining industries were also investigated, with the aim of identifying technologies that could potentially add value to the mining industry.

A general note of caution should, of course, be attached to all work on future trends as mentioned by the European Strategy and Policy Analysis System (ESPAS). Predictions rarely prove wholly accurate, since no trend is immutable, and unforeseeable events can, and often do, intrude dramatically to alter the course of history. Yet foresight exercises remain valuable. They allow us to view the present from a wider perspective and to understand it better. They make it easier to take early corrective action against potentially negative developments and to mould the policy environment in a more positive way. By providing predictions of what could happen, they force issues into the open and invite policy-makers to address them and to find solutions that are in the long-term interests of society as well as that of businesses (ESPAS, 2015).

With that in mind innovative technologies were investigated and it was found that a parade of new technologies and scientific breakthroughs is unfolding on many fronts. Some of these have the potential to disrupt the status quo, alter the way people live and work, rearrange value pools, and lead to entirely new products and services. Business leaders can’t wait until evolving technologies are having these effects to determine which developments need to be paid attention to. They need to understand how the competitive advantages on which they have based strategy might erode or be enhanced a decade from now by emerging technologies. Leaders need to investigate how technologies might bring them new customers (or new opportunities and solutions in the mining context) or force them to defend their existing bases or inspire them to invent new strategies (McKinsey Global Institute, 2013).

Many forces can bring about large-scale changes in economies and societies, e.g. demographic shifts, labour force expansion, urbanisation, or new patterns in capital formation. But since the Industrial Revolution of the late 18th and early 19th centuries, technology has had a unique role in powering growth and transforming economies. Technology represents new ways of doing things, and, once mastered, creates lasting change, which businesses and cultures do not “unlearn”. Adopted technologies become embodied in capital, whether physical or human, and it allows economies to create more value with less input. At the same time, technology often disrupts, supplanting older ways of doing things and rendering old skills and organisational approaches irrelevant. These economically disruptive technologies form a large portion of the focus of this study (McKinsey Global Institute, 2013).

The investigated technologies were classified as *Physical Technologies* – which included technologies that could add value under the technology categories, namely Mining Technologies and Energy Technologies – mentioned in Section 1.3.2; and *Digital Technologies*, which fell under the technology category termed Information Technologies, but further also included other data-based and communications technologies.

2.1. Overview: Potentially Value Adding Technologies to Consider

For the sake of focussing this research study to provide valuable insights while being completed within a specific timeframe, it was decided to carefully select the technologies that were included in the literature review. Before these technologies will now be discussed, an overview will be provided of various technologies – as well as identified focus areas for technology R&D – that have great potential to add value within the mining cycle. Many of these were investigated, while others were not included (either at all or in a full-depth analysis) in the literature review. However, all of these technologies have been identified as having sufficient potential to add value within the mining cycle and they will be referred back to in the Recommendation for Further Studies section.

To give an example of how the technologies were investigated and filtered, consider the following scenario: In 2012 the Technology Innovation Agency (TIA) of South Africa identified a need in mining for Real-Time Information Systems. The TIA (2012) stated that "*techniques for sensing, analysis, and communication and information management have become increasingly important. Each mining environment presents unique challenges to the design and operation of equipment and machinery. Increasing the productive operating time of equipment and mining systems will require modern monitoring technologies.*" To address this need there are numerous individual technologies that may be applied. These were not investigated individually. However, with the emergence of technologies such as the Internet of Things (IoT), Advanced Analytics and Machine Learning, new possibilities open up for the application of sensors and monitoring technologies. These emerging technologies were investigated and the value they could bring – through the use of monitoring/sensing technologies and of the information extracted from them – were assessed.

The TIA further also recommended four key R&D focus areas for the South African mining industry. The four focus areas were addressed throughout the literature study by investigating various technologies, both physical and digital, that could add value to these areas. These included (TIA, 2012):

1. Rock fragmentation, with the goal of achieving continuous mining and conserving overall energy consumption;
2. Sensors and sensor systems for mechanical, chemical, and hydrological applications;
3. Data processing and visualisation methods that produce real-time feedback; and
4. Automation and control systems.

To ensure a holistic approach, the developments and suggested focus areas of the global mining industry should also be considered. For example in Canada, the Ministry of Labour (2015), has also highlighted various technologies currently being developed that are intended to make the mining environment safer. Some of these hold great potential to add value to other mining operation and should not be ignored. A few examples include:

- Tier 4 engines that reduce emissions;
- Ventilation on demand systems that will improve air quality;
- Fire suppression systems to reduce risks associated with fires in ultra-deep mining environments or fires that occur as a result of new technology;
- Mobile equipment position and location monitoring devices to facilitate traffic control and prevent vehicular collisions;
- Proximity detection devices and cameras on equipment to reduce risks associated with mobile and other equipment.

In order to ensure that all technologies are considered with the potential to facilitate mine modernisation, it is important to also investigate technologies that are not mining specific. In this context the top 50 emerging technologies, as identified by Frost & Sullivan, were assessed as well. These technologies were identified as multi-billion dollar technologies that would propel industries and transform the world on various fronts. As such, it is vital for business leaders to assess them in detail while they are still being developed. The top 50 emerging technologies, falling under nine technology clusters, from Frost & Sullivan (2016) include:

- Health and Wellness:
  - Therapeutic Antibodies;
  - Next Gen Stem Cell;
  - Cancer Screening;
  - Biosimilars;
  - 3D Scaffolds;
  - Molecular Scissors.
- Information & Communication Technologies:
  - XaaS;
  - Cybersecurity;
  - Artificial Intelligence;
  - Mixed Reality;
  - Predictive Analytics;
  - 5G (Mobile Internet);
  - Cognitive Computing;
  - Software-defined anything.
- Medical Devices and Imaging:
  - Neuroprosthetics;
  - Optical Coherence Tomography;
  - X-eluting Stents;
  - Nuclear Imaging;
  - Smart Pill.
- Chemicals and Advanced Materials:
  - Lightweight Materials;
  - Bio-based Materials;
  - Nanocoatings;
  - Graphene;
  - Self-healing Materials;
  - Smart Packaging.
- Microelectronics:
  - Wearables;
  - OLED (Organic Light-Emitting Diode) Lighting;
  - SiC (Silicon Carbide) Electronics;
  - Transparent Electronics;
  - Rapid Charging.
- Sensors and Instrumentation:
  - Commercial Drones;
  - Biosensors;
  - Terahertz Sensing;
  - Next Gen RTLS (Real-Time Locating Systems);
  - Smart Haptics.

- Advanced Manufacturing and Automation:
    - Additive Manufacturing;
    - Digital Manufacturing;
    - Collaborative Industrial Robots;
    - Agile Robots;
    - Robotic Exoskeletons.
- Environment and Sustainability:
    - Waste-to-Energy;
    - Precision Agriculture;
    - Micro Irrigation;
    - Off-grid Desalination;
    - Wastewater Membrane Filtration.
- Energy and Utilities:
    - Lithium Batteries;
    - Home Energy Management;
    - Tight Oil Extraction;
    - Waste Heat Recovery;
    - Microgrid.

Most of the top 50 emerging technologies from Frost & Sullivan were investigated, placing focus on the potential to add value to the mining cycle. Those that were identified to fit the criteria add value to mining and as such facilitate mine modernisation, as described in Section 1.2, were included in the literature study. Similarly, in 2013 McKinsey had identified twelve potentially disruptive technologies that would drive the biggest global economic impact within the next decade. These will be discussed in detail in Section 2.3 as all twelve technologies were found to have potential to add value to mining.

However, many technologies included in the literature study do not have a direct impact on mining, although their application may still have an indirect impact on the mining value chain or any phase within the mining cycle. An example of this is Precision Agriculture from the list by Frost & Sullivan. This is a site-specific farm management system that utilises technologies and agronomic principles to optimise farm yields sustainably, while also preserving environmental quality. This is achieved by collecting data on the spatial and temporal variability on the various agricultural components (such as soil, climate, seed, fertilisers, water, pests, animals and diseases), thus enabling micromanagement of the relevant factors (Frost & Sullivan, 2016).

Precision agriculture can increase food security, aid in afforestation or reforestation, monitor crop and livestock growth and health, and assist with variable-rate irrigation and seeding. The result is that this technology may hold a $20billion cumulative market potential as it addresses the growing threat of food security due to decreasing natural resources and increasing population (Frost & Sullivan, 2016). Food scarcity, especially in third world countries, will also become an obstacle for mining companies that seek to exploit their mineral resources. It then becomes clear that the technologies addressing this may affect the mining cycle in some way. As such, R&D into agriculture will become more important for the sustainability of mining and therefore Precision Agriculture deserves more attention from business leaders. Investing in and applying this kind of technology may not only serve as a means to gain 'goodwill' and the stamp of approval from communities, but also assist in sustaining the labour force that is critical to the extraction process. With that said, Precision Agriculture, like many other technologies identified to have potential to add value within the mining cycle, was not investigated in detail beyond this point.

It should also be noted that the naming or description of technologies sometimes vary between different organisations. This is especially true for emerging technologies that have not found a common description or nomenclature across all organisations and industries. An example of this is Mixed Reality (MR) from the list by Frost & Sullivan. MR is a term referred to currently that in theory should supersede Augmented Reality (AR). The argument behind this is that AR has become known as virtual elements being blended into a live camera view instead of with reality. By definition, however, AR is a blend of virtual elements with the perceived real world (i.e. reality). This means that the actual definitions of these technologies are still being influenced by the perceptions of those that use and analyse them. For this study, the term Augmented Reality was used and in the broader context the descriptions for its application then also contain elements of the rising term Mixed Reality.

Other technologies that have already been identified to have potential application and benefit for mining include nanomaterials, robotics, 3D printing, modular design, bioengineering and alternative haulage (Deloitte & Touche, 2014). Similarly, for the mineral exploration phase technologies such as hyper-spectral imaging and interferometric synthetic aperture radar have been identified as having potential to add value. These technologies are already in use to monitor ground subsidence, landslides, volcanoes and active faults. Mining companies can also leverage techniques like simulation, technical modelling and seismic technologies borrowed from the oil and gas industry, instead of engaging in traditional drilling (TIA, 2012). Leading companies already use techniques like remote sensing to localise ore deposits, which can alter the industry’s ability to find deeper, more fragmented deposits (Deloitte, 2015).

In order to improve long-term planning and forecasting, companies must also explore emerging Information Technologies. Examples include cloud computing, sensors, GPS systems, embedded logic, cyber security, big data, 3D visualisation and simulation modelling (Deloitte & Touche, 2014). Some of these technologies include low-cost-off-the-shelf Wi-Fi networks, inexpensive wireless RFID tagging for vehicle and personnel location tracking, and software systems for mapping, modelling, estimation, design, scheduling, simulation and mine production management reporting tools. Exploiting these technologies has the potential to fundamentally change the way mining operations are managed (Rivard, 2014).

To combat the rising energy costs, reduce unwanted emissions and accelerate electrification, companies further also need to investigate energy technologies. Some of these include advanced materials, smart grids, energy storage technologies, renewable energy conversion, superconductivity, non-detonating solutions and high-energy lasers (Deloitte & Touche, 2014).

In order to fully understand the potential impact and value of technological advancement and why it is crucial to constantly reassess an organisation’s technology strategy, it is important to understand the predictions regarding the Technological Revolution. For this reason the Technological Revolution will first be discussed before the analysis of specific technologies will follow.

2.2. The Technological Revolution

The European Strategy and Policy Analysis System (ESPAS, 2015) conducted a study on global trends up until around 2030. What was highlighted was an economic and technological revolution that would change the way the world functions and the dependence of societies on technology. This stems from the convergence of technologies (biological, digital and industrial) and the proliferation of (digital) tools available to large multitudes which will transform economies and societies and the way they are functioning. Huge opportunities will result in terms of productivity, welfare gains and individual empowerment. The new "Knowledge Society" presents massive opportunities, in terms of productivity and average welfare gains as well as the empowerment of the individual. However, societal disruptions may include a further rise of unemployment, increasing inequalities and the impoverishment of the middle classes in developed countries (ESPAS, 2015).

"*A revolution in technologies and their applications transforms societies in almost every aspect. Digitisation is the invader and radical, disruptive change the consequence*." (ESPAS, 2015).

The report identified five main and interlinked policy 'challenges' for the European Union, to be addressed in the following years. It did not set out prescriptive policy initiatives, but it rather sought to frame a number of possible strategic challenges that decision-makers may face. These challenges to be dealt with call for a reshaping of the economy, promoting a society of change and innovation, combating the rise of inequality and growing exclusion, enabling individual empowerment and democracy and enhancing the international role of the European Union (ESPAS, 2015). Innovation was further highlighted as an imperative means in adapting to the upcoming changes and challenges for companies, businesses, societies, organisations and even governments.

While the report was focussed on Europe, it was identified that Europe (similarly the rest of the world) needs a new platform for sustainable, durable economic growth. The goal of a European renaissance was highlighted which can mostly be delivered by innovation, not merely digital, not only technological, but also societal and in the design and practice of governance (ESPAS, 2015).

While it is difficult (or closer to impossible) to predict the future, the increased uncertainty regarding the economic and technological revolution can also stimulate innovation and creativity, and open the way to different futures. Complexity can widen the spectrum of possible action and increase the density of social and economic life. New methods and new tools, in particular big data and artificial intelligence, will provide new ways of managing both uncertainty and complexity (ESPAS, 2015)

Projections for the world in 2030 (ESPAS, 2015):

- A technological revolution based on new industrial production, bio-scientific, communication and digital processes will transform societies;
- The speed of technological change is accelerating;
- Autonomous decision-making processes will rapidly rise;
- Europe and the United States will remain world leaders in science and knowledge-creation, though worries persist about applied research.

Technological innovation will act as a force and driver of change. Europe's future economic growth, employment and social cohesion will depend on its ability to understand, embrace and exploit all aspects of an innovation society. Its impact, driven by ever-accelerating innovations, is ever stronger and puts public policy under serious stress because effective action is needed across a very broad front. The areas in which the next major innovations will occur are mostly known, though surprises may, as ever, occur: big data, nano-technologies and bio-sciences, including synthetic biology, advanced robotics and automation, and super-computers. Core digital technologies are evolving and converging rapidly, fuelled by real-time and real-world data (ESPAS, 2015).

A dynamic future for Europe (and the same can be said of the rest of the world) will depend on the quality of its science and its technological innovation (STAC, 2014). Together with the United States and Japan, the European Union is currently a lead player in innovation and research, accounting for 24 % of world research and development expenditure and 32 % of patents in 2009 (ESPAS, 2015).

Technological innovation will continue to depend on investment in research and development (R&D). This should remain stable in the advanced economies and increase in China. Current trends indicate a European R&D investment rate of 2.2 % of GDP, a US rate of 3 % and a Chinese rate of 3 %. The result is that Chinese investment should overtake the European Union in total expenditure in 2022 and be twice as large by 2030 (ESPAS, 2015).

However, more than quantity, it is the quality of innovation and patents that will make the difference. In that respect, the efforts made by the European Union, Japan and the United States have so far enabled them to retain a comfortable lead (ESPAS, 2015).

Significance of the study

When looking at innovation, it is best to look at world leaders and learn from them. The tremendous drive for innovation in the most advanced and powerful countries in the world should serve to highlight the importance of innovation in maintaining a competitive advantage.

2.2.1. The digitisation of world markets

Core digital technologies are evolving and converging rapidly, fuelled by broad territorial connectivity and real-time, real-world data. We may be on the cusp of a real third industrial revolution. In the early 2010s, the Boston Consulting Group considered that 4 % of United States GDP could be related to the Internet and the economies or the new business opportunities it had generated (ESPAS, 2015).

This clearly indicates that the mastery, application and development of digital technologies will be key ingredients of economic and industrial competitiveness. Those companies ill-equipped with state-of-the-art digital technologies or with outdated capacities may just be cut off from global markets, with dramatic consequences for the less connected and agile (ESPAS, 2015).

In the near future, companies will face the additional challenge of big data management. If they do not master it, their competitive position will seriously weaken if it becomes the starting point of a genuine industrial revolution based on converging technologies (ESPAS, 2015).

2.2.2. A Potential Third Industrial Revolution (technological revolution)

The first industrial revolution (from 1760 to 1840) was launched by the development of the steam engine, the mechanisation of textile manufacture and the use of coke instead of charcoal, followed by the mass production of steel and lastly the development of the railways. The second industrial revolution (from 1870 to 1914) was triggered by the mass production of steel, electrification, telecommunications, and lastly the development of the motor car and the production line (ESPAS, 2015).

To date, notwithstanding their undeniable social impact, the development of information and communication technologies has not yet given rise to an industrial revolution on the scale of the 18th and 19th centuries. The convergence of several future technological leaps forward may mark the launch of a true ‘industrial revolution’. Existing value chains and their geographical breakdown could be transformed by requiring the reinvention of many current industrial business models. The economic order that could emerge would be based on a new structure of competition, change of performance across industries, a new energy system, new forms of capital accumulation, new forms of intermediation and a comprehensive reorganisation of trade (ESPAS, 2015).

Business environments should be significantly affected by new pressures on prices and margins, unexpected forms of competition, winner-takes-all dynamics, plug-and-play business models, growing talent mismatches and converging global supply and demand (McKinsey and Company, 2014). To manage these changes, policies will have to be adapted to facilitate businesses tackling a more complex and dynamic environment, and to mitigate the possibly brutal implications on the employment of the unskilled (ESPAS, 2015).

Significance of the study

The importance for companies to evaluate emerging technologies and to plan for innovation in order to mitigate disruption and avoid extinction, is clearly highlighted. This extends further to societies and communities as well. In the face of a likely technological revolution, all organisations need to pay heed to potential consequences that result from technology.

2.2.3. Coming Technological Breakthroughs

The most prominent technologies that are expected to develop on a massive scale between now and 2030 include (ESPAS, 2015), verbatim:

- *"The 'Internet of things': big data and data-mining, cloud computing and super-calculators, brain-machine interfaces and sensors.*
- *Multiplication of big data will affect and transform the whole of society. Collecting, purchasing and controlling these data will be regarded as an essential resource for the economies and societies of the future. The geopolitical and commercial requirements for competitiveness will be associated with access to resources, control of operating technologies and ethical questions relating to the fundamental rights and freedoms of individuals.*
- *In 2020, more than 50 billion items, ranging from cars to coffee machines, will be connected to the Internet (Deloitte, 2014). The estimated global revenues could be in the order of USD 14 trillion from 2013 to 2022. The mass of data generated could represent an incalculable resource for those who can access and interpret them.*
- *Cloud computing will revolutionise IT platforms while reducing operating costs, with very significant growth potential (with a turnover reaching EUR 174 billion in 2020, against EUR 30 billion in 2011). The economic impact of its use could be around EUR 1.2 to EUR 4.5 trillion in 2025.*
- *Intelligent mobility: in 2030, 75 % of the world's population will have mobile connectivity (European Internet Foundation, 2014) and 60 % should have broadband access (Roland Berger Strategy Consultants, 2011). Energy, transport and information systems will be closely linked by sensors of all kinds.*
- *Modelling and enhanced (virtual) reality will be everyday design tools across a broad spectrum, including infrastructure, cars and aircraft, climate forecasting and peace-keeping operations.*
- *Ubiquitous sensors will govern communications devices (including future smartphones), clothes, houses, vehicles and drones. It will be possible to merge information with satellite data and to use it for predictive modelling of events, like pollution or traffic.*
- *Additive transformation (3D printers) will play a significant part in industrial production systems, with impacts on the costs and localisation of production and the potential for the recycling of raw materials to be systematic (McKinsey Global Institute, 2013).*
- *A combination of robots, nano-technology and artificial intelligence should replace humans engaged in repetitive production or even in household services. By around 2025, autonomous and even self-teaching algorithms will enable vehicles, mini-drones and anthropomorphic robots to operate autonomously.*
- *A combination of nano-, bio- and information-technology will revolutionise healthcare (Copenhagen Business School, 2013). However, delivering high-tech, personalised forms of treatment while ensuring universal access to healthcare may create budgetary strains when shaping future health policy.*

- *Synthetic biology should enable many new applications through the industrial production of biomaterials, by replacing chemicals based on non-renewables with renewables (biofuels, including hydrogen) (ERASynbio, 2014)."*

Significance of the study

The forecasts from ESPAS lend credibility to the technologies that were investigated in this study.

2.2.4. The Emerging Mobile Revolution

Technological convergence will transform the transport sector in the near future (an example of this can be seen from Uber and similar applications). Combined progress in, inter alia, robotics, automatic systems, electric or hydrogen engines, sensors and satellite navigation systems will bring new meaning to how people and goods are transported (European Commission, 2010). When using autonomous vehicles, people will be able to work, access the internet, or interact with devices while 'driving'. Together with the use of mini-drones to transport objects, this evolution will revolutionise travel between and within urban centres. Considerable efficiency gains will be generated through autonomous transportation, with resulting economies of scale that will be significant when taking account for the convergence of holographic virtual reality and 5G, which will revolutionise tele-presence and therefore tele-work (ESPAS, 2015).

The mobility of the future will thus be an example of convergence between (ESPAS, 2015):

- Humans and machines with vocal and digital interfaces;
- Humans and humans (instant virtual communication);
- Machines and machines, in which all mobiles (vehicles, drones, etc.) communicate with each other.

The multiplication of big data will affect and transform the whole of society. Collection of data, ownership of data, access to data and exploitation of data are becoming primary sources of economic and political power. In particular, the collection and analysis of large quantities of personal data, and the use of big data analytics, could invade privacy to an unprecedented degree and generate broader societal effects (ESPAS, 2015).

Significance of the study

The predictions from ESPAS regarding future technological impacts hold true for all industries and businesses. It is vital for business leaders to analyse the coming impact on their operations, business strategy and models and prepare accordingly. Automation extends beyond physical technological implementations; the true benefits (as well as challenges towards successful application) will come from IT-type innovations and the mobility it brings.

2.2.5. Potential Consequences from the Technological Revolution

Technology convergence and the associated consequences

ESPAS (2015), listed a few potential consequences resulting from the technological revolution that companies, societies and governments should bear in mind as it may very well affect the societies, labour forces and other surrounding communities of the future, verbatim:

- ***"Transformation to a "Knowledge Society"****. The digital economy combined with biosciences and new industrial processes and boosted by pro-education public policies may transform societies into knowing societies which are more able to adapt in a dynamic environment.*
- ***Socio-cultural impacts****. At a more fundamental level, digital technologies may affect our relations with other individuals and make it more difficult for some to distinguish between reality and virtual reality. An ever-increasing abundance of information may impact cognitive and 'attentional' capacities, with implications for human interaction.*

- ***Human-technology fusion****. Technology may have a transformative effect on human beings, by boosting not just their physical abilities, but also their intellectual capacity. In addition to organ regeneration, stimulation of cognitive capacities, genetic choices, delayed ageing or even human augmentation may be possible. Over time, this could deeply affect intra-societal relationships, especially between the humans thus transformed and those who are not.”*

Significance of the study

Other countries, and even individual organisations, can learn from the identified global trends and prepare accordingly. It is vital for mining companies to be aware of the predicted coming technology revolution and to strategically plan mitigation measures against the associated effects. It also provides opportunities that companies and individuals can exploit, provided that they are able to adapt to the (inevitable) changes.

2.3. Potentially Disruptive Technologies

While numerous different technologies were studied and used in this research, greater focus was placed on the truly disruptive technologies that would potentially have the biggest global impact. The reason for this was firstly due to the fact that these technologies would impact many different sectors, economies and businesses, all of which creates an impact on the mining industry in one form or another. The second reason was that these technologies and the change they would bring is so massive that it is easier to gauge potential impacts or benefits over the next few years (even decades), compared to smaller technological innovations that purely impact the mining industry. The last reason stemmed from the fact that disruptive technologies impact the world and the lives and work of large quantities of people, leading to greater ranges of potential impacts that business leaders should account for.

The McKinsey Global Institute (2013), conducted a study on technologies that have the greatest potential to drive substantial economic impact and disruption between now and 2025. The study highlighted twelve potentially disruptive technologies that business leaders should not ignore. These technologies can come in any field or emerge from any scientific discipline, but each share four characteristics. Namely, high rate of technology change, broad potential scope of impact, large economic value that could be affected, and substantial potential for disruptive economic impact. These factors (or criteria) are described in greater detail below, verbatim (McKinsey Global Institute, 2013):

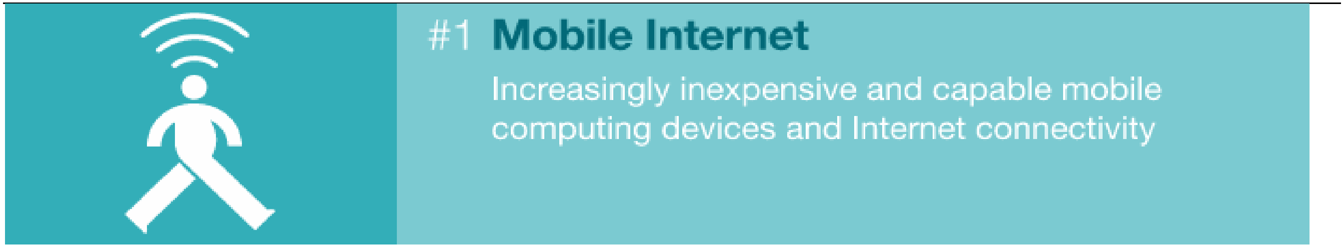
- ***“The technology is rapidly advancing or experiencing breakthroughs****. Disruptive technologies typically demonstrate a rapid rate of change in capabilities in terms of price/performance relative to substitutes and alternative approaches, or they experience breakthroughs that drive accelerated rates of change or discontinuous capability improvements. Gene-sequencing technology, for example, is advancing at a rate even faster than computer processing power and could soon make possible inexpensive desktop sequencing machines. Advanced materials technology is experiencing significant breakthroughs, from the first artificial production of graphene (a nanomaterial with extraordinary properties including strength and conductivity) in 2004, to IBM’s creation of the first graphene-based integrated circuit in 2011.*
- ***The potential scope of impact is broad****. To be economically disruptive, a technology must have broad reach—touching companies and industries and affecting (or giving rise to) a wide range of machines, products, or services. The mobile Internet, for example, could affect how five billion people go about their lives, giving them tools to become potential innovators or entrepreneurs— making the mobile Internet one our most impactful technologies. And the Internet of Things technology could connect and embed intelligence in billions of objects and devices all around the world, affecting the health, safety, and productivity of billions of people.*

- ***Significant economic value could be affected**. An economically disruptive technology must have the potential to create massive economic impact. The value at stake must be large in terms of profit pools that might be disrupted, additions to GDP that might result, and capital investments that might be rendered obsolete. Advanced robotics, for example, has the potential to affect $6.3 trillion in labour costs globally. Cloud technology has the potential to improve productivity across $3 trillion in global enterprise IT spending, as well as enabling the creation of new online products and services for billions of consumers and millions of businesses alike.*
- ***Economic impact is potentially disruptive**. Technologies that matter have the potential to dramatically change the status quo. They can transform how people live and work, create new opportunities or shift surplus for businesses, and drive growth or change comparative advantage for nations. Next-generation genomics has the potential to transform how doctors diagnose and treat cancer and other diseases, potentially extending lives. Energy storage technology could change how, where, and when we use energy. Advanced oil and gas exploration and recovery could fuel economic growth and shift value across energy markets and regions."*

Not all of these technologies will impact mining directly, however it can be reasonably predicted that they will then still play a role in supporting sectors to mining (e.g. manufacturing, health, services, daily lives of employees and other stakeholders etc.) (Heber, 2013).

The identified twelve potentially disruptive technologies up to 2025, along with identified component technologies and key applications, are shown below in Table 2.3.

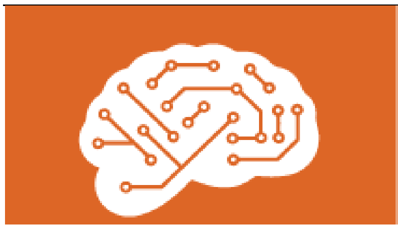
Table 2.3: Twelve Potentially Economically Disruptive Technologies (Adapted from McKinsey Global Institute, 2013 & Heber, 2013)



#1 Mobile Internet

Increasingly inexpensive and capable mobile computing devices and Internet connectivity

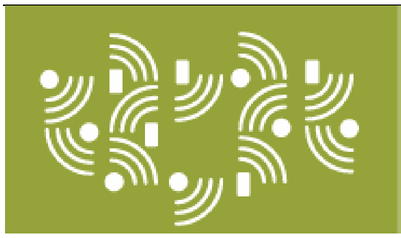
Potential Value	• 10-20 % potential cost reduction in treatment of chronic diseases through remote health monitoring.
Component Technologies	• Wireless technologies. • Small, low-cost computing and storage devices. • Advanced display technologies and natural user interfaces (e.g. for Augmented and Virtual Reality applications). • Advanced, low-cost batteries.
Key Applications	General (McKinsey, 2013): • Service delivery. • Worker productivity. • Additional consumer surplus from use of mobile-Internet services. Mining (Heber, 2013): • With improved and more widespread Internet networks and connectivity, also comes greater facilitation of increased remote mining operations and connectivity between people.



#2 Automation of knowledge work

Intelligent software systems that can perform knowledge-work tasks

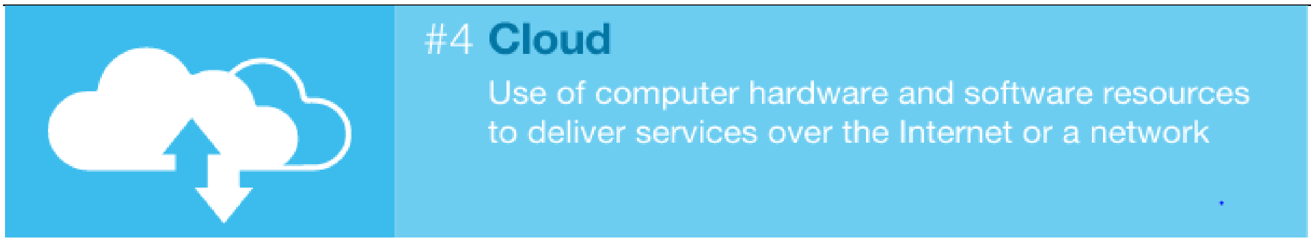
Potential Value	Additional labour productivity could equal the output of 110-140 million full-time workers.
Component Technologies	• Artificial intelligence & machine learning. • Natural user interfaces (e.g. AR and ambient user experience). • Big-data technologies.
Key Applications	General (McKinsey, 2013): • Smart learning in education. • Diagnostics and drug discovery in health care. • Discovery, contracts/patents in legal sector. • Investments and accounting in finance sector. Mining (Heber, 2013): • Automation in mining will improve safety and also streamline operations. Mining houses such as Rio Tinto and BHP Billiton have launched remote operation centres in Western Australia, leading the industry towards more autonomous mining.



#3 Internet of Things

Networks of low-cost sensors and actuators for data collection, monitoring, decision making, and process optimization

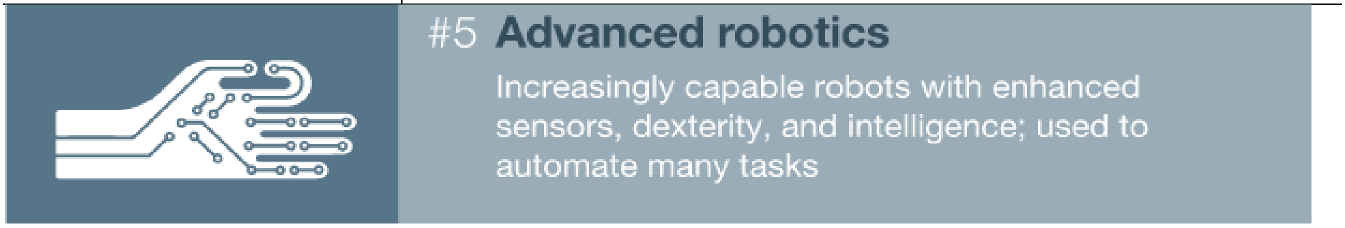
Potential Value	Offers the potential to drive productivity across $36 trillion in operating costs of key affected industries; namely manufacturing, health care and mining.
Component Technologies	• Advanced, low-cost sensors. • Wireless and near-field communications devices, e.g. RFID.
Key Applications	General (McKinsey, 2013): • Process optimisation, particularly in manufacturing and logistics. • Efficient use of natural resources, e.g. smart-meter and smart-grid control of water and electricity. • Remote health-care delivery, sensor-enhanced business models. Mining (Heber, 2013): • Establishing networks that collect, monitor and analyse data can optimise various mining processes. This will further also facilitate more efficient use of resources such as water and energy consumption.



#4 Cloud

Use of computer hardware and software resources to deliver services over the Internet or a network

Potential Value	15-20% potential productivity gains across IT infrastructure, application (App) development, and packaged software.
Component Technologies	• Cloud-management software, e.g. virtualisation, metering. • Data-centre hardware. • High-speed networks. • Software/platform as a service (SaaS/PaaS).
Key Applications	General (McKinsey, 2013): • Cloud-based delivery of Internet services and applications. • Enterprise IT productivity. Mining (Heber, 2013): • Software-as-a-Service (SaaS) and cloud computing allows companies to integrate various applications in order to centralise data, allow single data entries and to create consistency across business centres.



#5 Advanced robotics

Increasingly capable robots with enhanced sensors, dexterity, and intelligence; used to automate many tasks

Potential Value	Offers potential to improve the lives of 50 million amputees and those with impaired mobility.
Component Technologies	• Artificial intelligence/computer vision. • Advanced robotic dexterity & sensors. • Distributed robotics. • Robotic exoskeletons.
Key Applications	General (McKinsey, 2013): • Industrial/ manufacturing robotics. • Service robots, e.g. food preparation, cleaning, and maintenance. • Robotic surgery. • Human augmentation. • Personal and home robots, e.g. for cleaning, lawn care. Mining (Heber, 2013): • Similar to manufacturing, many mining operations across Australia are working to implement automated machinery and processes on site. • Machinery Automation and Robotics [MAR] has been working with Rio Tinto to develop the new MAR Robotic Idler Change-out which is able to replace idlers on loaded conveyors (over 6km long on the

	particular site) without having to shut them down.

#6 Autonomous or near-autonomous vehicles

Vehicles that can navigate and operate autonomously or semiautonomously in many situations

Potential Value	Could save 30,000-150,000 lives from potentially fatal traffic accidents.
Component Technologies	• Artificial intelligence, computer vision. • Advanced sensors, e.g. radar, Lidar, GPS. • Machine-to-machine communication.
Key Applications	General (McKinsey, 2013): • Self-driving cars and trucks. Mining (Heber, 2013): • Rio Tinto had reached 100 million tonnes moved via autonomous trucks in 2013, marking the successful implementation of autonomous vehicles/trucks into the mining industry.

#7 Next-generation genomics

Fast, low-cost gene sequencing, advanced analytics, and synthetic biology (ie, “writing” DNA)

Potential Value	Extending and enhancing lives accounts for 75% of potential impacts, e.g. through faster disease detection and new drug development.
Component Technologies	• Advanced DNA-sequencing technologies. • DNA-synthesis technologies. • Big data and advanced analytics.
Key Applications	General (McKinsey, 2013): • Disease treatment. • Agriculture. • Production of high-value substances. Mining: • Refer to the section on Genomics for various examples such as ore processing and health benefits.

#8 Energy storage

Devices or physical systems that store energy for later use

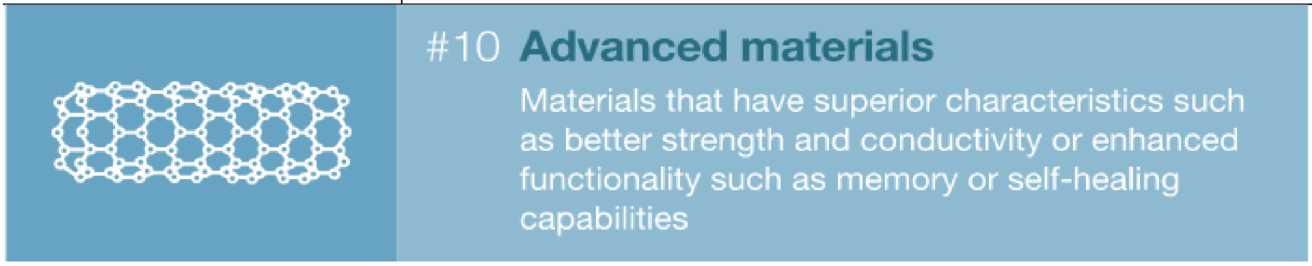
Potential Value	40-100% of new vehicles sold in 2025 could be electric or hybrid.
Component Technologies	• Battery technologies, e.g. lithium-ion and fuel cells. • Mechanical technologies, e.g. pumped hydro and pressurised gas. • Advanced materials and nanomaterials.

Key Applications	General (McKinsey, 2013): • Electric and hybrid vehicles. • Distributed energy (including off-grid distribution). • Utility-scale grid energy storage. Mining (Heber, 2013): • In order to reduce diesel consumption on equipment as well as generators, to reduce electricity costs and lower carbon footprints, mining companies are looking toward advances in energy storage technologies. Improvements in energy storage will realise greater energy management on consumption, costs, supply and associated risks.

#9 3-D printing

Additive-manufacturing techniques that create objects by printing successive layers of material using digital models

Potential Value	Consumers' use of 3D printing could save them 35-60% in costs per printed product, while enabling a high level of customisation.
Component Technologies	• Selective laser sintering (SLS). • Fused deposition modelling (FDM). • Stereoligraphy (SLA). • Direct metal laser sintering (DMLS).
Key Applications	General (McKinsey, 2013): • Consumer use of 3-D printers. • Direct product manufacturing. • Tool and mould manufacturing. • Bioprinting of tissue and organs. Mining (Heber, 2013): • Could potentially reduce or eliminate the need to have replacement parts for equipment and other machinery sent to a mining site.

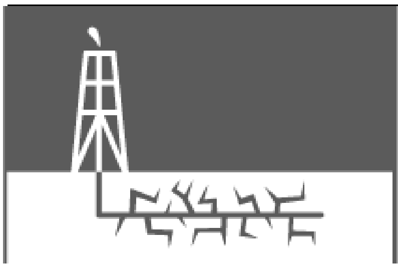


#10 Advanced materials

Materials that have superior characteristics such as better strength and conductivity or enhanced functionality such as memory or self-healing capabilities

Potential Value	Nanomedicine could be used to deliver target drugs to 20 million new cancer cases worldwide in 2025.
Component Technologies	• Graphene. • Carbon nanotubes. • Nanoparticles, e.g. nanoscale gold and silver. • Other advanced and smart materials, e.g. piezoelectric materials, memory metals, self-healing materials.

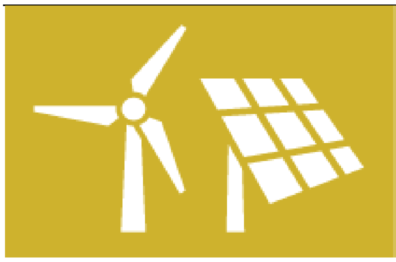
Key Applications	General (McKinsey, 2013): • Nanoelectronics and displays. • Nanomedicine, sensors, catalysts, advanced composites. • Energy storage and solar cells. • Enhanced chemicals and catalysts. Mining (Heber, 2013): • Improvements in the longevity of mining machinery. • Formulation of better engine oils that could reduce equipment downtime. • Creation of stronger machine parts, leading to reduced maintenance costs.



#11 Advanced oil and gas exploration and recovery

Advancements in exploration and recovery techniques that make extraction of additional oil and gas economical

Potential Value	Offers potential to supply an additional 3.6 billion to 6.2 billion oil-equivalent barrels of oil and gas annually by 2025.
Component Technologies	• Horizontal drilling. • Hydraulic fracturing (“fracking”). • Microseismic monitoring.
Key Applications	General (McKinsey, 2013): • Energy from fuel extraction, i.e. shale gas, light tight oil, and coal-based methane. • Coalbed methane and methane clathrate. Mining (Heber, 2013): • With rising fuel costs and a drive towards reducing CO_2 emissions, LNG may offset some of these energy issues (providing that the capital costs could be off-set).



#12 Renewable electricity—solar and wind

Generation of electricity from renewable sources with reduced harmful climate impact

Potential Value	Potential to avoid emissions of 1,0 billion to 1,2 billion tons of CO_2 annually by 2025.
Component Technologies	• Photovoltaic cells. • Wind turbines. • Concentrated solar power. • Hydroelectric and ocean-wave power. • Geothermal energy.

Key Applications	General (McKinsey, 2013): • Electricity generation. • Reduction in CO_2 emissions. • Distributed generation. Mining (Heber, 2013): • Reduced energy costs and reliance on the grid will lead to numerous benefits for mining operations, as well as reduce the impact on the environment.

From Appendix 1, refer to Table 7.1a for the speed, scope, and economic value at stake of the identified 12 potentially economically disruptive technologies. For the estimated distribution of potential economic impact between developed and developing economies for sized applications refer to Table 7.1b. To see how the disruptive technologies could affect society, businesses, and economies refer to Table 7.1c.

Many technologies, including advanced robotics, next-generation genomics, and renewable energy, have real potential to drive tangible improvements in quality of life, health, and the environment. For example, advanced robotic surgical systems and prosthetics could improve and extend many lives, while renewable energy sources could help clean up the environment and lessen the deleterious health effects of air pollution. Many of these technologies could change how and what consumers buy, or alter overall consumption of certain resources such as energy and materials. Others could fundamentally change the nature of work for many employees around the world, both in manufacturing and knowledge work (McKinsey Global Institute, 2013).

Almost every technology on the list above could change the game for businesses, creating entirely new products and services, as well as shifting pools of value between producers or from producers to consumers. Some, like automation of knowledge work and the mobile Internet, could also change how companies and other organisations structure themselves. These technologies greatly impact and drive the anytime/anywhere work style. With automation of knowledge work tasks, organisations that can augment the powers of skilled workers stand to do well (McKinsey Global Institute, 2013).

Other technologies on the radar for McKinsey & Company, but which did not make the final list due to the abovementioned criteria, include the following (McKinsey Global Institute, 2013) verbatim:

- ***Next-generation nuclear (fission)*** *has potential to disrupt the global energy mix but seems unlikely to create significant impact by 2025 given the time frames of current experiments and pilots.*
- ***Fusion power*** *also has massive potential, but it is even more speculative than next-generation nuclear fission in terms of both technological maturity and time frame.*
- ***Carbon sequestration*** *could have great impact on reducing carbon dioxide (CO2) concentration in the atmosphere, but despite sustained R&D investment it may not become cost-effective and deployed at scale by 2025.*
- ***Advanced water purification*** *could benefit millions of people facing water shortages, but approaches with substantially better economics than currently known approaches may not be operating at scale by 2025.*
- ***Quantum computing*** *represents a potentially transformative alternative to digital computers, but the breadth of its applicability and impact remain unclear and the time frame for commercialization is uncertain.*
- ***OLED / LED lighting*** *has potential for extensive reach in terms of people affected but seems unlikely to disrupt pools of economic value beyond narrow industries by 2025.*
- ***Wireless charging*** *is promising for some applications but overall offers limited impact at high cost. Simple versions exist, but it is not clear that the technology serves an important need versus substitutes such as improved energy storage technology.*

- ***Flexible displays** have long been in development and could offer exciting new possibilities for the designs of mobile devices and TVs, but on their own seem unlikely to have broad-based disruptive impact by 2025.*

It should be noted that most of these technologies are directly enabled, or enhanced, by information technology. Continuing progress in artificial intelligence and machine learning is essential to the development of advanced robots, autonomous vehicles, and automation tools in knowledge work. The next generation of gene sequencing depends highly on improvements in computational power and big data analytics, as does the process of exploring and tapping new sources of oil and natural gas. 3D printing uses computer generated models and benefits from an online design sharing ecosystem. The mobile Internet, the Internet of Things, and cloud technology are themselves information and communications technologies. Information technologies tend to advance very rapidly, often following exponential trajectories of improvement in cost/performance. Also, information technologies are often characterised by strong network effects, meaning that the value to any user increases as the number of users multiply. Just as IT creates network effects for users of social media and the mobile Internet, IT-enabled platforms and ecosystems could bring additional value to users of 3D printing or to researchers experimenting with next-generation genomics technology (McKinsey Global Institute, 2013).

Combinations of technologies could further also multiply impact. Certain emerging technologies could be used in combination, reinforcing each other and potentially driving far greater impact. For example, the combination of next-generation genomics with advances in nanotechnology has the potential to bring about new forms of targeted cancer drugs. It is possible that the first commercially available nano-electromechanical machines (NEMS), molecule-sized machines, could be used to create very advanced sensors for wearable mobile Internet devices or Internet of Things applications. Similarly, automated knowledge work capabilities could help drive dramatic advances across many areas, including next-generation genomics. Another example of symbiotic development exists between advances in energy storage and renewable energy sources. The ability to store electricity created by solar or wind helps to integrate renewables into the power grid. The advances in energy storage that make this possible could benefit from advances in nanomaterials for batteries. In the same way, the mobile Internet might never live up to its enormous potential without important advances in cloud computing to enable applications (including tools for automating knowledge work) on mobile devices (McKinsey Global Institute, 2013).

Although some technologies do not, or will not, have a direct impact on the mining cycle or production process, it is still important to be aware of changing technologies (especially disruptive technologies) and to gauge their potential impact on both a macro and micro scale. Some of these technologies may influence mining costs or health and safety of workers and should be studied in order to improve our management of, and analysis on, mining ventures.

Throughout the rest of the Literature Study, these disruptive technologies will be investigated in greater details along with other innovative technologies (e.g. component technologies of the disruptive technologies as well as others).

2.3.1. Potential Consequences from Disruptive Technologies

Energy technologies, such as unconventional oil and gas and energy storage, could power overall economic growth. Technologies such as advanced robotics and 3D printing could increase productivity and foster growth in the manufacturing sector. These types of impacts could help nations develop and exploit their unique resources and capabilities in new ways, potentially even shifting the global centre of gravity across sectors and regions. Many of these technologies also pose new regulatory and legal challenges. Some, such as autonomous vehicles, will require sensible regulatory regimes to help foster their growth and realise the potential benefits. Next-generation genomics and the Internet of Things will need appropriate controls to help avoid accidents, misuse or even malpractice (McKinsey Global Institute, 2013).

As these disruptive technologies continue to grow, it will be up to business leaders, entrepreneurs, policy makers, and citizens to maximise their opportunities while dealing with the challenges. Business leaders need to be on the winning side of these changes. This can be achieved by being the early adopters or innovators, or by turning a disruptive threat into an opportunity. The first step is for leaders to invest in their own technology knowledge. Technology is no longer something down the hall or simply a budget line, it is the enabler of virtually any strategy. Some of the ways technology could alter business strategy is by providing the big data analytics that reveal ways to reach new customer groups, or the Internet of Things connections that enable a whole new profit centre in after-sale support. Top leaders need to know what technologies can do and how to bend it to their strategic goals. Leaders cannot wait until technologies are matured to think about how they will work for, or against them. At times companies even need to disrupt their own business models before a rival, a new competitor or shifting markets does it for them (McKinsey Global Institute, 2013).

One thing is clear; the nature of work is changing. Technologies such as advanced robots and knowledge work automation tools move companies further to a future of leaner, more productive operations, and also to a far more technologically advanced environment. The need for high-level technical skills will only grow. Companies will need to find ways to get the workforce they need, by engaging with policy makers and their communities to shape secondary and tertiary education and by investing in talent development and training. The half-life of skills is shrinking, and companies may need to get back into the training business to keep their corporate skills fresh (McKinsey Global Institute, 2013).

The scope of impact of the technologies mentioned motivates that policy makers could benefit from an informed and comprehensive view of how they can help their economies benefit from new technologies. Policy makers can find ways to turn the disruptions into positive change, they can encourage development of the technologies that are most relevant to their economies. In many cases, such as in next-generation genomics or autonomous vehicles, the proper regulatory frameworks will need to be in place before those technologies can blossom fully. In other cases governments may need to be the setters of standards, or the funders of the research, that helps move ideas from science labs into the economy. In still others, they will need to draw the lines between progress and personal rights (McKinsey Global Institute, 2013).

Significance of this study

The potentially disruptive technologies and the coming impacts they bring cannot be ignored by any business that wishes to survive the coming Technological Revolution. These impacts will be felt on a global scale and it will not be limited to the working environment alone. Citizens, societies and all community members will be impacted in some way, however miniscule perhaps. These coming changes to how people and technology interact, synchronise and to some extent “co-exist”, will influence the way people go about both their daily lives and how they approach their working lives.

2.4. Physical Technologies

Various emerging technologies of a “physical” nature were investigated in this section. Amongst these were technologies, recent and emerging, in both mining and non-mining sectors. This section covers two of the three main categories of technologies, as described in Section 1.3.2, namely Mining Technologies and Energy Technologies.

2.4.1. 3-D Printing (Additive Manufacturing) and Modularisation

Additive manufacturing is the technique employed by 3-D printers that allows the creation of an object by adding ultrathin layers of material on each other, one by one (LaMonica, 2013). Until recently, 3-D printing has largely only been used by product designers, hobbyists and for a few select manufacturing applications. However, the performance of additive manufacturing machinery is improving, the range of materials is expanding, and prices (for both printers and materials) are decreasing. These factors allow rapid adoption by consumers and also for more manufacturing uses. With 3-D printing, an idea can go directly from a 3-D design file to a finished part or product, potentially skipping many traditional manufacturing steps (McKinsey Global Institute, 2013).

The ability to achieve on-demand production has massive impacts on both supply chains and the stocking of spare parts. Both of which constitute great costs for manufacturers and consumers alike. 3-D printing can further also reduce the amount of material wasted in manufacturing and create objects that are difficult, or even impossible, to produce with traditional techniques (McKinsey Global Institute, 2013).

General Electric (GE), had made the decision to mass-produce a critical metal-alloy part used in jet engines through additive manufacturing (the industrial version of 3-D printing). The part was a nozzle in the LEAP jet engine, which was due to go into planes in late 2015 or early 2016. GE chose 3-D printing technology since it uses less material than conventional techniques, resulting in reduced production costs. Conventional techniques also required a labour intensive welding process, which had been replaced by using a computer-controlled laser to shoot pinpoint beams into the bed to melt the metal alloy in specific locations (LaMonica, 2013).

Additive manufacturing works directly from computer models, as shown in Figure 2.4.1a and 2.4.1b, which removes numerous limitations to physical manufacturing as well as machine design and setup (LeMonica, 2013).

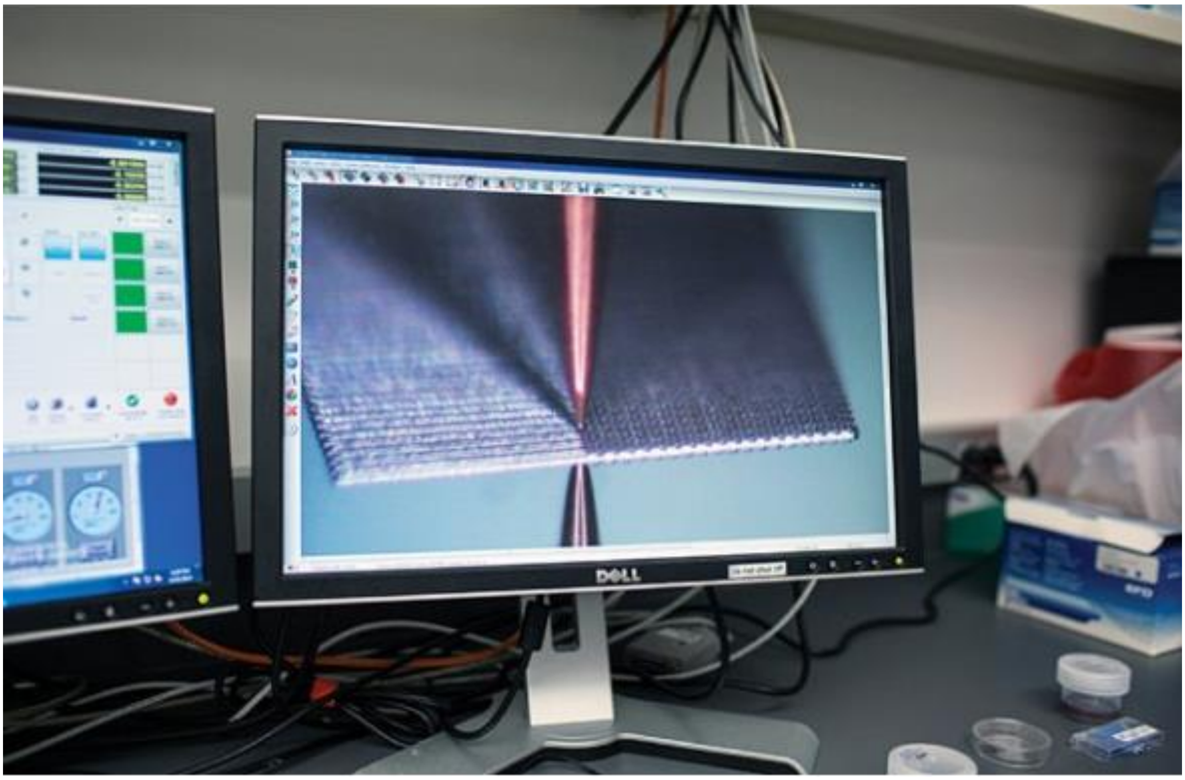


Figure 2.4.1a: 3-D Model being designed prior to printing it (Rotman, 2014)

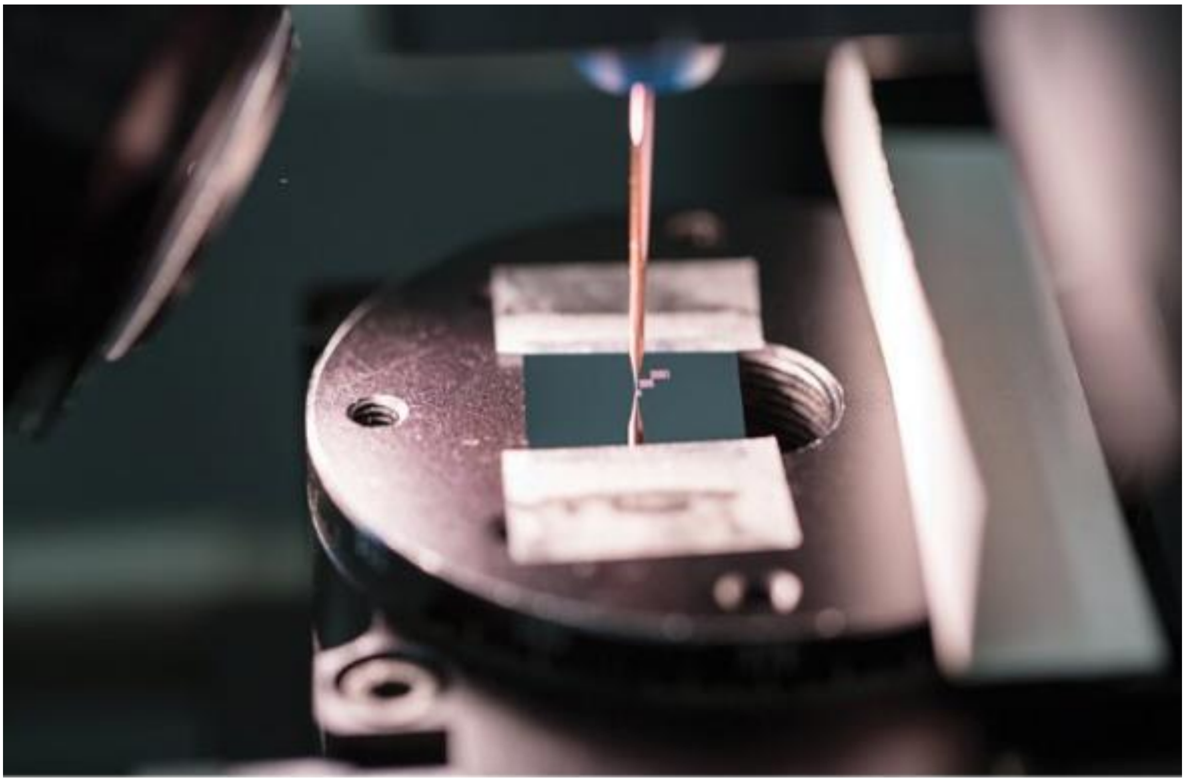


Figure 2.4.1b: Printed Model of Electrodes of a few Micrometres in size, using Silver Nanoparticles (Rotman, 2014)

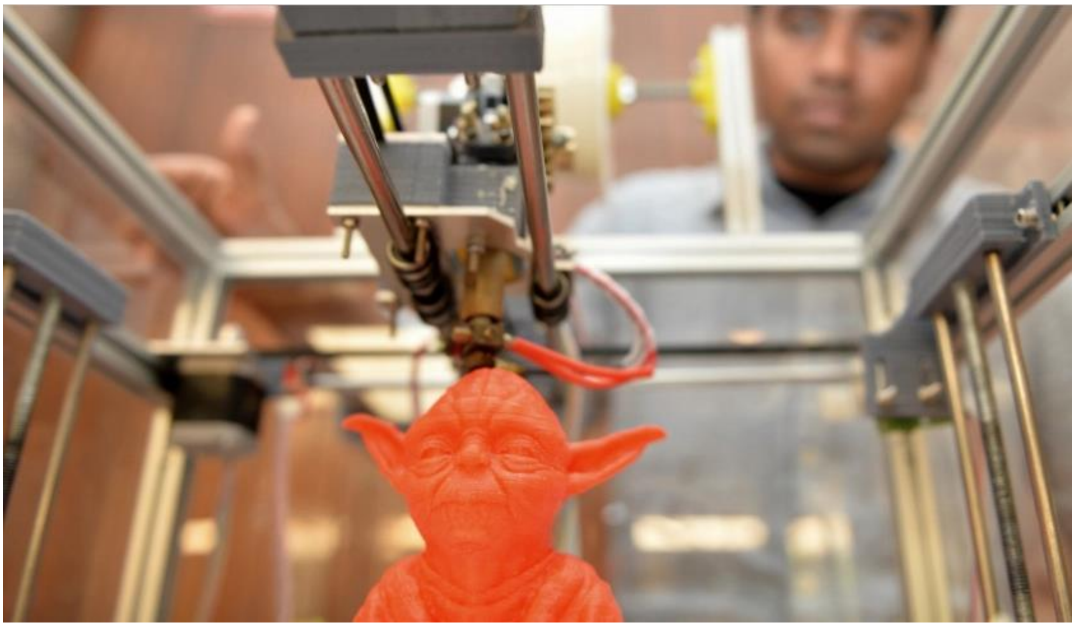


Figure 2.4.1c: 3-D Printed Model Example using a Plastic Material (VanderMey, 2015)

3-D printing has changed into a production-ready technology with a wide range of applications with various levels of detail (see Figure 2.4.1c for an example of the detail that can be achieved with 'standard' 3D printers). For mining operations the implications are especially significant, as this technology could enable operations to custom manufacture critical parts on demand. This is particularly beneficial for mines in remote locations. 3-D printing could not only reduce delays during unplanned maintenance in awaiting the arrival of replacement parts, but also reduce the need to hold costly inventories (DDTL, 2016).

Advances in 3-D printing have enabled the use of a wide range of materials, including advanced nickel alloys, glass, carbon fibre, electronics, conductive ink, pharmaceuticals and biological materials (Gartner, 2015). Depending on the type of model to be printed other materials can also be used, such as sintered powdered metal, carbon nanotubes and graphene embedded in plastics, Nithinol, water-absorbing plastic, conductive carbomorph, paper, concrete, food, yarn, stem cells, and other metals (such as stainless steel, bronze, steel, gold, nickel, aluminium, and titanium) (Giges, 2014).

Scientists have even "bioprinted" organs, using an inkjet printing technique to layer human stem cells along with supporting scaffolding (McKinsey Global Institute, 2013). A team of researchers at the University of Cambridge has printed retinal cells to form complex eye tissue, while at Princeton University a bionic ear has also been printed through the combination of biological tissue and electronics (Rotman, 2014).

Furthermore, in the energy sector, the microscopic electrodes in lithium-ion batteries have also been 3-D printed successfully. Harvard University has rigged a 3-D printer with a microscope than can precisely print structures with features as small as one micrometer (as reference, a human red blood cell is around 10 micrometers in diameter). While this fine detail can be accomplished, the total size of the model printed by this printer can be up to around a meter across (Rotman, 2014).

These advances will necessitate a rethinking of assembly line and supply chain processes to exploit 3-D printing. The technology will also see a steady expansion over the next 20 years of the materials that can be printed, speed improvements in printing and the emergence of new models to print and to assemble composite parts (Gartner, 2015).

As this technology matures, the entire equipment provision supply chain is set to shift, driving OEMs to favour modular designs. For instance, European Truck Factory is bringing this concept to fruition with the design of modular components capable of being used by a full array of mining trucks. As more equipment becomes modular, mining operations can also begin to rely more on new forms of heavy lift transport (e.g. such as hybrid air vehicles) that are capable of moving modular equipment to remote sites. This will enable operations to construct processing units in low-cost factories and transport them where they are to be used (DTTL, 2016). Similarly powerline assemblies can potentially be achieved in difficult to navigate terrains with the use of hybrid air vehicles, such as when exploring the Arctic for mining (Davidse, 2016). The result is reduced dependence on expensive, full on-site construction. Potentially, operations will be positioned to access smaller ore deposits more economically than ever before, due to reduced construction and assembly costs (DTTL, 2016).

Progress in 4D printing, a field popularised by MIT's Skylar Tibbits and his "self-assembly lab", will also be expected within the near future. 4D printing goes further than 3D printing, by aiming to have parts of a product assemble themselves, or have physical objects that can adapt to a user over time. An example is having a 4D-printed chair that could become more comfortable over time, or become stronger at stress points instead of breaking, by adapting to the function and specifications it is exposed to (Salesses, 2015). It is likely that improving nanomaterial technology will play an important role in the success and breadth of application for 4D printing.

Significance of the study

The potential benefits to the mining industry from 3-D printing technology appear to be clear-cut. Not only could it drastically reduce the dependence on, and costs associated (i.e. storage, logistics, downtime of equipment etc.), of parts and other consumables, but it could allow greater customisation than ever before. Mining operations have the ability to create and produce a customised part, of whichever application and material, to solve a particular problem or fix a broken piece of machinery. For service providers the value that can be obtained from 3-D printing is just as great. They can assemble specific components and address unique customer needs without the traditional planning, building and costs that were associated with creating a new machine to make new parts. This not only reduces costs and waste, but also allows faster output as well as the possibility of modularisation. With modularisation further comes other benefits, such as off-site assembly of components for reduced costs and complexity, or on-site assembly for reduced logistical challenges.

2.4.2. Advanced Materials & Nanomaterials

The ability to manipulate existing materials on a molecular level has enabled advances in numerous products, ranging from sunglasses and bike frames to intricate medical equipment. Scientists have a growing level of control over nanomaterials in a variety of substances, and their knowledge is still expanding in the field (VanderMey, 2015).

This way, over the past few decades, scientists have discovered ways to produce materials with enhanced attributes. Some of which include, smart materials that are self-healing or self-cleaning, memory metals that can revert to their original shapes, piezoelectric ceramics and crystals that turn pressure into energy, and nanomaterials. Nanomaterials in particular have experienced a high rate of improvement, have a broad potential applicability, and also long-term potential to drive massive economic impact (McKinsey Global Institute, 2013).

At nanoscale (less than 100 nanometers), ordinary substances take on new properties. Some of these properties include greater reactivity, unusual electrical properties, and even enormous strength per unit of weight. These properties can further enable new types of medicine, super-slick coatings, stronger composites as well as other kinds of improvements. Advanced nanomaterials, such as graphene and carbon nanotubes, could drive significant impact. For example, graphene and carbon nanotubes could help create new types of displays as well as highly efficient batteries and solar cells. Pharmaceutical companies are also progressing in research to use nanoparticles for targeted drug treatments, e.g. for diseases such as cancer (McKinsey Global Institute, 2013).

Nanoparticles, designed to live within the human body, are opening up opportunities for real-time monitoring of a person's health with high accuracy. This emerging technology, along with other advanced diagnostics techniques, could enable instant disease detection. This will in turn result in much faster treatments and better outcomes (Everdell, 2015).

A scientist has created a ceramic that is one of the strongest and lightest substances ever made. It is also not brittle like traditional ceramics. Tests on the created material were performed, and a video showed how the cube shuddered under a lab press and then collapsed. When the pressure was removed, the material simply rose back to its original form. Provided that such materials could be produced in large quantities, they could replace composites and other materials used in a wide range of applications. These nano-altered materials would be just as strong but with a fraction of the weight (Bourzac, 2015).

Another possibility arising from this technology is the ability to greatly increase the energy density of batteries, resulting in larger amounts of power that can be stored at a given size. For this purpose, researchers have been attempting to develop electrodes that are lighter than current ones but that could store more energy. Promising materials such as silicon are prone to cracking under strain. However, an electrode made by coating a metal nanolattice with silicon, could potentially have crack-resistant toughness in its very structure (Bourzac, 2015).

A machine resembling a 3-D printer has been used to create intricate polymer scaffolds, by using flashes of laser. The polymers are coated with metals, ceramics or other materials and then the sides are shaved off in order to etch away the polymer inside. The result is a small block of material that is made up of nanoscale trusses (of about 10 nanometres thick), which are crisscrossed like the struts in the Eiffel Tower, see Figure 2.4.2a. Using this method, a nickel metal sample had been created that is lighter than a feather. This metal has the potential for ultra-light thermal insulation applications (Bourzac, 2015).

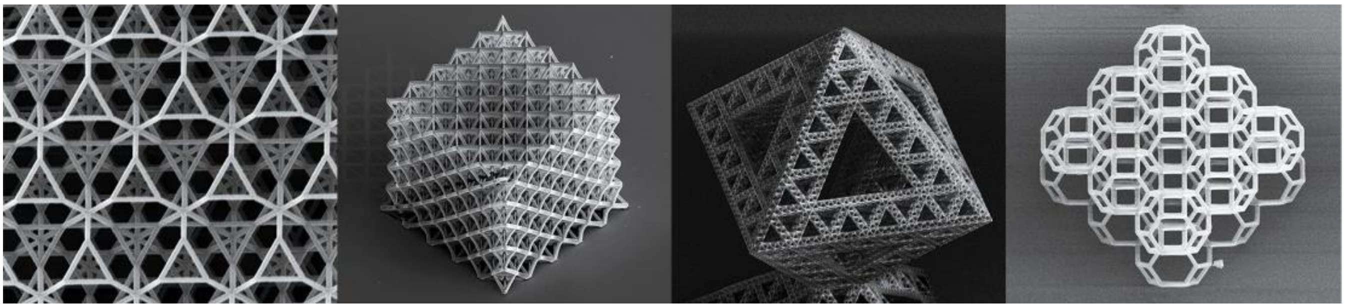


Figure 2.4.2a: Nanotechnology used to create tiny lattices with valuable characteristics (Bourzac, 2015)

This type of nanotechnology has been in R&D for other uses as well, such as to precisely control the flow of light from light-emitting materials and the flow of heat in thermal insulation materials. Similarly, the nanostructured ceramic has been under investigations to attempt to use the principle as a scaffold for growing bones (such as the ones in the ear whose degeneration is one cause of deafness) (Bourzac, 2015).

Another, and somewhat different, example of advanced materials is "Green Concrete". Making cement for concrete typically involves heating pulverised limestone, clay, and sand to 1,450 °C with a fuel such as coal or natural gas. The process generates large quantities of carbon dioxide (CO_2). To make one metric ton of cement releases around 650 to 920 kilograms of CO_2. In 2009, around 2.8 billion metric tons of cement was produced worldwide, which contributed about 5 percent of all carbon dioxide emissions. A company called Novacem had been working to reduce these emissions with cement that absorbs more CO_2 than what is released during manufacture. This is achieved by using magnesium compounds that react with atmospheric CO_2 to make carbonates than strengthen the cement while trapping the CO_2 gas. In this process as much as 100 kilograms of the greenhouse gas has successfully been locked away per ton of cement produced. See Figure 2.4.2b (Bradley, 2010).

These five blocks are different varieties of concrete made with Novacem's new type of cement. The magnesium compounds below form the cement's basic ingredients, replacing limestone, a carbon-rich mineral used to make traditional Portland cement.

Cements are mixed with sand, gravel, and water to make concrete. Varying the ingredients' proportions and adding other materials, such as glass, can yield different types of concrete for different applications.

As Novacem's cement hardens, carbon dioxide from the atmosphere is absorbed.

Figure 2.4.2b: Green Cement (Bradley, 2010)

Significance of the study

Advances in advanced materials technology (which includes nanotechnology) could allow further manipulation of various materials, resulting in alterations of traditional characteristics. This could have a major impact on mining, which is not only the producer of these materials that are used in this technology, but also a major consumer of various materials for high-duty purposes. Enhanced material characteristics could benefit materials exposed to tough working conditions or abrasive environments, e.g. drill bits and the picks on continuous miners and longwall shearers.

When the strength to weight ratio of materials can be improved through technology, the impact and potential benefits will extend even further. Smaller, lighter and also stronger materials will allow deeper and safer mining by potentially improving rock support (e.g. rock bolts, tendons, wire mesh and other cable anchors etc.). Mining equipment, such as ultra-low profile equipment, could also be designed smaller and stronger to mine difficult to navigate deposits, reduce waste mining, and therefore, mine both more economically and be able to reach previously uneconomical deposits.

Similarly, advances in this field could open up major breakthroughs in electrical equipment and vehicles if energy storage could be improved and batteries reduced in size and weight.

Using green cement would also help companies reduce their carbon footprint during mine construction.

2.4.3. Advanced Oil and Gas Exploration and Recovery & Directional Drilling

The ability to extract unconventional oil and gas reserves from shale rock formations has driven technological advances for nearly four decades. The combination of horizontal drilling and hydraulic fracturing (“fracking”) makes it possible to reach oil and gas deposits that were previously deemed uneconomical to extract. Of these deposits many are situated in the United States, but they were not economically accessible by conventional drilling methods. With continued improvements, fracking and horizontal drilling technology could significantly increase the availability of fossil fuels for decades. This would produce an immediate benefit for energy-intensive industries such as petrochemicals manufacturing. Eventually, improving technology for oil and gas exploration and recovery could potentially also unlock new types of reserves, including coalbed methane, tight sandstones, and methane clathrates (also known as methane hydrates), potentially ushering in another energy “revolution” (McKinsey Global Institute, 2013). The International Energy Agency predicts that, due to major advances in these technologies, the U.S. will be the largest oil producer by 2020 (VanderMey, 2015).

The effect of reduced fuel costs may bring significant impacts on mining operations, especially those operating with diesel equipment. The associated financial impacts need to be assessed in detail in order to plan accordingly. However, the underlying technologies of the oil and gas sector may hold further value for the mining sector. In particular, directional drilling may bring substantial benefits to mining.

Schlumberger Water Services and Freeport-McMoRan have collaborated to develop, test, and implement a new generation of high-performance mine dewatering well systems. This is done by combining mine hydrogeology and dewatering expertise with crossover technology of oil and gas directional well placement (Dowling & Rhys-Evans, 2015). Refer to the case study on Schlumberger Water Services for more details and the associated benefits of using this method.

Directional drilling as a whole is considered a mature technology with widespread acceptance and commonplace use in the oil and gas, utilities, and infrastructure industries. However, directional well placement in hard rock mining has a very limited track record and was previously untested for application in open pit mine dewatering. The geological and geo-mechanical environments, size and scale of equipment, flow and production pumping regime, along with the associated well design requirements are inherently different. Therefore significant adaptation and modification is required. However, Schlumberger Water Services and Freeport-McMoRan recognised that the principal benefits of directionally drilled dewatering wells are highly applicable to open pit mine dewatering (Dowling and Rhys-Evans, 2015). The use of directional drilling enables (Rowland *et al*, 2016):

- The enhancement of hydraulic contact between multiple fracture zones and the production well(s);
- Access to permeable water-bearing zones that are unreachable with vertical drilling;
- Permanent positioning of the well-heads outside of the planned mine operating areas.

- Increased well yield due to the design trajectory, interception of sub-vertical structures, and enhanced hydraulic contact.
- Improved well runtimes with the well-heads located outside of operating areas, thereby avoiding interference between dewatering infrastructure and mine operations
- High well yield and improved runtimes leading to a step-change increase in long-term volumes of groundwater produced from the dewatering programme
- Reduced number of well-head installations with associated burdens of procurement, implementation, and in-pit operation interactions.

A conceptual layout of a conventional dewatering system in a hard rock, fractured environment is shown in Figure 2.4.3a. Some or all of the various aspects illustrated may be included in any given system, and often a combination is deployed based on local requirements. Figure 2.4.3b shows 3D visualisations of directional well placement trajectories beneath the Morenci Copper Mine. The trajectory on the left is the proof-of-concept well as completed in April 2013, while the trajectory on the right was completed in January 2015 (Dowling and Rhys-Evans, 2015).

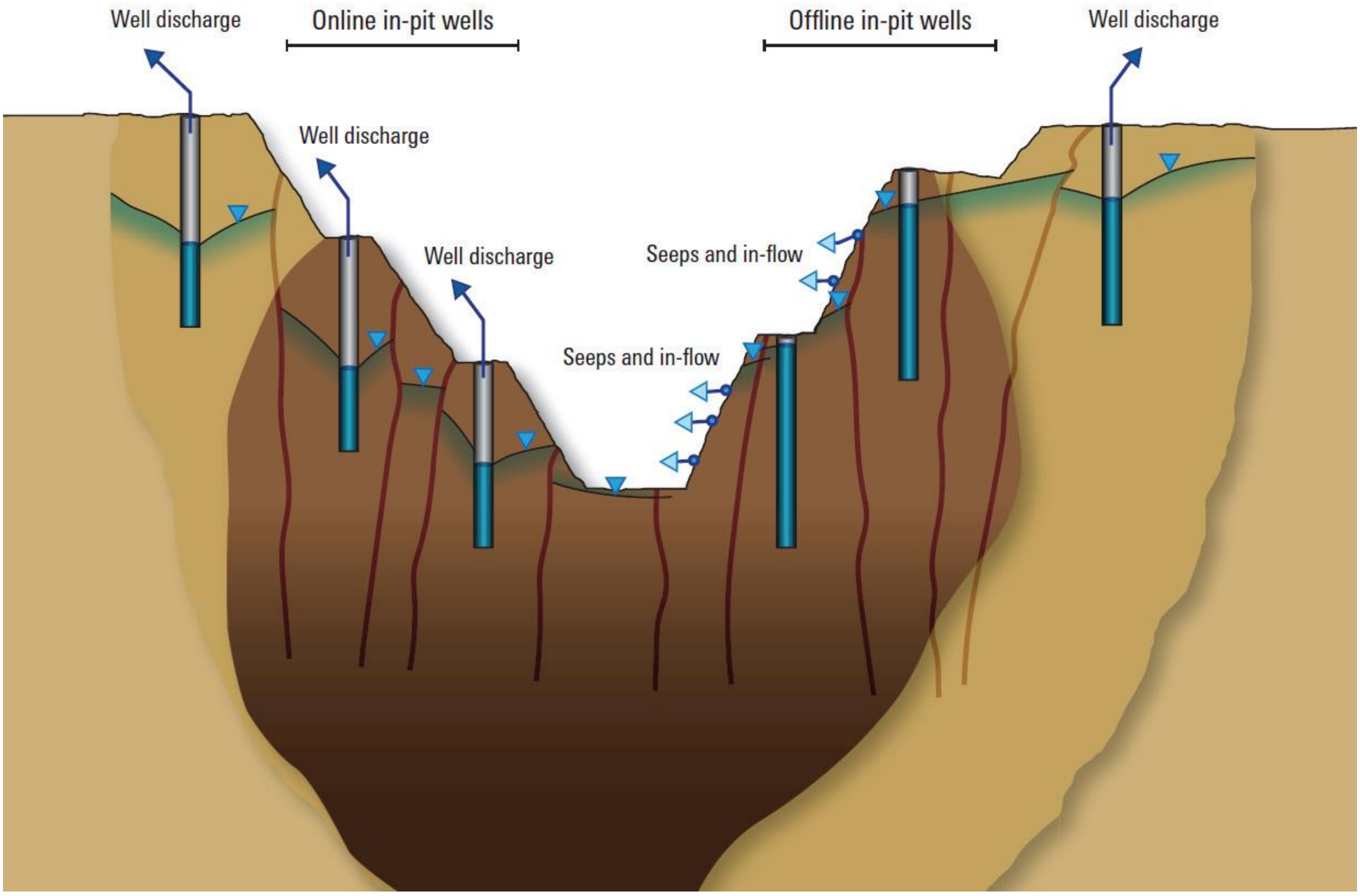


Figure 2.4.3a: Conceptual layout of a conventional dewatering system in a hard rock, fractured environment (Dowling & Rhys-Evans, 2015)

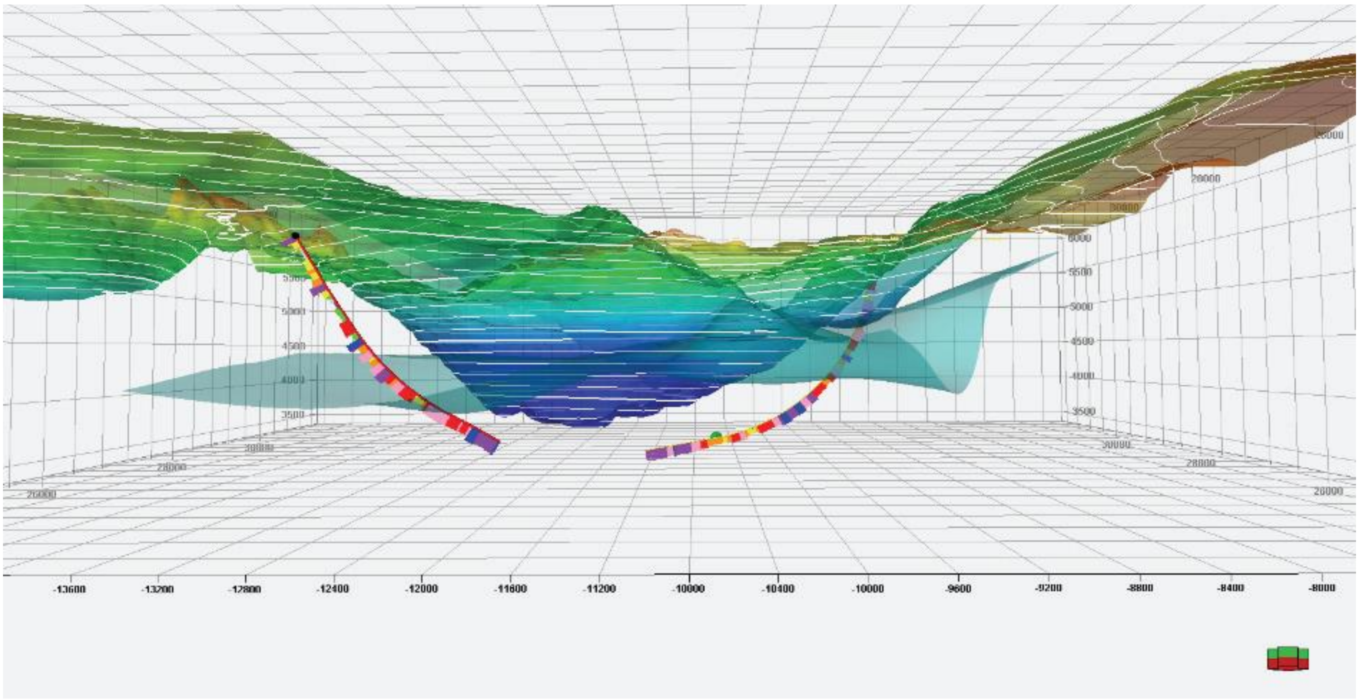


Figure 2.4.3b: 3D visualizations of directional well placement trajectories beneath the Garfield pit at the FreePort McMoRan Morenci Copper Mine in the USA (Dowling and Rhys-Evans, 2015).

Significance of the study

Directional drilling has clearly been applied to the mining environment for dewatering purposes. However the technology may hold further potential applications for other drilling practices, such as for production or exploration drilling.

2.4.4. Advanced Robotics

Industrial robots have played an increasingly more prominent role in doing physically difficult, dangerous or dirty jobs, such as spray painting or welding. These robots have seen massive improvements over the last few decades, going from being expensive, bulky, inflexible (typically bolted to the floor) and being fenced off, to becoming much more advanced. Currently robots are gaining enhanced senses, dexterity and intelligence. Many of these improved characteristics stem from advancements in machine vision, artificial intelligence, machine-to-machine communication, sensors, and actuators (a component of machines that is responsible for moving or controlling a mechanism or system). These robots are now easier for people to program and interact with. They can also be more compact and adaptable, making it possible to deploy them alongside workers (McKinsey Global Institute, 2013).

These advanced robots could, as a result, make it practical to substitute robots with human labour in a wider range of manufacturing tasks and service jobs (e.g. cleaning, maintenance and even surgery). This technology could enable new types of surgical robots, robotic prosthetics, and “exoskeleton” supports that can help people with limited mobility to function more normally and help to improve and extend lives (McKinsey Global Institute, 2013).

Robotics replacing existing jobs, however, is only part of the picture. The International Federation of Robotics estimates that these devices will create as many as 2 million additional job positions between 2017 and 2020. A major factor in robotics-driven job growth is the simple fact that the combination of humans and machines can often produce better results than either could accomplish on their own. In dire situations, an expert may always be required take control. With Robotics classified as an exponential technology, finding the balance between man and machine proves important (Dupress, 2015a).

Looking firstly at exoskeletons, there are suits available that can return movement to a disabled wearer's hips and knees with small motors attached to standard orthotics. The "Phoenix", shown in Figure 2.4.4a, is an example of a medical exoskeleton. Wearers can control the movement of each leg and walk at up to 1.1 miles per hour by pushing buttons integrated into a pair of crutches (Brewster, 2016).

Figure 2.4.4a: Phoenix Exoskeleton (Brewster, 2016)

Anthropomorphic robots (robots that could mimic human characteristics such as in the example in Figure 2.4.4b), on the other hand, could take over numerous repetitive production or other tasks that traditionally required human traits (ESPAS, 2015). As robots get cheaper, more dexterous, and safer to use, they will continue to grow as a substitute for human labour in a wider range of fields. Between 2009 and 2011, sales of industrial robots grew by 170%. It is expected that the industry's (industrial robotics) annual revenues will exceed US$40 billion by 2020 (VanderMey, 2015). This may have a significant impact on the economies of some of the Asian countries (particularly Japan, China and the Republic of Korea), who are world leaders in robotics, as many businesses may wish to tap into that expertise (IFR, 2014).

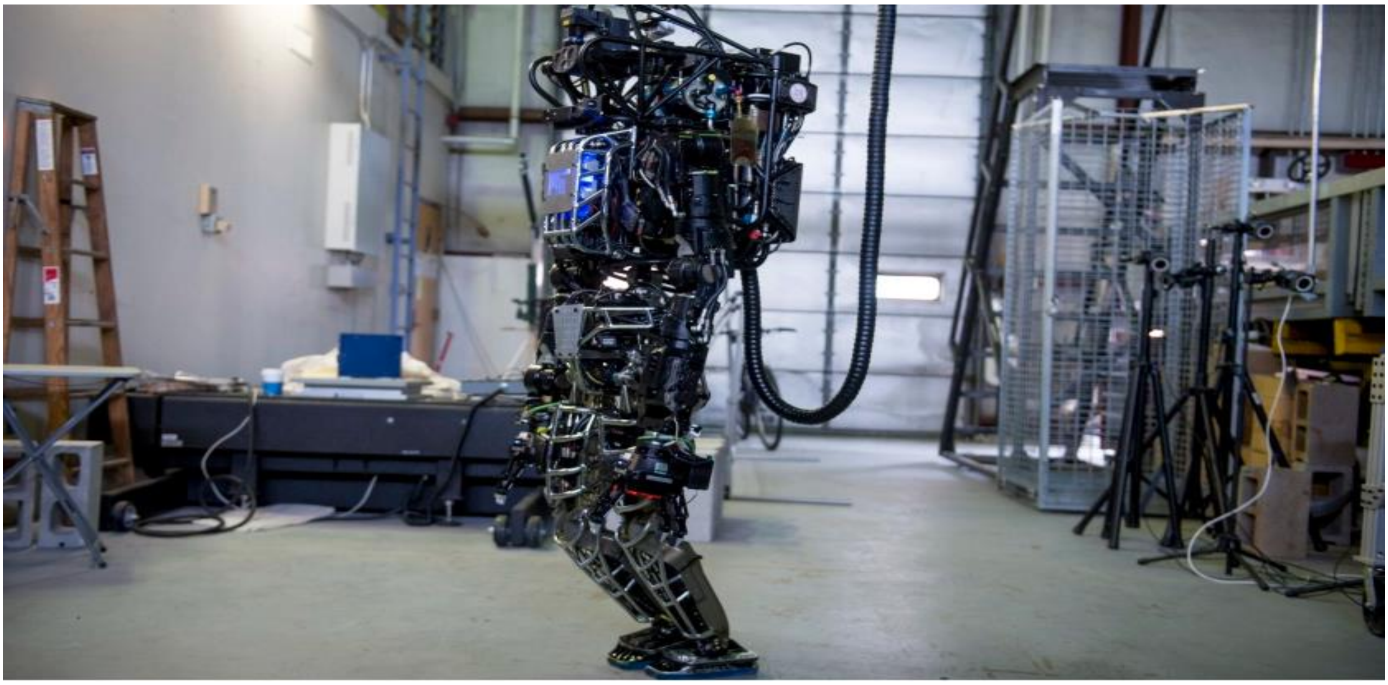


Figure 2.4.4b: Photograph of a project in robotics, built to resemble human movement (VanderMey, 2015)

Boston Dynamics, a company that Google acquired in December 2013, created a robot that can walk across rough terrain and run on even ground. While other robots have had the ability to walk before, the Atlas from Boston Dynamics is able to adjust its balance at a much faster rate. The Atlas (shown in Figure 2.4.4d) can stabilise itself with ease, demonstrating dynamic balance and the ability of robots to move around in human environments safely and easily. It could even respond quickly enough to prevent itself from falling over when losing balance, similar to human reactions. Robots that are able to walk, balance and otherwise navigate difficult terrain could eventually find far greater use in emergency and rescue operations (e.g. as a locator, excavator and carrier). They could also play a role in other routine jobs, such as assisting physically disabled people with chores or leading the blind (Knight, 2014). Figure 2.4.4c shows an example of a four-legged robot from Boston Dynamics, called Spot.

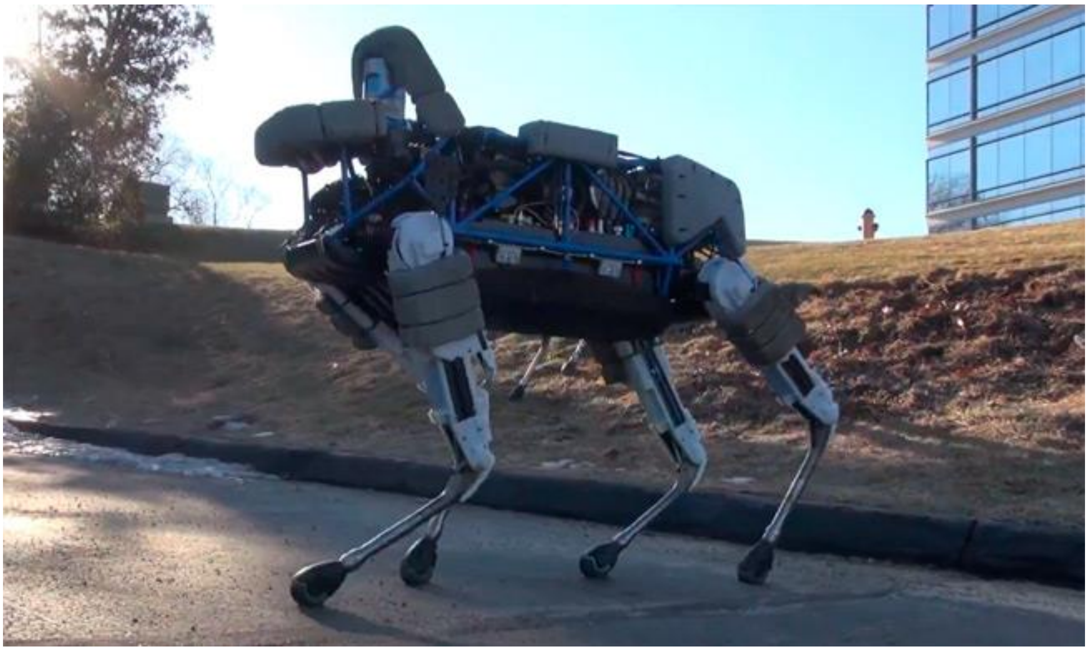


Figure 2.4.4c: Four-legged Robot called Spot from Boston Dynamics (Knight, 2016a)

These robots have been created with dynamic balancing abilities (termed dynamic stability in the Atlas), the ability to grasp objects more effectively (an ability taught to the robot and its arms through machine learning) and more effective machine vision to recognise objects. This is opening up applications where robots need to recognise, pick up and carry objects (or even use them as tools). The latest video (also shown in Figure 15) from Boston Dynamics showed its newest humanoid robot moving through a warehouse and picking up boxes (Knight, 2016a). The robot can even recognise, open certain doors, and walk through them. In the event that the robot failed to keep its balance and it fell over, it is further also able to get back up on its own (Reilly, 2016).

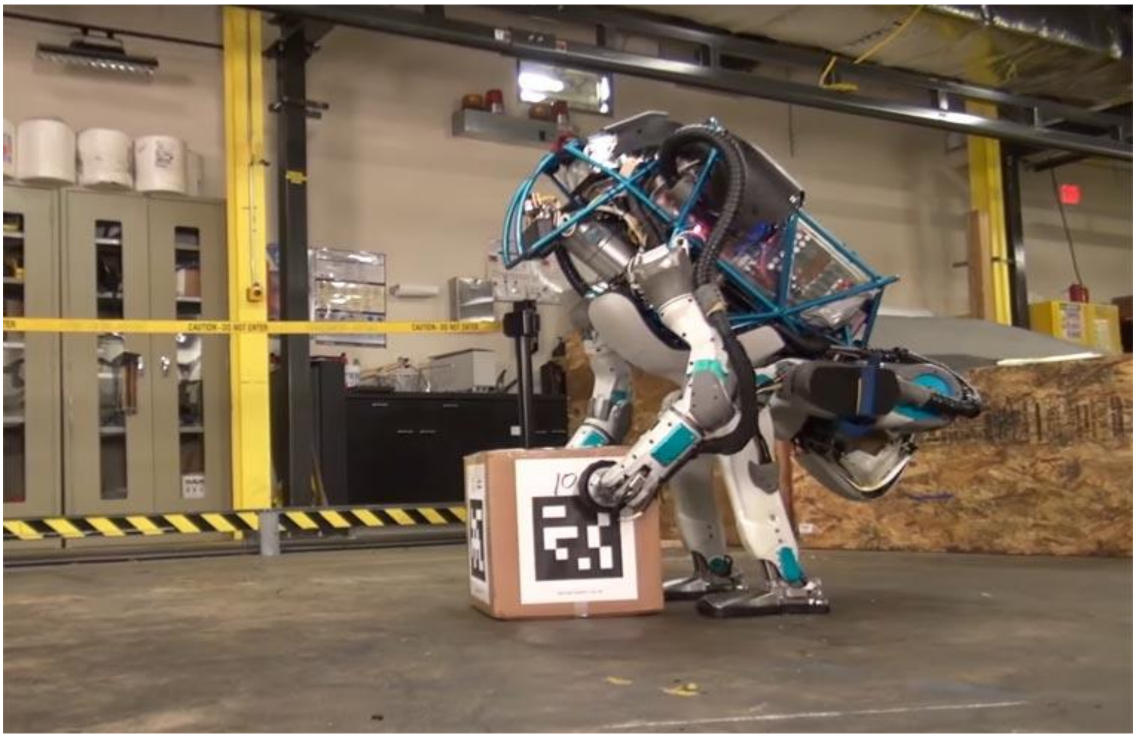


Figure 2.4.4d: Atlas picking up a box (Reilly, 2016)

Significance of the study

Robots are advancing at a rapid rate and are fast approaching the point where they can not only assist, but even replace humans in various tasks. Applications currently include tasks of strenuous, repetitive, dangerous or dirty nature. Robots can also be manufactured to be far more resilient to the natural elements and other physical dangers which may make them ideal for search and rescue operations in explosive and fiery mines, flooded areas or dangerous storms on surface (e.g. blizzards, wind- or sandstorms). Robots also add to other benefits associated with mechanisation and automation, reducing risks and errors associated with human nature.

Robotic exoskeletons may bring a new meaning to human-machine interaction and open up major possibilities in human assistance from technology (particularly from robotic technologies). It may be foreseen that similar types of applications could become possible to aid people in a wide variety of tasks. This could limit injuries, reduce risks and greatly enhance the physical capabilities of the human body.

2.4.5. Autonomous and semi-autonomous vehicles

It has become possible to create cars, trucks, aircraft, and boats that are completely or partly autonomous. Applications already span wide, from drone aircraft on the battlefield to Google's self-driving car. The underlying technologies responsible for autonomous vehicles are machine vision, artificial intelligence, advanced sensors, and actuators. These component technologies are fast improving and the result is that combination systems (such as autonomous driving) are also improving at a fast rate. Over the coming decade, low-cost, commercially available drones and submersibles could be used for a range of applications (e.g. performing deliveries and doing underwater exploration). Autonomous cars (such as in Figure 2.4.5) and trucks could enable a revolution in ground transportation, provided that the regulations and public acceptance would be permitting. Short of that, there is also substantial value in systems and technologies that assist drivers in steering, braking, and collision avoidance. The potential benefits of autonomous cars and trucks include increased safety, reduced CO_2 emissions, more leisure or work time for motorists, and increased productivity in the trucking industry (McKinsey Global Institute, 2013).

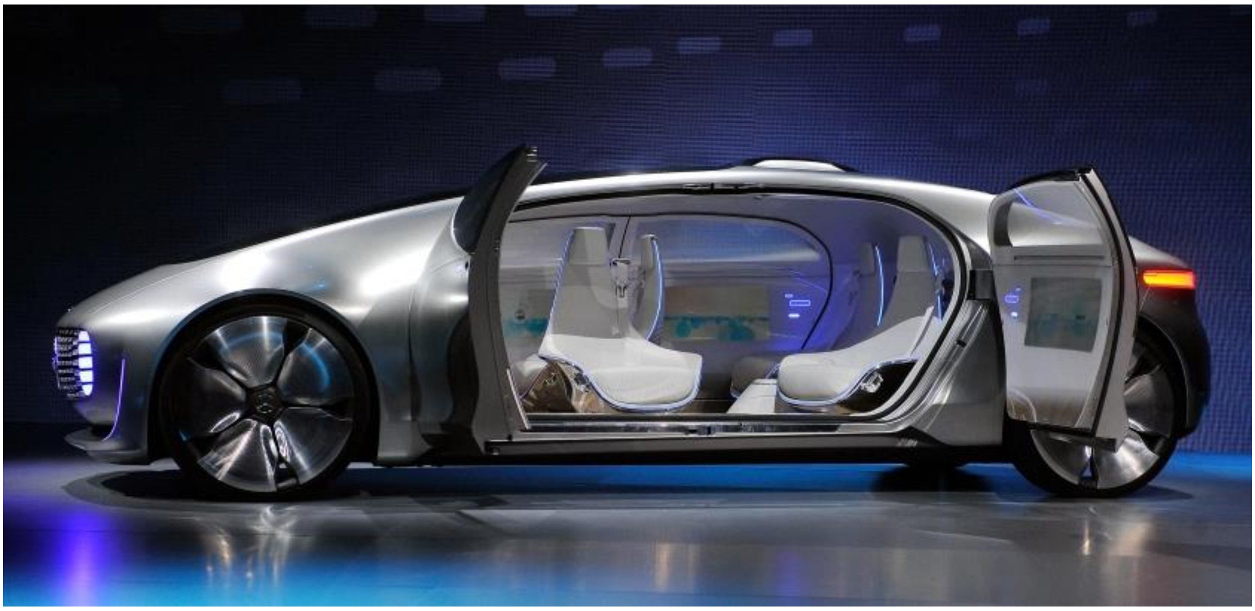


Figure 2.4.5: Autonomous Vehicle Prototype (VanderMey, 2015)

A few companies (such as Otto, Peloton and Daimler Trucks North America) have been making great progress towards putting autonomous trucks on the long-haul freeway in the US. The engineers on the project believe that automating trucks, instead of passenger vehicles, would be more achievable in the short run in terms of financial and regulatory challenges. This could have major implications for the commercial trucking industry and revolutionise the way long distance transportation takes place on land. It could also improve on road safety, provided the underlying technologies perform according to requirements (Markoff, 2016a).

When looking at self-driving cars, it is not just Google (or some of its former employees as with Otto), that are implementing and advancing self-driving technologies. Many vehicles manufacturers, from Tesla to Audi, are testing and implementing these technologies, which clearly indicates a major push towards obtaining these features and bringing autonomous vehicles and equipment closer to fruition (Larsen, 2014).

Significance of the study

Autonomous and semi-autonomous vehicles would expand over the next few years in applications and in variety of different vehicles and equipment. This technology (as a system of a multitude of sub-technologies) could enable a reduction in human error, risks associated with fatigue, more efficient use of energy when driving, near perfect time and activity management, and reduced wear and tear as a result of ineffective operating. The case study on Riot Tinto also demonstrates successful implementation of autonomous mining equipment. A wider range of autonomous machinery may further become possible within the near future, ranging from drilling, loading and hauling to autonomous graders and mobile pumping stations.

2.4.6. Computer Processing - Neuromorphic Chips

Neuromorphic chips attempt to model the parallel way the brain processes information as billions of neurons and trillions of synapses respond to sensory inputs, such as visual and auditory stimuli. Those neurons also change how they connect with each other in response to changing sensory inputs. This is the process we call “learning”. Neuromorphic chips do the same, as they are modelled on the biological brain and incorporate brain-inspired models called neural networks (Hof, 2014).

These chips will be designed to process sensory data and to respond to changes in that data in ways that were not specifically pre-programmed. This holds the potential to accelerate progress in artificial intelligence and advanced robotics, and lead to machines that are able to understand and interact with the world in humanlike ways. For example, medical sensors and devices could track individuals' vital signs and response to treatments over time, learning to adjust dosages or even catch problems early. Your smartphone could learn to anticipate what you want next, such as background on someone you're about to meet or an alert that it's time to leave for your next meeting (Hof, 2014).

In 2011 the DARPA-sponsored Synapse program developed a neuromorphic, or cognitive computing, chip that replicates some neural processes with 262,000 programmable synapses. In 2014, IBM announced the True North architecture for neuromorphic computing and a chip that has 256 million configurable synapses and uses less power than a hearing aid. These chips could eventually outperform today's supercomputers. This represents a dramatic increase in the processing power of a low-power chip and a significant shift in the architecture that can support artificial intelligence (Dupress, 2015a).

Significance of the study
Although this technology cannot be slotted into the technology map, it is important to remain aware of advances within the field if an organisation wishes to monitor advances in advanced robotics and artificial intelligence. Both technologies may be greatly impacted by advances in neuromorphic chips, as it forms the foundation for creating "intelligent machines".

2.4.7. Cooling Technologies

The following cooling technologies form part of emerging technologies identified by McKinsey (2015c) with the potential to transform the way an industry uses energy. The three technologies were categories under "advanced industries" but they may hold potential to be modified and applied to the mining environment for cooling purposes. These technologies include:

- Immersion-cooling technology
    - Immersion-cooling platforms employ a method in which equipment is submerged in a container filled with a thermally conductive but inert liquid. This technology could reduce energy consumption by up to 75% for environment control (e.g. equipment in data centres which are generally cooled through climate-control). Environment control typically accounts for half the energy needs of a data centre, making this a substantial saving.
- Liquid-desiccant systems
    - Liquid desiccant is a salt-water solution that removes humidity without the energy-intensive cycle of cooling, followed by heating.
- Pressurised-plenum-recirculation-air system
    - In clean-room environments these is a definite pressure drop between supply- and return-air paths. This air ventilation system maintains a higher pressure inside the chamber compared to outside, which then reduces the need to use fans to drive air flow. Compared to traditional technologies, pressurised plenum is able to achieve the lowest pressure drop, resulting in significant energy savings.

Significance of the study
With increased digitisation, automation, remote operating centres and more, also comes increased requirements for data centres. Immersion-cooling can assist to reduce the growing energy demand disproportionately to the growing capacity demand.

Further analysis on the last two technologies would be required to determine suitability to the mining environment. They are however most likely to assist in clean-air environments, making their potential use in underground environments difficult to determine. The increase in mechanisation, robotic and remote mining, and automation will however lead to changes in ventilation and cooling requirements for underground working areas.

As a result the focus may eventually shift more to clean-air and climate-controlled environments where people perform their tasks and interact with technology and machinery. In this context, these technologies may bring benefits.

2.4.8. Energy

Energy Supply and Demand Forecasts

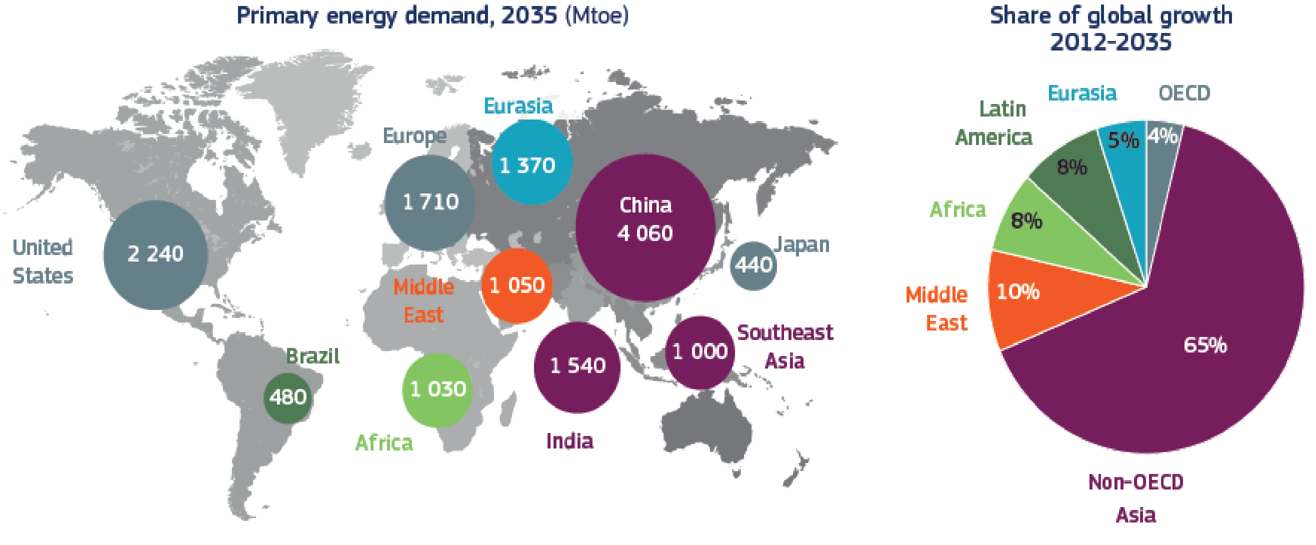
While McKinsey forecasts drastic reductions in energy costs relating to increased oil and gas extraction in the US, Deloitte notions that, although the current lower cost for oil is reducing energy expenses, the trend is not likely to last. This is partly why many forward-thinking companies continue to make strides towards the adoption of renewable energy alternatives, since future predictions are often difficult, inaccurate and also subject to numerous variables.

Global energy demand is however set to increase until 2030. The contribution from non-renewable energy sources is also estimated to decrease within the total supply for power generation. As a result, alternative power sources are expanding to bridge the gap between coal supply and energy demand (DDTL, 2016 & ESPAS, 2015). Currently renewables amount to around 3% of the global energy mix, but it is set to increase to an estimated 8% by 2035. The contribution to actual power generation is also set to increase from 21% in 2012 to 33% in 2040 (DDTL, 2016). In the next 25 years, renewables will account for an estimated 43% of Africa's new power plants, 48% of that of Asia, and 63% of that of Latin America. Asia alone is projected to add 1,587 renewable-power plants, almost as many as the rest of the world combined (McKinsey, 2016b). Consequently, Deloitte marks renewable energy generation technologies as a potential exponential technology (DDTL, 2016).

China for example is investing billions of yuan to fund clean energy production, both in developing domestic gas supply (including shale) and in signing contracts with global LNG (Liquid Natural Gas) suppliers. China further plans to increase installed capacity of wind power from 96GW to 200GW, and of solar power from 28GW to roughly 100GW. It also plans to use natural gas for more than 10% of its primary energy consumption by 2020. China is not alone in this drive. In 2014, new installations of renewable power plants surpassed 100,000 megawatts of capacity (DDTL, 2016).

The effects of the present rising energy consumption will be lasting and may even become a major problem in the more distant future. The increase in global energy consumption will be linked mainly to population growth and rising incomes. By 2030, an estimated 93% of the rise in consumption will come from non-OECD countries. Energy savings and the development of renewables will not be enough to limit the growth of CO_2 emissions by 2030–2040 (ESPAS, 2015).

World energy consumption is predicted to be about 30% higher in 2030 than in 2010 (See Figure 2.4.8a for an estimated future global energy demand). The proportion accounted for by fossil fuels is projected to remain roughly constant. Natural gas will play a bigger role in many countries, replacing coal in electricity production, and possibly oil for some forms of transport. Nuclear and renewables are expected to account for 24% of energy production and 40% of the growth in energy demand by 2035. (ESPAS, 2015).



Source: International Energy Agency, world energy outlook 2013

Figure 2.4.8a: Global Energy Demand, 2035 (consumption estimates in MTOE) (ESPAS, 2015)

Energy Efficiency and Renewable Energy

Renewable energy sources, such as solar, wind, hydro-electric, and ocean waves, hold the promise of an endless source of power. This can also be obtained in manners that do not reduce depletable resources, contribute to climate change, or that can be affected by competition for fossil fuels. Solar cell technology is especially progressing at a rapid rate. In the past two decades, the cost of power produced by solar cells has dropped from nearly $8 per watt of capacity to one-tenth of that amount. Meanwhile, wind power constitutes a fast growing proportion of renewable electricity generation. The result is that renewable energy sources such as solar and wind are increasingly being adopted at scale in advanced economies, like the United States and the European Union. Even more importantly, China, India, and other emerging economies have aggressive plans for solar and wind adoption that could enable further rapid economic growth while mitigating growing concerns about pollution (McKinsey Global Institute, 2013). It then makes sense for major enterprises that are heavily reliant on energy consumption to also critically evaluate these technologies.

Many companies already employ solar, wind, hydro and biomass power generation technologies. These are often supplemented by variable-speed backup generators capable of maximising fuel efficiency, which is a solution that also works for companies that run power off the grid (DTTL, 2016). Companies further along the maturity curve are also looking at changing work processes to align with energy availability and consumption. Cronimet Chrome Mining SA (Pty) Ltd is piloting this type of system in South Africa with the commissioning of the world's largest solar PV-diesel hybrid power system (Cronimet, 2015). The company aims to run more energy-intensive activities (such as processing) during daytime since it comes at a cheaper electricity rate, whilst running other less energy-intensive activities at night when costs are higher (DDTL, 2016).

When focussing in on mining operations, the general energy inefficiencies are staggering. In the case of diesel power (which typically accounts for close to half of surface mining energy consumption), 30-40% of actual energy is converted to a productive output. This means that when accounting for mechanical losses and friction, only about 12% of the energy is actually being converted to measurable work (moving the machine and load). In reality, it is estimated that only 3% is actually used for haulage. This is based on simple calculation of the vehicle and payload weights and the time spent hauling rock (Bryant, 2015). Table 3 is an example that compares the typical energy consumption at a mining company to the actual productive output.

Table 2.4.8: Sample of Mine Energy Consumption (Bryant, 2015)

Activity	Energy Source	Energy	Work Done	Valuable Work Done
Drilling and blasting	63,000 TANFO	101 TJ	20 %	20 %
Mining	11,000 MWh	40 TJ	40 %	5 %
Haulage	79 Mi Diesel	2 844 TJ	12 %	3 %
Processing and handling	313,000 MWh	1 127 TJ	15 %	10 %
Rail	115 Mi Diesel	4 140 TJ	12 %	5 %
Ports	244,000 MWh	878 TJ	20 %	2 %
Infrastructure	172,000 MWh	619 TJ	N/A	0 %
Transportation losses	50,000 MWh	180 TJ	N/A	0 %
Generation losses	1,485,000 MWh	5 346 TJ	N/A	0 %
Total		1 485 000 TJ		2.9 %

From the above example it is clear that energy inefficiency is a challenge currently faced by mining operations. While these inefficiencies persist, the energy costs in the mining sector also become more prohibitive with each passing year. These include rising costs for diesel fuel due to falling grades and longer hauling distances, building long-distance transmission lines to connect to local grids, transporting fuel to high-altitude sites and installing appropriate ventilation systems (Deloitte, 2015).

Energy already forms a sizable portion of operating costs, with McKinsey's analysis indicating a 25% share for mining (see Figure 2.4.8b). When considered as a portfolio that incorporates diesel, heavy fuel oil, grid electricity, gas, LNG and other sources, energy can represent around 30% of a mining company's total operating costs (DTTL, 2016). In some operations the use of energy can represent as much as 40-60% of a mine's operating costs. As energy costs rise, operating costs inevitably increase as well. With commodity prices in dire straits, these rising costs pose a threat to the sustainability of many operations. As a result, mining companies can no longer rely on incremental component-based performance improvements. Instead, they need to take a broader view of innovation and question underlying systemic decisions (Deloitte, 2014b). By tackling energy costs, true productivity can be achieved by finding ways to cut some of the industry's largest expenses (Deloitte, 2015). New technologies, greater reliance on renewable energy sources and electrification (moving away from diesel powered equipment) all play a role in helping to make this shift (Deloitte, 2015).

From an energy perspective, this means taking a more integrated approach to mine design and planning. The aim is to synchronise energy supply and demand from the outset. Companies should look at ways to automate mine processes at the design phase, in order to reduce reliance on fossil fuels. They must also gain a full understanding of local renewable energy capacity, from geothermal and hydroelectric to solar and wind. In addition to achieving cost savings, this approach can also help companies reduce carbon emissions (from diesel equipment), minimise the supply chain and logistical challenges associated with transporting fossil fuels to remote sites, and use automation to reduce labour costs and enhance on-site safety (Deloitte, 2014b). These and other kinds of operational improvements alone can reduce energy consumption by considerable amounts. McKinsey's research has shown mining operations that have achieved energy savings of between 3% and 15% of total energy costs with payback on investment in less than 3 years (McKinsey, 2015b). This integrated approach is a good example of leveraging the three technology categories to achieve substantial gains on various fronts.

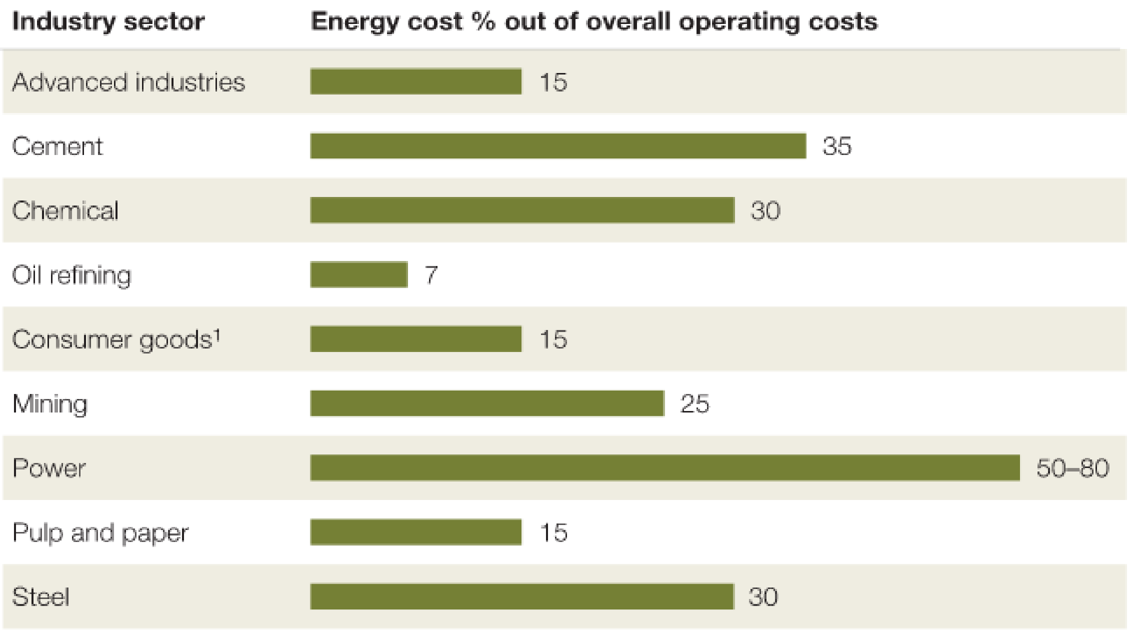


Figure 2.4.8b: Energy Cost as a Percentage of Operating Cost (McKinsey, 2015b)

On the cost front, the capital costs for renewables have dropped considerably in recent years, pushing many alternatives below the price of diesel. This is especially true for solar installations, whose costs have fallen by close to 50% over the past decade as shown in Figure 2.4.8c (Deloitte, 2015). The International Energy Agency even predicts that the sun could surpass fossil fuels to become the world's largest source of electricity by 2050 (VanderMey, 2015). Although renewable installations have higher up-front capital costs than diesel or gas plants, lower operating costs combined with the ability to lock in fixed energy prices significantly push down total project costs. This typically results in fuel savings of anywhere between 10% and 40% (Deloitte, 2015).

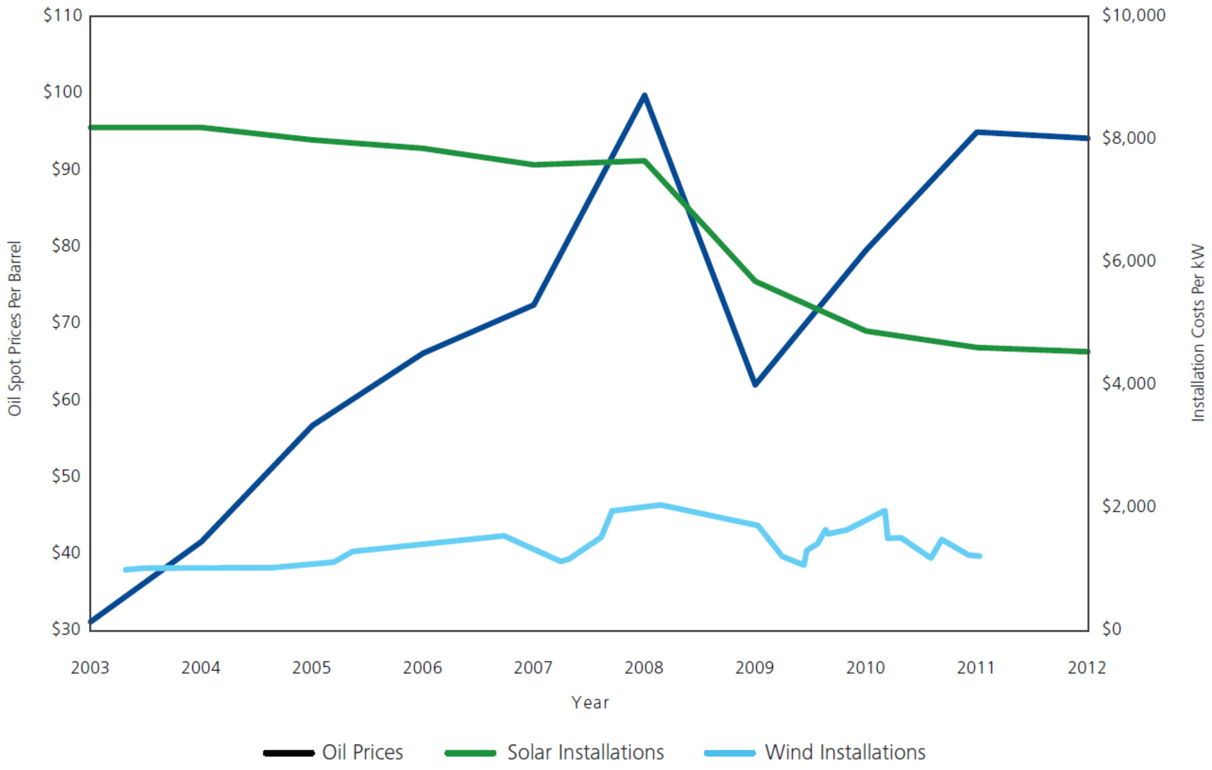


Figure 2.4.8c: Cost of solar and wind installations vs. oil prices, 2003 to 2012 (Deloitte, 2015)

Currently renewable energy technologies are experiencing an exponential decrease in their associated costs. Mining companies and individual operations need to continuously re-evaluate the feasibility of renewable installations and switching to electrical equipment. A feasibility study that was performed eighteen months ago may no longer be relevant in the present due to the fast declines in costs, as well as the negative impacts and challenges that come with using fossil fuels (Davidse, 2016).

Solar and wind energy are predicted to experience the most increased implementation while their costs will continue to decrease. By 2027 they are predicted to become cheaper than existing coal and gas plants in most countries worldwide. Solar energy costs for example have fallen by around 80% since 2008 and is estimated that it will fall another 60% by 2040. Wind energy on the other hand will also fall another 40%, mostly driven by improving capacity factors that will rise to 33 per cent in 2030 and 41 per cent in 2040. Wind energy is also predicted that it will account for more than 20% of all new additions to energy generation (Parkinson, 2016).

Although wind and solar installations may be the most familiar options, other renewable alternatives exist, such as hydroelectricity, biomass and geothermal energy. Companies looking for alternatives to traditional fossil fuels should consider their full range of options, along with the viability of hybrid systems (for example diesel linked to a renewable energy source). Some factors to consider include the availability of specific renewables and existing local systems (e.g. installed power lines), the amount of energy required, and times of operation compared to the energy costs for those time periods (Deloitte, 2015).

It should also be noted that the shale oil boom in the U.S. has spurred the use of biofuels and liquid natural gas (LNG) as more economic alternatives to diesel. Using LNG to fuel trucks, power shovels, haul fleets and other energy-intensive equipment can help reduce diesel consumption and result in a lower emissions profile (Deloitte, 2015). This also provides further alternatives for hybrid systems between LNG and electricity. Mining operations should explore new technology advances to reduce energy consumption and associated costs. One such a technology is using small-scale LNG facilities that make the fuel source more accessible, along with new engine technology that allows companies to substitute diesel for LNG on haul trucks. This is done by running dual fuel systems and solar technology (DTTL, 2016).

Various new technologies are also addressing concerns around power intermittency. Examples include innovations in battery technology that enable improved power storage. As well as data analytic solutions that are already being used successfully to achieve predictable power reliability. This is done by aiding companies in synchronising workflow to meet the availability of renewable energy and hybrid systems (Deloitte, 2015).

When considering various energy alternatives and evaluating technologies, the following list may be borne in mind from Deloitte (2015), which sets out a series of compelling and viable innovation strategies regarding energy generation and usage, verbatim:

- *"**Rethink energy management**: While renewable energy sources are intermittent in the aggregate, they offer predictable output in certain countries at certain times of the day or year. Chile and Australia, for instance, can produce roughly eight hours of highly predictable solar energy each day. By understanding the real-time local availability of alternative energy, companies can optimize their systems to operate during times of greatest energy availability, ultimately accessing reliable sources of renewable energy in real time, without resorting to storage.*
- ***Electrify processes**: Beyond renewables, miners should use electricity more strategically. For instance, using conveyors and similar electric technologies, rather than trucks, to move ore can reduce a company's energy requirement by more than 80%. Given the proportional cost of energy for most mine operations, this saving alone could reduce overall operational costs by at least 10%.*

- ***Automate****: As Rio Tinto has demonstrated in Western Australia, driverless trucks are already changing the cost equation in the mining industry. However, they are not the only examples of automated technologies that have reached viability. Adopting automated drills, automatic longwall shearers, autonomous trucks and trains and remote operating technologies will also prove efficient (Deloitte Touche Tohmatsu Limited, 2014). Companies engaging in altitude mining, for instance, also have innovative options. Simple gravity is now being harnessed to move ore and waste down a mountain (at no energy cost) while at the same time generating electricity to power other processes. Using conveyors and similar electric technologies, rather than trucks, to move ore can further also save on energy usage (Deloitte Touche Tohmatsu Limited, 2014).*
- ***Borrow best practices****: Adopting an innovation mindset and implementing a process to leverage it allows for new approaches to a wide range of traditional processes. For instance, miners have long relied on costly and sometimes inefficient surveys and drilling to unearth new mineral deposits. However, by borrowing techniques like simulation, technical modelling and 3D and 4D seismology from the oil and gas industry, miners can identify mineral-rich deposits more economically. Leading companies already use techniques like remote sensing to localize ore deposits, which can alter the industry's ability to find deeper, more fragmented deposits.*
- ***Build shared infrastructure****: Mining companies face input challenges beyond energy availability. Water, for instance, threatens to become scarcer in numerous regions; yet, despite this trend, many organizations continue to compete for the same scarce resources. To access local water sources, many companies build their own pipelines. By collaborating to achieve economies of scale (e.g. by building shared pipelines, water plants, power plants, etc.), companies can reduce costs while strengthening community relations in the process."*

Some of the abovementioned and other emerging energy technologies will now be discussed, for both energy generation and storage.

Emerging Energy Technologies

It was already identified that renewable energy technologies advance at a rapid rate and experience a strong decline in costs. As a result they are on a curve that makes individual technology analysis difficult. These technologies, perhaps even more than digital technologies at this point in time, should be re-assessed with regular intervals in order to re-evaluate applicability. It was then decided to include energy technologies that have recently experienced rapid developments in their progress, although they in themselves have been around for a long time.

Fusion Energy Generation

ESPAS (2015) predicts a dramatic positive technological shift by 2030. "*Unexpected progress has recently been made in useable plasma confinement under the ITER international fusion project*" (ITER is the world's greatest energy project and it focuses on using fusion for energy generation). This could have a significant impact on fusion energy generation in the next estimated 2 to 3 decades (ESPAS, 2015). Plasma consists of charged particles (positive nuclei/ions and negative electrons), or an electrically-charged gas, that can be shaped and confined by magnetic forces. This is shown in Figure 2.4.8d, where the plasma particles are confined and shaped by magnetic field lines that combine to act like an invisible bottle (ITER, date unknown). A ten years' testing program is due to come into service in 2025, up to 2035. Such a technological breakthrough could rapidly change the global energy landscape, and in the longer run slow down and even halt global warming attributable to 'traditional' energy consumption (ESPAS, 2015).

Figure 2.4.8d: The spherical tokamak MAST at the Culham Centre for Fusion Energy (UK) (ITER, date unknown)

Significance of the study

Although this technology will only have impact after many years of further development, it holds the potential to greatly affect electricity supply from governments to businesses. Mining operations often have a Life of Mine of decades, after having taken years to analyse the feasibility, design and develop the mine. In this context it makes sense that any technology that may impact the operation in some point of its lifetime should be investigated, particularly if it could drastically affect operating costs and production strategies.

Fuel Cell Technology

Fuel cells convert chemical energy from hydrogen-rich fuels into electrical power and usable high quality heat in an electrochemical process. This process is clean and efficient and virtually absent of pollutants. Similar to a battery, a fuel cell is comprised of many individual cells that are grouped together to form a fuel cell stack. Each individual cell contains an anode, a cathode and an electrolyte layer. When a hydrogen-rich fuel such as clean natural gas or renewable biogas enters the fuel cell stack, it reacts electrochemically with oxygen (i.e. ambient air) to produce electric current, heat and water. While a typical battery has a fixed supply of energy, fuel cells continuously generate electricity as long as fuel is supplied. Because there is no combusting of fuel, virtually no harmful emissions are generated by the fuel cells (Fuelcellenergy, 2013)

Factors that affect the overall effectiveness of hydrogen fuel cell technology include: reducing the cost and increasing the efficiency to produce hydrogen; improving the safety and method for high-density storage of hydrogen (particularly in automobiles); building sufficient infrastructure for hydrogen distribution; improving the capacity of the fuel-cell systems themselves to become more durable, efficient and inexpensive. Over the past few years, all four of these factors have seen notable advances (foreignaffairs, 2016).

Advances in using Platinum catalysts for fuel cell energy generation will further spur increased R&D in the field with great potential for clean, off-grid energy generation. This may hold particular value for mining operations that do not wish to be dependent on grid electricity, especially in under-developed countries struggling to cope with the high energy demand of mining operations (Du Plessis, 2016).

Significance of the study

Fuel cell technology was chosen as a potential technology that may benefit mining due to mining's energy intensive nature, in remote locations, with increasing restrictions on emissions, while often being dependent on unreliable grid electricity. In the South African context in particular, with its high Platinum resources, this technology may see a stronger drive in R&D.

Lithium-ion Battery Storage

Energy storage technologies include batteries and other systems that store energy for later use. Lithium-ion (Li-ion) batteries and fuel cells are already powering electric and hybrid vehicles, along with billions of portable consumer electronics devices. Li-ion batteries in particular have seen consistent increases in performance and reductions in price, with cost per unit of storage capacity declining considerably over the past decade (McKinsey Global Institute, 2013).

Over the next decade, advances in energy storage technology could make electric vehicles (hybrids, plug-in hybrids, and all-electrics) cost competitive with vehicles based on internal-combustion engines. On the power grid, advanced battery storage systems can help with the integration of solar and wind power, improve quality of delivery by controlling frequency variations and handle peak loads. It could also reduce costs by enabling utilities to postpone infrastructure expansion. In developing economies, battery/solar systems have the potential to bring reliable power to places previously unreached (McKinsey Global Institute, 2013).

The McKinsey Global Institute predicts that the price of lithium-ion battery packs could fall by a third up until 2025. This will have a large impact on electric cars and also on renewable energy storage. Impacts from such price drops would be felt on transportation, power generation, and the oil and gas industries as batteries become both cheaper and more efficient (VanderMey, 2015).

Figure 2.4.8e: Lithium-ion battery (VanderMey, 2015)

Significance of the study

Advances in energy storage technologies may greatly benefit other technologies as well, from mobile smart devices and hand-held equipment, to larger equipment such as battery haulers. When electronic devices, machinery and equipment experience longer operating spans and a reduced need for recharging, then other potential production benefits can also be gained.

Gold Nanowire Battery Storage

Smartphones, tablets, and most other electronics rely on rechargeable batteries. After a few thousand uses, the batteries start to lose their ability to hold a charge. The batteries of today mainly consist of lithium and over time that lithium corrodes inside the battery (Gershgorn, 2016).

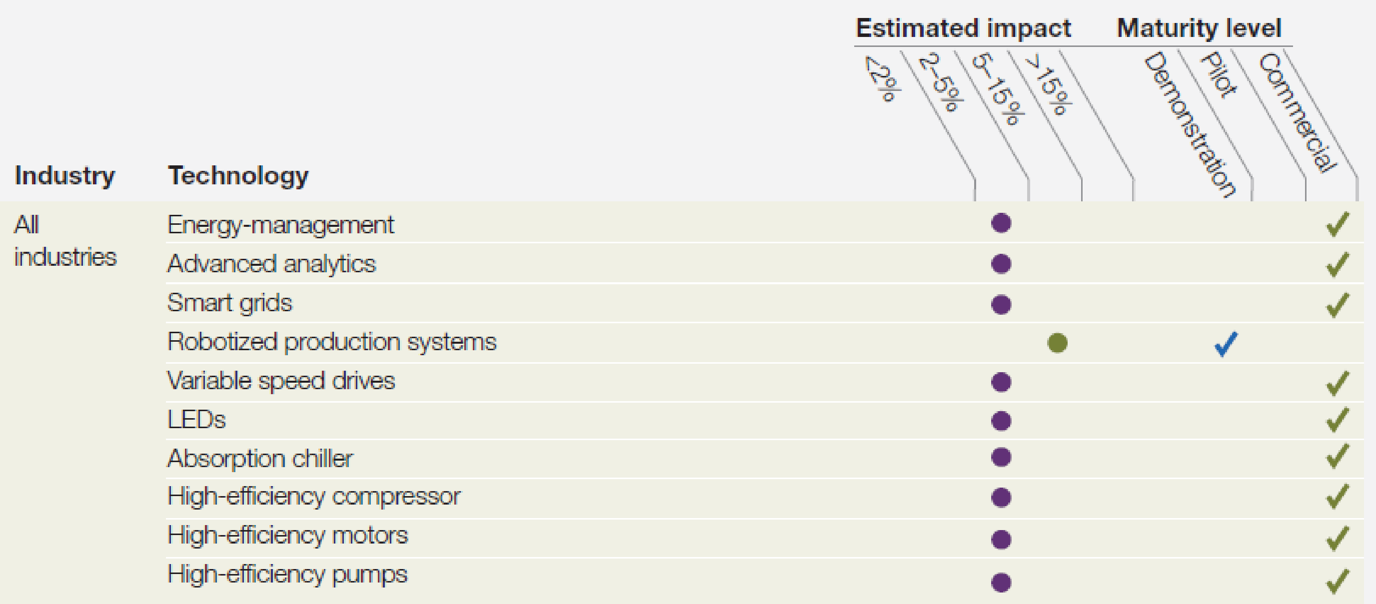
Researchers at the University of California (UC) have pursued using nanowires in batteries for years. The reason is that the filaments are highly conductive and have a large surface area for the storage and transfer of electrons. Nanowires are however highly fragile and don't hold up well to repeated discharging and recharging, known as "cycling." For example, in a typical lithium-ion battery, they expand and grow brittle, which leads to cracking. A Doctoral candidate at UC, Mya Le Thai, solved the brittleness challenge by coating a gold nanowire in a manganese dioxide shell and encasing the assembly in an electrolyte made of a Plexiglas-like gel. The combination is said to be reliable and resistant to failure. It is believed that the gel 'plasticises' the metal oxide in the battery and gives it flexibility, which prevents cracking (Mearian, 2016).

This technology promises consumer electronics that last 400 times longer. However, this initial test platform isn't a true battery as of yet. The lab's future work will entail building batteries with this technology, and further investigating why the process works. (Gershgorn, 2016).

Significance of the study
Although this technology requires a lot of development before it will become commercially available, it challenges the status quo on what use to be the norm for how batteries behaved. The effects of successful implementation will be drastic on electronics and will greatly aid all digital efforts.

Technologies that Enhances Energy Efficiency and/or Reduces Consumption

Various emerging technologies could assist with reducing energy consumption through different means of optimisation. These technologies need to be considered as an integrated whole in an organisation's energy strategy. As stated in Section 1.3.2, companies should consider Mining Technologies, Information Technologies (extending to all Digital Technologies) and Energy Technologies with cross integration in mind. Leveraging all three categories can lead to major operational breakthroughs on multiple fronts. Figure 2.4.8f displays some of these technologies with the highest potential, along with estimated impact on energy consumption and the maturity level of the technology.



		Estimated impact				Maturity level		
Industry	Technology	<2%	2–5%	5–15%	>15%	Demonstration	Pilot	Commercial
All industries	Energy-management		●					✓
	Advanced analytics		●					✓
	Smart grids		●					✓
	Robotized production systems			●		✓		
	Variable speed drives		●					✓
	LEDs		●					✓
	Absorption chiller		●					✓
	High-efficiency compressor		●					✓
	High-efficiency motors		●					✓
	High-efficiency pumps		●					✓

Figure 2.4.8f: Technologies with Potential to Reduce Energy Consumption across All Industries (McKinsey, 2015c)

The technology innovations with sufficient analysis, as provided by McKinsey (2015c) to determine their potential to enhance energy strategies, will now be investigated.

Energy-Management System (EMS)

EMS includes monitoring (e.g. of ambient climate, equipment status, and energy consumption rate), demand limiting (e.g. load scheduling, duty cycling), maintenance, and record generation (including operational logs and utility-demand profiles). From these data inputs, along with benchmarking data and other metrics, the EMS can define the most important parameters and scrutinise major consumer items to find significant saving opportunities (McKinsey, 2016c).

EMS is another step towards digitisation (i.e. increased digital integration) and can be coupled with various ITs. Examples may include Visualisation, access to EMS on mobile devices for ease of tracking, and other computerised tools to monitor, measure and control aspects such as for example, plant performance. In this way EMS can provide the means to control and improve on energy usage. It further also forms the basis for advanced analytics and digitisation using smart grids (McKinsey, 2016c).

Advanced Analytics

Advanced analytics are discussed in greater detail in the section on Digital Technologies. In short, it is a digital technology that assists in converting data to insights by using specialised tools such as neural-network techniques, Monte Carlo simulation, queuing and shift optima. Through the effective use of advanced analytics improvement opportunities can be identified to optimise various aspects of an operation, one of which may include energy consuming activities and machinery (McKinsey, 2015c).

Smart Grids

The term ‘smart grids’ broadly refers to the hardware and software that support advanced metering, demand response, improved distribution, and the integration of renewable energy sources and other forms of distributed energy. While smart grids in themselves do not enhance efficiencies in energy use, they offer benefits through their constituent components to do so. An example is smart metering, which provides real-time information on energy demand, supply, and grid operations to various points of consumption. These insights can then be used to improve grid operations and efficiency. By helping organisations understand how they use energy it also encourages them to be more efficient (McKinsey, 2015c).

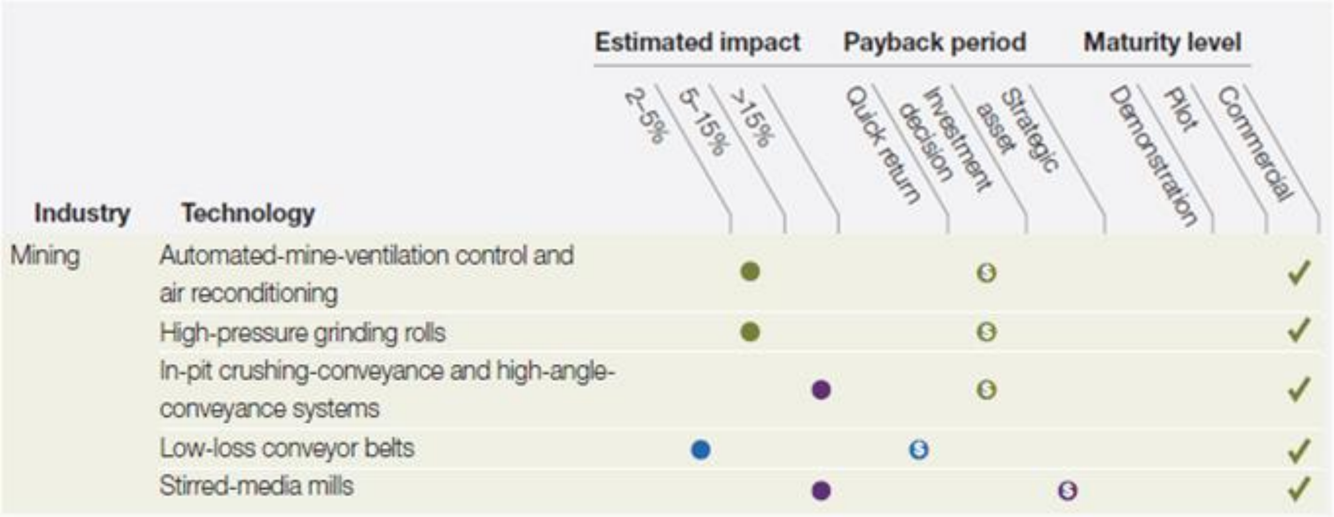
Mining technologies that Reduce Energy Consumption

Various technology innovations can also be applied to the mining process to reduce energy consumption. McKinsey identified those technologies that have emerged with some of the biggest impact on operations from a global perspective. These include (McKinsey, 2015c):

- Automated-mine-ventilation control and air reconditioning;
    - This system deploys an energy management system that is customised for mine ventilation. Sub-components include sensors, monitors and remote controls. When considering that ventilation can sometimes account for up to half of the total power requirements of a mine (and as much as 30% of operating costs) it is crucial to enhance the efficiency at which energy is used. Automated systems operate ventilation according to production requirements and area specific needs instead of manual control or continuous ventilation supply.
- High-pressure grinding rolls;
    - Ore particles are placed between two rolls and they are fragmented as pressure is applied on the material bed by springs or hydraulic cylinders. Considering that comminution (or grinding) is the most energy-intensive activity in ore processing, it is clear that efficiency enhancing technologies

  - may greatly benefit an operation. High-pressure grinding rolls rank as more energy efficient as compared to semi-autogeneous (SAG) or ball mills alternatives.
- In-pit crushing-conveyance and high-angle conveyance systems;
  - In-pit crushing involves processing/fragmenting ore using portable crushers. High angle conveyance systems then transport the ore and waste out of the pit. The main benefit is energy savings compared to using a fleet of trucks with high diesel consumption (this also reduces emissions).
- Low-loss conveyor belts;
  - Low-loss conveyor belts use advanced compounds and fibres to reduce the resistance between the belt and the drives. For example, aramid fibres are as strong as steel, but five times lighter, which reduces resistance significantly. The reason for this stems from the fact that rolling resistance (in this definition being the process in which the rubber passes through the support rollers and deforms) accounts for a large share of energy consumption in conveyor operation. Low-loss rubber and fibres reduce this resistance and the result is a reduction in energy consumption as well.
- Stirred-media mills.
  - Instead of using an outer rotating shell, stirred-media mills impart motion to the feed by moving an internal stirrer. A medium (often water) can also be used to distribute the particles across the mill surface in order to optimise efficiency. This way stirred-media mills enhances the efficiency of grinding, which is a process that continuously consumes more power due to declining grades of ore.

These technologies are also already commercially available. Their estimated impact (in %) is shown in Figure 2.4.8g along with an estimated payback period on investment. "Quick return" is defined as those that pay back costs in two to three years. "Investment decisions" are those that need special management consideration because the payback is three to five years. "Strategic assets" refer to technologies that pay for themselves over their lifetime. Of course, the numbers will not be identical for all companies and operations. These estimates do however provide a sense of direction and scale (McKinsey, 2015c).



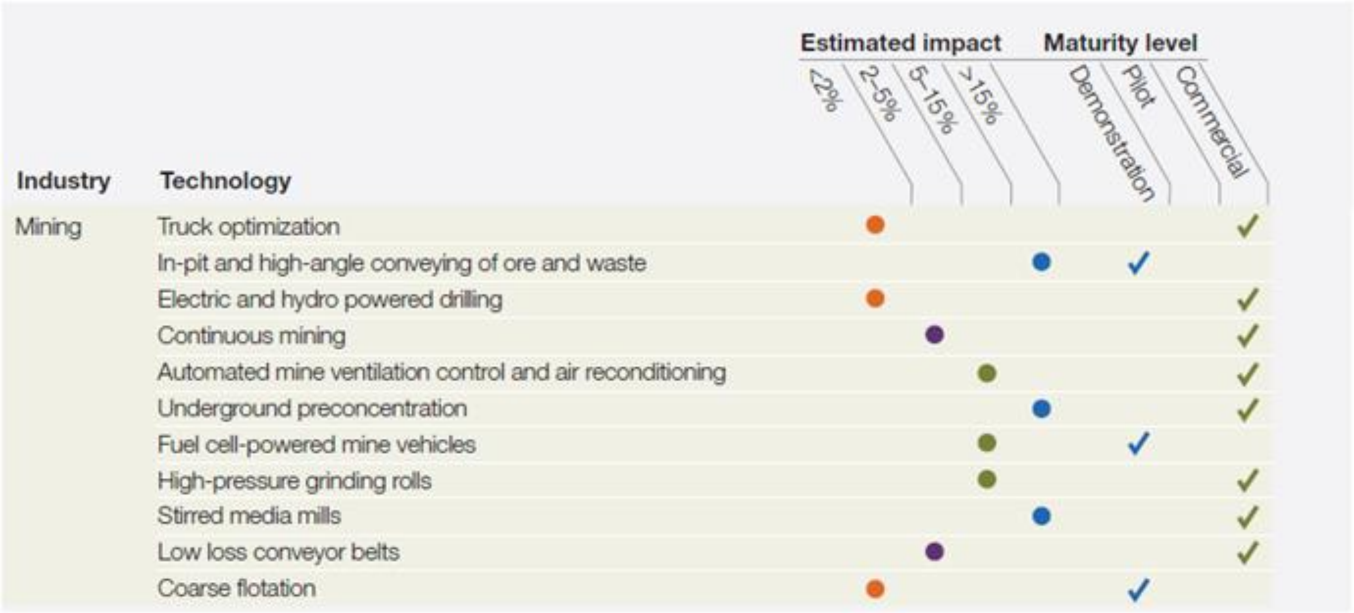
		Estimated impact			Payback period			Maturity level		
Industry	Technology	2–5%	5–15%	>15%	Quick return	Investment decision	Strategic asset	Demonstration	Pilot	Commercial
Mining	Automated-mine-ventilation control and air reconditioning		●			$				✓
	High-pressure grinding rolls		●			$				✓
	In-pit crushing-conveyance and high-angle-conveyance systems			●		$				✓
	Low-loss conveyor belts	●			$					✓
	Stirred-media mills			●			$			✓

Figure 2.4.8g: Technologies that promise significant Energy Savings (McKinsey, 2015c)

Other technologies and/or technology strategies that were identified to hold similar potential, but that require more detailed analysis or which are not commercially available in a sufficiently mature state, include (McKinsey, 2015c):

- Truck optimization;
- Electro and hydro powered drilling;
- Continuous mining;
- Underground pre-concentration;
- Fuel cell-powered mine vehicles;
- Coarse flotation.

Figure 2.4.8h shows more details on these technologies, in a similar fashion as Figure 2.4.8g.



		Estimated impact				Maturity level		
Industry	Technology	≤2%	2–5%	5–15%	>15%	Demonstration	Pilot	Commercial
Mining	Truck optimization	●						✓
	In-pit and high-angle conveying of ore and waste				●	✓		
	Electric and hydro powered drilling	●						✓
	Continuous mining		●					✓
	Automated mine ventilation control and air reconditioning			●				✓
	Underground preconcentration				●			✓
	Fuel cell-powered mine vehicles			●		✓		
	High-pressure grinding rolls			●				✓
	Stirred media mills				●			✓
	Low loss conveyor belts		●					✓
	Coarse flotation	●				✓		

Figure 2.4.8h: Technologies with Potential for Energy Savings (McKinsey, 2015c)

Significance of the study

The technologies and systems discussed may hold value to improve energy efficiency of reduce cost through various means. In order to amplify their benefits, they should be pursued in parallel instead of as individual implementations, while attempting cross-integration with various other technologies across the value chain.

2.4.9. Genomics

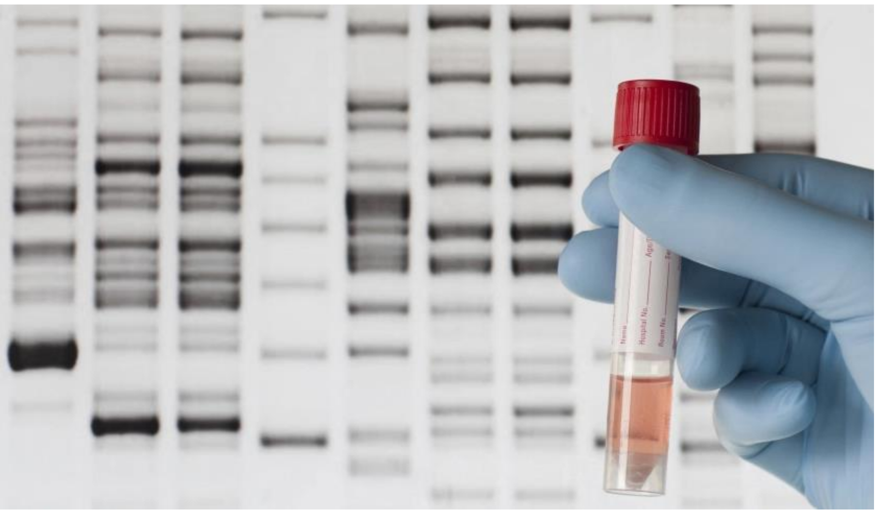


Figure 2.4.9: Genomics testing sample (VanderMey, 2015)

Next-generation genomics combines advances in the science of sequencing and modifying genetic material with the latest big data analytics capabilities (McKinsey Global Institute, 2013). In short, genomics combines biology, genetics and computer science (GenomeCanada, 2016a). Today, a human genome can be sequenced in a few hours and for a few thousand dollars, a task that took 13 years and $2.7 billion to accomplish during the Human Genome Project. With rapid sequencing and advanced computing power, scientists can systematically test how genetic variations can bring about specific traits and diseases, instead of using trial and error. Relatively low-cost desktop sequencing machines could be used in routine diagnostics, potentially significantly improving treatments by matching treatments to patients. The next step in progress is synthetic biology, which is the ability to precisely customise organisms by "writing" DNA. These advances in the power and availability of genetic science could have profound impact on medicine, agriculture, and the production of high-value substances (such as biofuels). It could also help speed up the process of drug discovery (McKinsey Global Institute, 2013).

As super computers make the genetic analysis process much simpler, the McKinsey Global Institute predicts a world in which genomic-based diagnoses and treatments will extend patients' lives by between six months and two years in 2025. Sequencing systems could eventually become so commonplace that doctors will have them on their desktops (VanderMey, 2015). This will revolutionise many aspects of the medical field.

Beyond the focus of DNA manipulation and medical applications, genomics can control how various things function at the molecular level. As such, it has become possible to manipulate a wide range of areas. Some examples include (GenomeAtlantic, 2015a):

- Increased production of plants and animals with fewer inputs;
- Reduced damage from pests and diseases;
- Improved ability to extract valuable elements from the earth and ocean without disrupting the fragile ecological balance;
- Better ability to provide the right treatment at the right time to the right patient;

In the Canadian energy sector, energy companies experience growing environmental and cost pressures associated with resource development and industry processes. This compels them to adopt sustainable technologies with socially acceptable operations. The sector can be advanced by integrating new genomics-based technologies into existing processes, such as the water-intensive extraction of bitumen from oil sands. This extraction is straining water and energy resources and generating considerable waste for storage in tailings ponds. Genomic knowledge of the microbial processes involved in both hydrocarbon extraction and waste remediation is helping to improve the management of water use, recycling and treatment in the energy industry (GenomeCanada, 2016b).

In the energy and mining sectors, the microbial communities (microbes) can also be manipulated through genomics. These microbial communities are involved in a number of processes, including microbially influenced corrosion (MIC), resource extraction and tailings ponds (GenomeAtlantic, 2016b). Further genomics research is also underway in Canada with the aim of improving industrial mineral extraction and processing, mitigating environmental risk, and providing tools for more effective remediation of mining tailings. Genomic tools are already providing new strategies to help manage and clean up contaminants, and to control acid mine drainage and the unwanted leaching of metals (GenomeCanada, 2016a).

Some of the research within this field has already spawned unanticipated genomic mining solutions. Examples include the use of bacteria capable of extracting minerals in situ, and bio-remediation processes that use natural enzymes to clean sites contaminated by metal leaching and drainage. Whilst still relatively new, genomics solutions have already been used to bio-remediate polluted soils, improve mine drainage and mitigate threats to biological diversity through bio-monitoring (DTTL, 2016). The applications of, and opportunities for, genomics in the mining sector are just starting to be recognised as a tremendous growth area both for research and the industry. By understanding the way microbes function, bio-leaching can be enhanced and applied in more efficient manners. This can extend the value of metal recovery by as much as 50%. Overall, this technology can help improve productivity, cut costs and improve sustainability in the mining industry (GenomeCanada, 2016a).

The uses for genomic technology in the mining process can currently be summarised as follows (GenomeAtlantic, 2015a):

- **Provide enhanced recovery**: The successful application of microbial organisms can dramatically enhance the recovery of gold and copper in particular.
- **Addressing resource-intensive extraction**: Large amounts of water and energy are used for a range of extraction and processing activities in the energy and mining sectors. These include concentration of metals and minerals. Bio-recovery of metals can reduce the consumption of large volumes of water through irrigation-style bioleaching of heaped ore, or stirred tank bio-oxidation of crushed ore. Improved omics (term referring to genomics, proteomics, metabolomics etc.) knowledge could also help mining industries improve metal leaching rates and also the extent of mineral extraction. It could further help develop bacteria better suited to optimal leaching environments, e.g. withstanding agitation of stirred-tank treatments, higher processing temperatures, acidity, metal toxicity, etc.
- **Accelerating remediation**: Bio-remediation employs biological agents to treat contaminants, such as naphthenic acid from tailings ponds or heavy metals from effluents, to a suitable level for reuse, discharge or disposal. Phytoremediation utilises the most effective associations of plants with bacteria or fungi to decontaminate polluted sites. In the Netherlands a full-scale bioremediation plant exists to remove heavy metals from mining effluents.
- **Mitigating acid mine drainage (AMD)**: Remediation generally involves either treatment with a basic compound, or manipulating the oxidising bacteria. Bacterial AMD treatment can reduce the need for expensive chemical neutralisers.

- **Advancing bioleaching/bio-oxidation**: Particularly effective bacteria are used to leach valuable metals into solution for electroplate recovery (bioleaching), or to concentrate valuable solids through the leaching of low value impurities (bio-oxidation). These bio-hydrometallurgy processes play an increasingly important role for low-grade ore as high-grade reserves become depleted. Bioleaching currently produces almost a quarter of the world's copper, and bio-oxidation enables 20-fold concentration of gold prior to extraction. In the interest of advancing this field, bacteria that thrive in both high and low temperatures are being explored, with the aim of using them in diverse climate sites.
- **Regulatory restrictions**: Certain microorganisms can perform leaching activities similar to cyanide leaching, which is banned in many countries (e.g. Germany, Hungary and the Czech Republic).

When considering the rate of advance of genomic technology, coupled with the decrease in associated costs, mining companies would do well to pay attention to the advances in the technology. More applications for wider purposes may become possible in the near future. The availability and ease of use of the technology itself may also experience rapid advances, allowing wide scale adoption (Davidse, 2016).

Significance of this research

Further applications may include the planning phase, when permits need to be obtained mining companies may offer to assist local communicates through the use of genomics in agriculture or local health. Often operating mines are scourged by health issues related to mining (e.g. tuberculosis, silicosis etc.) which incur detrimental effects financially, to health and safety, to worker morale and further also spurs pressure from local regulating bodies. Mines could be held accountable for such illnesses during operation or even post mine closure. Applying genomics to the medical field, some of these illnesses could potentially be alleviated or even cured. Bioremediation can also assist in complying with mine closure requirements in environmental protection and remediation projects, as well as with environmental issues that emerge after successful mine closure.

When employees experience prolonged lifetimes (as with the rest of society), the impacts on retirement plans and length of credible working life should be analysed as well. This may further have an impact on emerging tele-work technology applications and remote operations serviced by a small number of highly skilled experts.

The implications on mineral processing, extraction rates and percentage recovery seem highly beneficial. AMD, cyanide leaching and other contaminants can also be bio-remedied with this technology.

2.4.10. Mechanised Mining Technologies: Hard rock mining

The South African mining industry holds considerable expertise in narrow reef, hard-rock mining along with a large portion of world resources in Platinum and Gold. Mining these resources has been at continuously increasing depths, which brings numerous challenges and associated risks. With the slump in commodity prices, coupled with rising costs, there is a necessity for research and development (R&D) to address some of the challenges that are faced (Chamber of Mines of South Africa, 2015).

The basic method that has been used since the early 1900s in South African mining (particularly in hard-rock mining) is conventional drilling and blasting. As shown in Figure 2.4.10a, this is a labour intensive process which is plagued by reduced available drilling time since the depth and distance to travel increases as mining progresses. Drilling and blasting enforces adherence to the blasting cycle (a forced exit and re-entry cycle due to toxic fumes and other hazards associated with explosives). This cycle causes inefficiencies, which is exacerbated with increases in depth and travel distances as well. Adding on to this, the mining circumstances at these depths, along with hard-rock geological characteristics, causes challenging operating environments and dangerous working conditions in many South African mines (Chamber of Mines of South Africa, 2015).

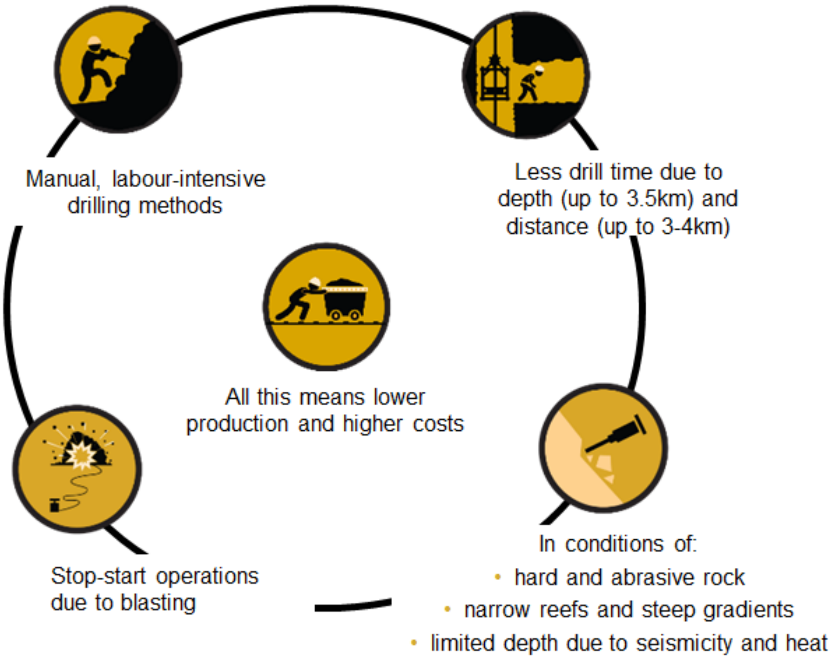


Figure 2.4.10a: Drilling and blasting has been the basic method used since the early 1900s (Chamber of Mines of South Africa, 2015)

When looking at the gold and platinum resources of South Africa in Figure 2.4.10b, mined and in-situ, it is clear that the country's mining industry still has a future. However, in order to exploit these resources for the economic benefit of the country, a very different approach to mining will be required (Chamber of Mines of South Africa, 2015).

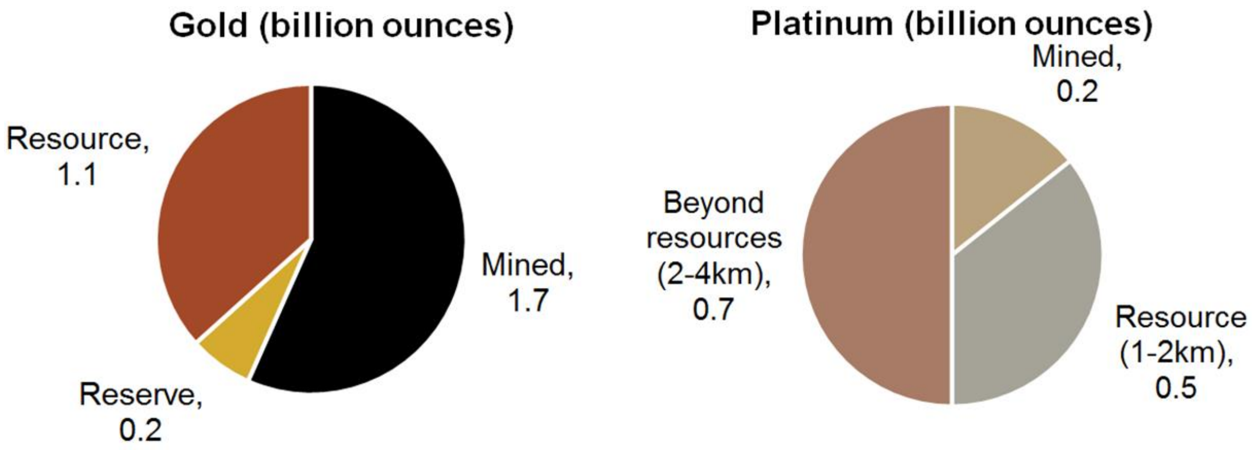


Figure 2.4.10b: South African Gold and Platinum Resources (billion ounces) (Chamber of Mines of South Africa, 2015)

The Chamber of Mines of South Africa (CMSA) has set goals, to reach an improved future for mining in the country in order to align itself with the aim of "Operation Phakisa". These goals aim to establish a future that allows safer (stive for zero harm) and more productive mining, in order to permit the profitable exploitation of South Africa's deep-level, complex ore bodies (Chamber of Mines of South Africa, 2015). Operation Phakisa in its own right is a drive from the South African government, which aspires to intervene in the short term to keep the mining industry afloat during the commodity price slump. In doing this it also aims to alleviate, as far as possible, the negative impacts of the slump. Operation Phakisa further strives to put in place initiatives to set the mining cluster on a firm foundation to grow, transform and contribute to the economic and social development of mining related communities and the country as a whole (Du Plessis, 2016).

More specific to the scope of this study is the focus of research and development areas, as highlighted by the CMSA for Operation Phakisa, which is to improve mechanisation in South African hard-rock mining. As such, R&D

in hard-rock, narrow reef, mechanised equipment and systems will aim to provide an alternative to conventional drilling and blasting. Through Operation Phakisa, the South African mining industry will strive to establish itself as a world leader in mechanised hard-rock mining equipment and systems. The objectives and timeline for the required R&D to lead to successful implementation is shown in Table 2.4.10a (Chamber of Mines of South Africa, 2015).

Table 2.4.10a: Next Generation Mining Roadmap as described by the Chamber of Mines of South Africa (2015)

Market Product Milestones	**Pre-2020, Optimised Conventional Mining**	**2020, Mechanised Mining**	**2025, 24/7 Mechanised mining**	**Beyond 2025, 24/7 Remote Mining**
Products	Load, Haul, and Dump trucks (LHDs). Development of drill rigs.	Multi-boom stope drill rigs. Remote stope cleaning machines. Longhole drill rigs. XLP/ULP units. Wide Raise rigs.	Continuous rock cutting machine. Development boring machine. Reef boring machine.	In-situ leaching methods.
Technologies	Information and Communication Technologies (ITC). Fuel cell power.	Modern support technologies. Fuel cell conversion. Advanced-geology technologies PDS and VDS systems	Rock disc cutting tools. Power systems.	Fracturing systems. Solution recovery and pumping. Underground precipitations and elution.
People	Artisan and supervisory training. R&D skill development.	Advanced operator and artisan skills.	Super operator skills development and training.	Geometallurgical engineering skills.
Infrastructure	ICT backbones	Continuous, integrated monitoring.	Teleremote control systems. Control centres.	Fully monitored, remote sensing systems. Autonomous control centres.

The R&D for mechanised mining systems and equipment (or other products) will focus on the Platinum and Gold commodities for customisation to commodity specific needs. The R&D focus areas for Table 2.4.10a above is expanded for Mechanised Mining in Table 2.4.10b, 24/7 Mechanised Mining in Table 2.4.10c, and 24/7 Remote Mining in Table 2.4.10d. Furthermore, Table 2.4.10e contains technologies for advanced ore-body knowledge in mechanised mining which forms part of R&D in sub-systems (Chamber of Mines of South Africa, 2015).

Table 2.4.10b: Mechanised Mining R&D (Chamber of Mines of South Africa, 2015)

Systems	Products & Technologies
Robotics: line of sight remote ops. Equipment monitoring. Environmental monitoring. Seismic monitoring.* Planning and control systems. Requisite mine designs. PDS and CAS systems. Reconciliation systems. Ventilation & refrigeration systems.* Ore-body knowledge systems.	Stope development & redevelopment rigs. Roof bolting systems. Remotely placed backfill.* Stope drill rigs. Dozers or other rock removal. Rock handling systems. Efficient remote tramming. Efficient people transport systems.
* is Gold commodity specific	

Table 2.4.10c: 24/7 Mechanised Mining R&D (Chamber of Mines of South Africa, 2015)

Systems	Products & Technologies
Robotics. Equipment monitoring & control. Seismic monitoring. Planning and control systems. Requisite mine designs. Reconciliation systems. Control room, tele-remote operation. Power systems.	Rock cutting tools. Rock cutting drive machine. Reef boring. Advanced preconditioning with impact ripping and rock splitting options. High performance, remotely placed backfill. Continuous rock removal systems. Hydraulic transport.

Table 2.4.10d: 24/7 Remote Mining R&D (Chamber of Mines of South Africa, 2015)

Systems	Technologies
Geophysical systems. Planning and design systems. R&D design.	"Fracking". Pre-fracturing. Remote development. Oil well technology application. In-situ leaching solutions.

Table 2.4.10e: Advanced ore-body knowledge for mechanised mining (Sub-system) (Chamber of Mines of South Africa, 2015)

Systems	Technologies
Modelling systems and interpretation. Planning systems. Mine design and layout for data collection and analysis. Systems integration. Reconciliation systems.	Ground penetrating radar. Sonar. Electromagnetics. Heat sensing. Vibroseismics. Drilling equipment. Down-the-hole measurement.

Various potential pilot projects for mechanisation technologies in narrow reef, hard-rock mining were identified by the Chamber of Mines of South Africa (2015). These are shown in Table 2.4.10g. The projects were ranked according to the Technology Readiness Level shown in Table 2.4.10f. The technological readiness of these potential pilot projects can be seen to range from concept designs to some that are already set for manufacturing of final designs.

Table 2.4.10f: Technology Readiness Scale (Chamber of Mines of South Africa, 2015)

Technology Readiness Level	1	2	3	4	5	6	7-8	9
Description	Basic research	Conceptual design	Proof of concept	Full design	Factory testing	Prototype	Production trial	Manufacturing

Table 2.4.10g: The Potential Pilot Projects For Hard-Rock Mechanised Mining R&D (Chamber of Mines of South Africa, 2015).

Project	Technological Readiness
PGM low profile LP (>1.7m) mining fleet	9 (most), except rope bolter and fuel cell conversion
PGM extra low profile (XLP) (1.2 – 1.7m) stoping fleet	9
PGM ultra low profile ULP (0.9 – 1.2 m) stoping fleet	7
Wide raise rig	5
Disc cutting	4
Geological information system (3D imagining, 30 metres ahead of mining)	2
Gold XLP drill and breaker for stoping Gold XLP multi-drill for stoping Remote control mechanical sweeper and dozer	3
Reef boring	7
Cost-effective, integrated Info-Comm-Tech (ICT) backbone for underground ('Google underground') – communication, data, collision management, real-time monitoring, ventilation on demand	9 (elements) 3 (integration)
Underground testing and training facility (accessible by decline, low maintenance cost, not in operating environment)	9

Significance of the study

The mechanisation technologies identified for (near) future R&D in this section are very specific in application. Compared to mechanised coal mining, narrow reef mining (particularly in South Africa) has been lagging behind in advancement on the technological front. Some of the technical constraints that have caused this lag are the physical and economical restraints that the abrasiveness of a hard-rock environment has on mechanised equipment. With the improvement of Advanced Materials and Nanomaterial, the successful implementation of hard-rock mechanisation may become a feasible possibility in more and more mining operations. As mechanisation in hard-rock environments improve, so too will other opportunities arise for more automation and improved mining efficiencies.

2.4.11. Rock Breaking Technologies

Studies in mining tunnel development revealed that developments in drilling technology, as well as increasing drilling rates, have not led to a significant increase in the rate of tunnel development. Drilling rates with mechanised drills have increased by fivefold in the last 50 years, while tunnel development rates in mechanised mining operations have reduced to about one-third of those 50 years ago (Pickering & Young, 2016).

A major obstacle to development rates, and overall productivity, is the blasting cycle in underground mining. However, the blasting cycle can be removed by implementing a form of non-explosive mining. Should this cycle be eliminated, the rate of face advance can be increased and the length of face being worked can be reduced. This could further lead to more concentrated mining, which results in less service infrastructure, less ventilation, and more effective management (Pickering & Young, 2016).

Replacing blasting, with rock-cutting or non-explosives, also reduces the blast damage to the surrounding rock and therefore improves the integrity of the rock. Rock-cutting machines that have been operated successfully in hard-rock mining include raise boring machines and, to a more limited extent, tunnel-boring machines (TBMs). These machines use discs or buttons to break the rock in compression. In order to overcome the high compressive strength of the rock, high forces, massive machines to supply these forces, high power, and consequently high capital outlays are required. This is exacerbated by high running cost on these machines due to the exceedingly high abrasivity of the rock. The machines are also often difficult to manoeuvre, which makes following the reef difficult, if not impossible. Non-production development may however find sufficient applications of these technologies at this stage (Pickering & Young, 2016).

Original equipment manufacturers (OEMs) have conducted extensive work to develop rock-cutting machines for hard-rock mining. Some OEMs have developed rock-cutting machines that attack the rock in an undercutting mode to break the rock in tension, as the tensile strength of these hard rocks is typically 5–10% that of the compressive strength. Some examples include (Pickering & Young, 2016):

- The Mobile Tunnel Miner (MTM6), first developed by Wirth in the 1990s for HDRK and recently given a new lease of life by Rio Tinto when a new machine for tunnel development was commissioned. After a few months of underground trials the project was cancelled. It is unknown if this was due to technology challenges or change in mine ownership.
- The Sandvik MN220 Reef Miner, was first developed in 2001 and extensively developed over the next four years. Trials were recommenced in 2014. Despite achieving defined key performance indicators during both trial periods it has not been implemented as a mining machine and the required associated mining system is still under development.

To date, except for specialised applications of raise boring circular shafts and TBM-driven mine access projects, no hard-rock cutting machine for everyday commercial use in the mining industry has been successfully implemented. Existing primary rock breaking technologies/methods include (Pickering & Young, 2016):

- Jet piercing;
- Erosion drilling;
- Diamond cutting/drilling;
- Percussion drilling;
- Drag bit cutting;
- Roller bit drilling;
- Impact driven wedge;
- Explosives.

The energy efficiency of the rock breaking process is of paramount importance. Figure 2.4.11a shows how specific energy consumption per cubic metre of rock broken is directly proportional, on the log-log graph, to the fragmentation size produced by the various rock breaking processes. The top line is that of primary rock breaking from a solid face and the second line is secondary rock breaking associated with crushing and milling processes. These are two entirely different activities best demonstrated by considering milling at 200 MJ/m³ and diamond drilling at 10 000 MJ/m³ for the same particle size. It can be seen that with normal blasting the average fragmentation size is 100 mm and the specific energy about 6 MJ/m³, whereas in roller-bit drilling the average fragmentation size is 10 mm and the specific energy consumption 300 MJ/m³. With explosives, this energy comes from a chemical process, but with other rock breaking processes the energy arrives at the face in the form of electrical energy. A typical example is the Wirth MTM6, which has an installed power of 1870 kW and was designed to drive a 5 m × 5 m tunnel at a rate greater than 12 m/day (Pickering & Young, 2016).

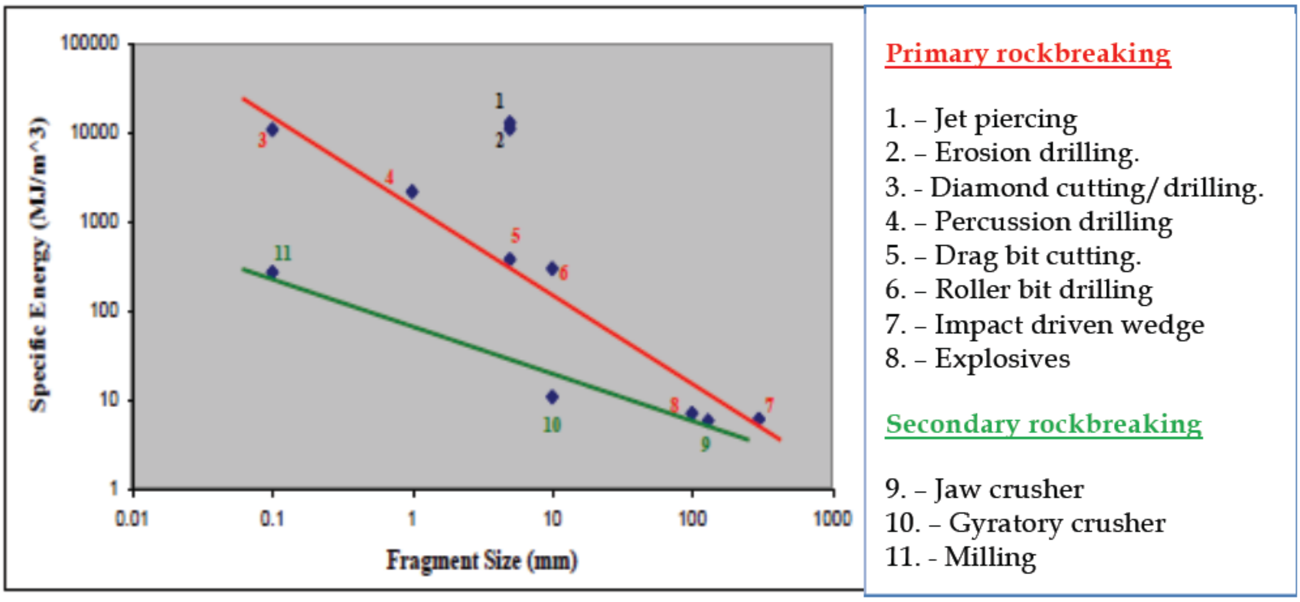


Figure 2.4.11a: Specific energies of rock breaking processes and resulting average fragmentation (Pickering & Young, 2016).

With advances in nanotechnology it is likely that rock breaking equipment would become more efficient. However, it is unlikely that these advances will realise economically achievable gains within the short-term for hard-rock mining environments.

Controlled foam injection (CFI), is a highly effective, non-explosive rock breaking technology that with the appropriate implementation and application can replace traditional drilling and blasting methods with drilling and non-explosive rock breaking. CFI technology is safer, more productive, environmentally friendly and fully developed. It can also operate with the same flexibility of more traditional small-hole drilling and blasting (Pickering & Young, 2016).

Through extensive trials, CFI has successfully broken every type of rock encountered. It could potentially, as a result, be used to replace all mining and civil engineering rock breaking processes that utilise explosives in short and small diameter blast-holes. The narrow-reef hard rock mines, typical of the southern African gold, platinum, and chrome sectors would then be able to operate continuously on a 24/7 basis. This would in turn result in higher advancement rates in development ends, leading to shorter lead times to production and better NPV returns (Pickering & Young, 2016).

CFI breaks the rock in tension by pressurizing the bottom of a drilled hole with foam. Typical operating pressures of the foam are less than 50 MPa, as it exploits the tensile strength of rock, which is much lower than the compressive strength. The successful features of CFI are the development of a cheap and easily installed seal at the bottom of the hole and the use of foam as the pressurising fluid. The foam is chemically inert and environmentally safe. It has the ability to pressurise a controlled fracture (or system of fractures) in such a way that the pressures required to adequately propagate the fractures (without over pressurising them) can be maintained and it is possible to break the rock, propagate the fractures, and liberate the rock in a controlled manner (Pickering & Young, 2016).

Figure 2.4.11b shows the general features of a CFI device for rock excavation or concrete demolition. The foam injection tube or barrel is inserted into a pre-drilled hole. The successful sealing of this tube into the hole is needed for the proper operation of the CFI process (Pickering & Young, 2016).

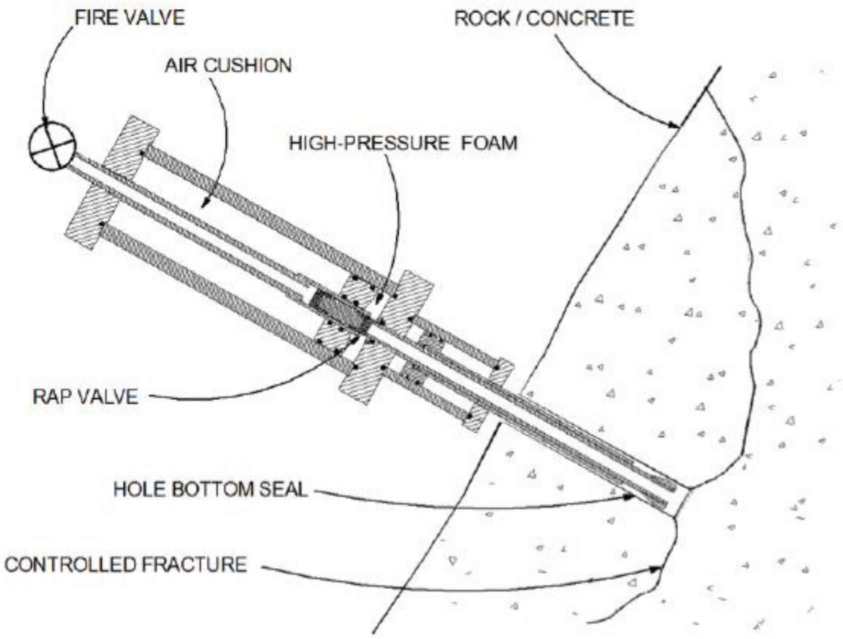


Figure 2.4.11b: Basic hardware and geometry for controlled foam injection (CFI) fracture of rock (Pickering & Young, 2016).

What is still lacking is a mining machine to accurately demonstrate the mining rate and operating cost in a specific application. Some potential application areas for a tunnel development type CFI machine further include development and stoping of narrow-reef tabular orebodies using a room-and-pillar layout, as well as all tunnel-type developments (Pickering & Young, 2016).

With time, other specialised machines could also be developed, such as (Pickering & Young, 2016):

- Narrow-reef stoping at steep and flat dips;
- Narrow-vein mining methods;
- Breaking through dikes and rock that are too hard to mine with continuous miners in mechanised coal mining operations;
- Secondary breaking in all cave and longhole open stoping operations.

Other potential applications further include the following (Pickering & Young, 2016):

- Many civil rock breaking activities that take place in urban environments. Non-explosive technologies reduce the impacts from noise, vibrations, and fly rock;
- TBMs have found extensive application in civil rock excavation, but in hard rock it is often necessary to excavate rock not cut by the TBM, such as the interconnections between two drives or the corners of a round TBM excavation. CFI could be used as it is a gentle rock breaking process and the lack of violent fly rock would minimize damage to other installed infrastructure in the already developed and equipped TBM drive.

R&D in building a rock breaking machine based on CFI is underway according to Pickering & Young (2016), which will be the basis for a mining machine designed to operate in a specific application such as tunnelling or stoping. It was also mentioned that, at a later stage a mining machine that concurrently breaks the rock, removes the broken rock from the working face, and installs support would be designed and manufactured.

The machine that comes closest to meeting these requirements was developed by Ripamonti and used to break out safety niches when the Fréjus rail tunnel was enlarged and refurbished. This machine is shown in Figure 2.4.11c.

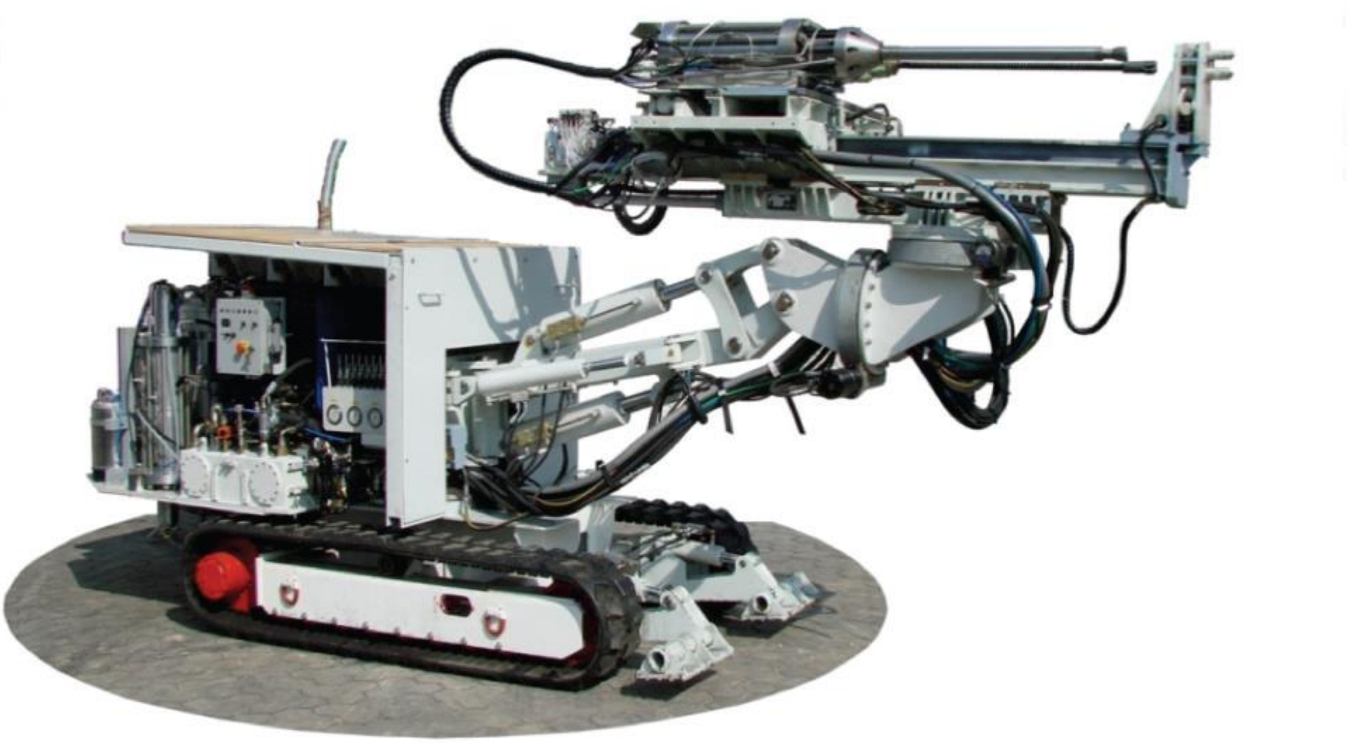


Figure 2.4.11c: Eagle 500 with CFI developed by Ripamonti and fitted with a 36 kW hydraulic power pack (Pickering & Young, 2016).

Economic and societal pressures make it essential for narrow-reef, hard-rock mining to improve the safety and productivity of mining. This can potentially be achieved by replacing drilling and blasting with non-explosive rock breaking technology, such as CFI. As with normal blasting, where the explosive charge weight and composition can be varied to achieve a specific performance, so can CFI parameters of pressure, hole size and foam composition be varied to achieve different rock breaking performances. Changes and adjustments in CFI parameters are simple to make to adapt to specific rock conditions in a tunnel (Pickering & Young, 2016).

The major benefits of CFI can be summarised as follows (Pickering & Young, 2016):

- CFI is safer than conventional blasting as it does virtually no damage to the rock surrounding the excavation. The controlled manner in which the rock is fractured therefore leads to minimal over-break and back-break. The rock breaking process is sufficiently non-violent to allow workers in close proximity to continue mining. There have been no measurements of dust generated during a CFI event. However, on observing a rock breaking event it can be seen that the newly fractured surface is covered in white foam (which further reduces dust release into the air). Experience with the change from blasting to non-explosive cutting demonstrated a massive improvement in safety in coal mining. CFI can have the same impact on narrow-reef hard rock mining, provided the application machinery is developed to operate effectively.
- CFI is a very productive and efficient method of breaking rock as it generates more broken rock per metre drilled than conventional drilling and blasting. Over a ten-year period of experimentation CFI has successfully broken every rock type in which it has been tested. It is flexible in operation, with the CFI parameters easily modifiable to address different rock conditions. Installed machine power is low, and the specific energy of rock breaking is very low when compared to hard rock cutting. The installed power for the Wirth MTM6 is just under 2 MW. The power for a CFI machine would be around 60–90 kW, as the stored energy in the foam is accumulated over a period of time. The fracture is generated from the bottom of the hole and thus maximises the use of the drilled hole. The production of broken rock per metre drilled is higher than that in conventional drilling and blasting. A machine utilising CFI will have to drill a hole and then break the rock. It is envisioned that such a machine will be similar to a mechanised

drill rig and consequently the capital cost of equipment should be similar to electro-hydraulic drill rigs. Additionally, because of the low power demand and low forces the equipment can be light and hence low cost, in comparison to a MTM6 or TBM. Operating costs should also be similar to electro-hydraulic drill rigs, with the main costs being drilling consumables and general operation of the machine.

- The CFI breaking process is environmentally friendly as it yields no fumes, no dust (except that released from existing rock fractures), very low noise levels, and very limited fly rock. As a result, people are able to work relatively close to the breaking process. The chemicals used in the foam are totally inert and thus environmentally safe.
- The CFI technology is well developed, having been tried and tested for over 15 years. The hardware used to provide the high-pressure foam has proven to function reliably in long periods of service. The hardware for generating and delivering high-pressure foam to the bottom of the drilled hole has been proven in prototype rigs. These rigs have had a primary function of developing CFI and not of developing a mining machine. Lastly, the sand seal is a very effective and very low-cost seal. This high-performance seal allows the injected foam to maintain the pressures to initiate and propagate the unique hole-bottom fracture.

CFI could be used in place of all mining and civil engineering rock breaking processes where the rock is broken by explosives in short, small-diameter blast-holes. The narrow-reef, hard rock mines typical of the southern African gold, platinum, and chrome sectors would then be able to operate continuously on a 24/7 basis. The next step will be to manufacture a narrow-reef mining machine for tunnel development or stoping and prove that this non-explosive rock breaking technology can be integrated into a machine that will deliver safer and more productive mining operations (Pickering & Young, 2016).

Limitations exist with the application areas for CFI as well as the practically achievable depth and size of drill holes. Perimeter control is also difficult with CFI, however this could potentially be resolved with closer spaced drill holes on the excavation boundaries. Currently CFI seems to have valid application for hard-rock, tunnel development with short and smaller diameter drill holes (De Graaf, 2016). Lastly, the energy required to excavate a unit volume of rock decreases with increasing scale of breakage. This effect is primarily due to the interaction of larger and weaker rock defects (fractures, joints, parting planes, etc.) with the process at larger scales (Pickering & Young, 2016).

Significance of the study

Technological advances, such as advanced robotics and nanotechnology may also benefit rock-cutting and other rock breaking technologies, making them more feasible when comparing with drill and blast practices. CFI in particular seems to have found application with notable benefits in tunnel development in hard-rock mining, however to implement the technology economically a suitable machine would need to be developed.

2.4.12. Tracking Technologies

Tracking and monitoring of mining assets and employees provides enormous amounts of data that mining operations and organisations are able to analyse for various purposes. This can also be done in real time for faster decision making or improved analysis. By combining tracking technologies with various ICTs, it becomes possible to not only monitor but also manage assets and arising non-standard situations (e.g. emergencies or other deviations from normal operating conditions) more effectively.

Some of the available and readily applied tracking technologies include:

- Radio Frequency Identification (RFID): This is a system that communicates between a read and a tag. The reader is used to detect the presence of tags entering its vicinity (NIOSH, 2016).
- WiFi: WiFi based communications consist of wireless access points that communicate with each other (Radinovic and Kim, 2008).
- Bluetooth: Signal exchange between wireless access points (Radinovic and Kim, 2008).
- Leaky feeder: Uses cables to send and receive voice, video and data signals at a “leak node”. The leak node allows signals to “leak” in and out of the cable (Douglas, 2014).

Physical search units can also be used for tracking purposes, such as:

- UAVs (Your Flying Camera Drone, 2016);
- Thermal imaging cameras (Mine Rescue Services, 2016)
- Electromagnetic, magnetic and seismic wave detecting units (Schiffbauer and Mowrey, 2006)

Tracking technologies have been applied to protect mining employees in hostile environments. Some companies have begun embedding tracking devices and panic buttons into laptops, mobile phones and other pieces of equipment. In addition to this, other physical security measures and technologies have also been stepped up on some operations to amplify the effect of technology on asset and worker safety. These include the erecting of security fences, mounting cameras, posting security guards and installing facial recognition or other biometric technologies. Along with the instalment of advanced monitoring systems, these security measures can help to control and track access to facilities, pinpoint how workers move and detect anomalous patterns (DTTL, 2016).

For the Mine of the Future initiative operations are urged to employ new “smart” programs and technologies. Location awareness technologies may include GPS, RFID and collision detection/avoidance systems. By using such technologies, companies could deploy sophisticated and automated Identity and Security Management programs. These programs can then systematically and centrally track employees’ access rights, location, duration, training, safety certification, permissions, compliance and site security. Security information can then be integrated and available to those who need it, including security and human resources. By integrating the solution with the security measures and systems described above, the data within HR systems can also be used to compare employee information with other people on-site. The system can then identify unauthorized personnel within a zone and automatically notify safety personnel, who can take fast corrective action to ensure the safety of the employees (IBM, 2009).

Beyond being able to improve employee safety, these programs and technologies can also assist during catastrophes or accidents. Real-time monitoring and personnel location tracking can help companies with planning, management and responses to arising issues. One application may involve employees wearing RFID tags that could send location information at frequent intervals, with the data uploaded to a control centre. The company could then integrate all these capabilities into a comprehensive location awareness and safety program, with a real-time visualisation engine that provides a rich graphical view of employee locations and associated metrics. In the event of an emergency or disaster, the system can then present an accurate and real-time view of the location of employees (and assets) for each area or section. This visual assistance drastically impacts search & rescue operations in terms of management and the need to conduct sweeps for unaccounted for people (IBM, 2009). Similarly the visual assistance can also be relayed to Augmented Reality enabled devices to assist emergency operation managers as well as the rescuers themselves. Managers could use AR for enhanced 3D visualisation to improve planning and rescuers may receive guidance and instructions in visual form to assist with searches and navigation through dangerous areas (Jacobs, 2015).

Companies are also using this approach of employee tracking in order to reduce accidents associated with movement of vehicles, equipment or other machinery. By integrating RFID position information, these other assets may become aware of personnel within their vicinity and the other way around. This way a collision avoidance system can be implemented that warns employees of potential harmful assets within a dangerously close distance, or these assets can automatically be stopped or slowed to avoid harm to people or damage to other assets (IBM, 2009).

Significance of the study

The resulting benefits from implementing tracking technologies form a good example of broader system integration between ITs and other physical technologies. The kinds of systems described in this section can provide great benefits to mining operations and will also add value to other technological applications such as Enhanced Asset Management or non-stationary IoT-type sensors. Operations in particularly dangerous zones, such as Africa, South America or certain parts of Asia, may also greatly improve site safety with comprehensive safety programs that leverage the appropriate tracking (and other) technologies.

2.4.13. Transportation

Various emerging transportation based technologies were investigated. While some of these, such as solar fuel (a fuel created through artificial photosynthesis by genetically engineered microorganisms that turn sunlight into ethanol or diesel) and hoverboards (ultra-strong electromagnetic technologies that allow hovered transportation) may hold value in future, they seem too far down the line for adequate analysis. A technology that is however close to fruition is the development of hybrid air vehicles, which will now be discussed.

Hybrid Air Vehicles (HAVs)

Hybrid airships (or hybrid air vehicles, HAVs), are under development and some of the first models are expected to become commercially available around 2019. These HAVs combine the direct lift of a helicopter and the aerodynamic lift of a fixed wing aircraft, with the buoyant lift of an airship. The helium-filled envelope of the HAV shown in Figure 2.4.13 provides around 80% of the lift, since the HAVs are not lighter than air as traditional airships (blimps) are (Els, 2016).

Figure 2.4.13: Hybrid Airship prototype version of LMH-1 named the P-791 (Els, 2019)

The rotary side-mounted engines provide thrust vectoring propulsion as well as vertical take-off and landing. An HAV also has the ability to hover and manoeuvre at low speeds, making landing much safer compared to many other aircrafts and it allows for precision placement of the HAV or its cargo. HAVs can also fly low, slow and they produce low noise levels. Some HAVs have distinct hovering and landing capabilities, such as the ones from Lockheed that uses what is called an Air Cushion Landing System (ACLS). By reversing the air-flow, the landing gear can act as suction cups and allow both landing and a grip on any unimproved field such as ice, snow, mud, sand and water (Els, 2016).

HAVs can transport passengers, materials and fuel to remote locations, as well as fully assembled equipment due to the large volume available for haulage and the large loads they can carry (a 90 tonne hybrid airship is in R&D by LockHeed, followed by a 500 tonne concept). Other applications may include bringing humanitarian relief during natural disasters (including configuring the crafts as "flying hospitals"), search and rescue (including at sea) transport relays, monitoring and surveying equipment and pipeline inspections (Els, 2016).

Using HAVs will lower construction costs by reducing the need to build transport infrastructure to remote locations. They also produce a low environmental impact that would reduce associated clean-up costs at remote sites. The airships will use around a fifth of the fuel of a helicopter and a third of that of a jet aircraft (Els, 2016). In terms of the operating costs for HAVs, typical transport costs can be compared to that of truck transport over icy roads (Shalal, 2014).

This type of air transport technology would enable great possibilities for modularisation. Mining companies could make use of hybrid air vehicles to transport and assemble various pieces of equipment and materials for construction. Remote locations (such as the Arctic) could become accessible for mining, and due to their precision in manoeuvrability HAVs can further also assist with infrastructure development such as the instalment of powerlines (Davidse, 2016).

Significance of the study
From the literature it can be seen that HAVs may add great value to many existing operations. Some operations will inevitably benefit more than others, depending on the structure, costs and challenges of the existing supply chain and logistics of each operation. As most easily accessible deposits are being mined out, this type of technology may prove more valuable and perhaps even essential to new mine designs.

2.4.14. Unmanned Aerial Vehicles (UAV) / Drones

Drone technology, once limited to military aviation, enables a means of combining sensors and robotics to bring big data to precision planning work. This technology spans across various unmanned aerial vehicles (UAVs), from miniature fixed-wing airplanes to quadcopters and many other multi-bladed small helicopters. Whichever type of assembly is chosen, they can all provide a low-cost aerial camera platform (Anderson, 2014).

In the mining industry, the application of UAVs (or drones) is currently still a relatively new concept and technology in general. Applications have so far been limited to capturing terrain and outcrop photos from multiple angles. However, there still exists space for drone technology in mining from productivity applications to safety and security areas (Rathore & Kumar, 2015).

Some of the potential applications for drone technology include aerial surveys, field mapping, and monitoring, which can be done in real-time depending on the system. Most importantly, drones can provide access to areas that are hard to reach and/or dangerous, such as dense forests, vertical cliffs or hills, unstable volcanic areas and historical war zones with unexploded bombs. They can further be used to survey disaster areas during and after events in mining operations. The potential uses can further be enhanced by developing or modifying applications to collect data, such as weather data, geological data, thermal imaging, or risk hazard data (Rathore & Kumar, 2015).

Further, in the mining sector specifically, UAV-based technology has huge potential to reduce manual efforts in surveying, mapping, data capturing, sample collection, pipe line and conveyor belt inspection, aerial mapping of mineral prospect zones, disaster management and monitoring, machinery tracking, infrastructure monitoring, and safety and security surveillance of mines and mills (Rathore & Kumar, 2015). By allowing surveyors to collect accurate spatial data from above, UAVs can vastly reduce risk by minimising the time these staff spend on site. Drone-based data collection can also boost productivity. Surveying projects that once took days or weeks using traditional surveying techniques are now possible in just a few hours (Sensefly, 2016). Some UAVs also use a blimp-based design and are suitable to carrying large amounts of cargo (Rathore & Kumar, 2015).

To expand on the abovementioned areas where drones can add value, the following further possibilities (both in practice and in progress) are listed from Sensefly (2016) and Rathore & Kumar (2015):

- Short-term planning
    - Pit & dump management
    - Communication of daily/weekly mining plans
    - Haul route surface optimisation
    - Storm damage assessment & control
- Long-term planning
    - Haul road, dump and pit design
    - Geotechnical
    - Surface stability monitoring
    - Joint mapping
    - Control for mining in void areas
    - Mapping of steep inaccessible inclines
- Survey and mapping
    - Mapping of mineral deposits
    - Exploration target survey
    - Outcrop and stockpile yard mapping
    - Infrastructure mapping
    - Inaccessible area surveys
- Drill & blast
    - Up-to-date surfaces for optimised blast designs
    - Pre- & post-blast data
    - Identification of misfires & wall damage
- Geology
    - Stock pile management
    - Grade control & exploration planning
    - Physical sample collection
- Productivity
    - Mine mapping
    - Stockpile mapping
    - Optimised blast design
    - Reconciliation and time lapse photography
    - High resolution photography
    - Detection of fractures in mine faces/hanging-wall
- Hydrology
    - Drainage and water management
    - Watershed, drainage basin & water flow mapping

  - Thermal detection of ground water inflows
  - Tailings dam management
- Construction
  - Feasibility studies
  - Leach pad, dam wall & platform construction quality control
  - Progress monitoring & reporting
- Mineral exploration
  - Resource calculation
  - Geophysical & watershed/catchment area modelling
  - Supporting photography (land usage etc.)
- Safety and security
  - Risk and hazard identification (e.g. misfires, wall damage in highwalls, slope movement, chemical spills etc.)
    - On operational mines, exploration and drilling sites, abandoned pits, and processing plants.
  - Surveillance and monitoring (e.g. of pipelines, conveyor belts, and equipment fleet management)
  - Search and rescue operations (e.g. by relaying confined space information, landslide zone assessment, incident root cause analysis and investigations in an operational environment)
- Heritage & environmental management
  - Reporting
  - Erosion detection
  - Vegetation change tracking
  - Inundation tracking
  - Slurry pipeline stability & leakage detection
  - Game counting
  - Surrounding community mapping
- Legal
  - Cadastre (comprehensive register of the real estate or real property's metes-and-bounds)
  - Property rights definition
  - Change detection
  - Security
  - Incident evidence capture
  - Corridor & boundary surveillance
- Community
  - Community relations/marketing
  - Impact reporting
  - Oblique imagery

To provide a few examples of various drones, Table 2.4.14 displays values for various types in terms of mass, range, flight altitude and endurance. Figure 2.4.14a shows examples of some existing micro and mini drones for small-scale applications.

Table 2.4.14: Different Types of UAVs with Mass, Range, Altitude and Endurance (Rathore & Kumar, 2015).

Type of UAV	Mass [kg]	Range [km]	Flight altitude [m]	Endurance [hours]
Micro	< 5	< 10	< 250	1
Mini	< 25/30/150	< 10	150/250/300	< 2
Close Range	25 – 150	10 - 30	3000	2 – 4
Medium Range	50 - 250	30 - 70	3000	3 – 6
High Altitude Long Range	> 250	> 70	> 3000	> 6

Figure 2.4.14a: Sample snapshot of Micro and Mini UAVs (Rathore & Kumar, 2015).

Mining and exploration companies often face challenges in accessing remote and unsafe locations due to difficult topographies. This inaccessibility then often results in no or little information of the area in question, resulting in an unavailability of data and sometime an area that remains largely unexplored. UAVs are turning the mining sector into an emerging frontier for new technology. In recent years, these miniature helicopters have helped the industry find cheaper and safer ways to map deposit sites and explore for minerals via remote controls (Rathore & Kumar, 2015).

Drones are often used to take photos from multiple angles of a specific site or area. By combining (or “stitching”) these photos together, a 3D model of the area, site, object or equipment can be created. This provides a comprehensive coverage of the area or object in question and the obtained 3D model can also be incorporated into other visual technologies (e.g. VR or AR) for further exploitation (Rathore & Kumar, 2015).

As these drones become ever-smaller, lighter, less expensive, more versatile, and easier to operate, so too does their range of potential uses continue to expand. They can also become bigger for other applications. In 2016, the world’s first passenger drone was given clearance for testing in Nevada. The drone, called the Ehang 184 (Shown in Figure 2.4.14b), is a fully autonomous drone with the ability to carry a single passenger. It was built by a Chinese firm called Ehang in partnership with the Nevada Institute for Autonomous Systems (NIAS) and the Governor’s Office of Economic Development. The partnership has had the aim to put the drone through testing and regulatory approval, which is currently unchartered territory with numerous challenges. When regulations for achieving safe flight have been established, this could mean the beginning of the autonomous aerial transportation industry (Gibbs, 2016).

The company envisages a system whereby a passenger simply inputs the destination and the drone takes off automatically. It further has the ability to take off vertically, fly at altitudes of up to 3.5km and reach a velocity of up to 100kmph. The Ehang 184 uses eight propellers on four arms, each with its own electric motor, and can currently fly for up to 23 minutes. In the event of a motor failure, the other propeller motors will compensate for the loss and the UAV can still fly and land safely (Gibbs. 2016).

Figure 2.4.14b: World's first passenger drone, Ehang 184, cleared for testing in Nevada (Gibbs, 2016)

As a final example of the application of drone technology, consider robotic submarines that are capable of traveling hundreds of feet below the surface of lakes, rivers and oceans. A start-up company called OpenROV has been working on replicating airborne drones for underwater environments. This application allows underwater exploration via remote control from surface. The drone is however trailed by a thin power and networking cable as current remote signals are inadequate for this application at great depths underwater (Markoff, 2016b). This further opens up application in the mining environment, for the exploration and inspection of flooded areas.

The significance of this study

UAVs could be used throughout the mining cycle and provide large amounts of data in an efficient and cost effective manner. UAVs could fit in well with other technologies such as Big Data and Advanced Analytics by forming a source from which data can be obtained, in real time, through a remote controlled “bird’s eye view”. The efficiency of drone technologies will also be related to improving energy technologies, e.g. as energy storage improves so can the duration of flight for drones.

2.4.15. Water Treatment & Supply

In 2030, the amount of people estimated to suffer globally from a lack of water is between 1.9 and 2.6 billion. Food and water supply will be about managing scarcity (a problem made worse by climate change) (ESPAS, 2015). As a result, it becomes even more critical for mining companies to consider future water planning around supply, treatment and consumption.

It may become necessary for operations close to the shoreline to consider desalination plants in order to provide water for their own needs. While this technology may prove unfeasible at this stage for many single operations, it may become mandatory for multiple operations and other water consumers to band together in order to secure private water supply for an area in future.

The world’s largest desalination plant is in Israel. It uses reverse osmosis to produce clean water from seawater at a scale that has not been achieved before. Due to advances in engineering and materials the plant has a low operating cost, it provides 20% of the country’s water and the development cost was around $500million. With an expected 1.8 million people to lack access to clean water by 2025 already, the supply of clean water will become even more important over time. As industrial type activities continue to grow, their water needs will also continue to impinge on the needs of water for sustaining life. Figure 2.4.15a shows a colour map of how much fresh water is consumed compared to how much is available to highlight the stress on different zones around the world (Talbot, 2015).

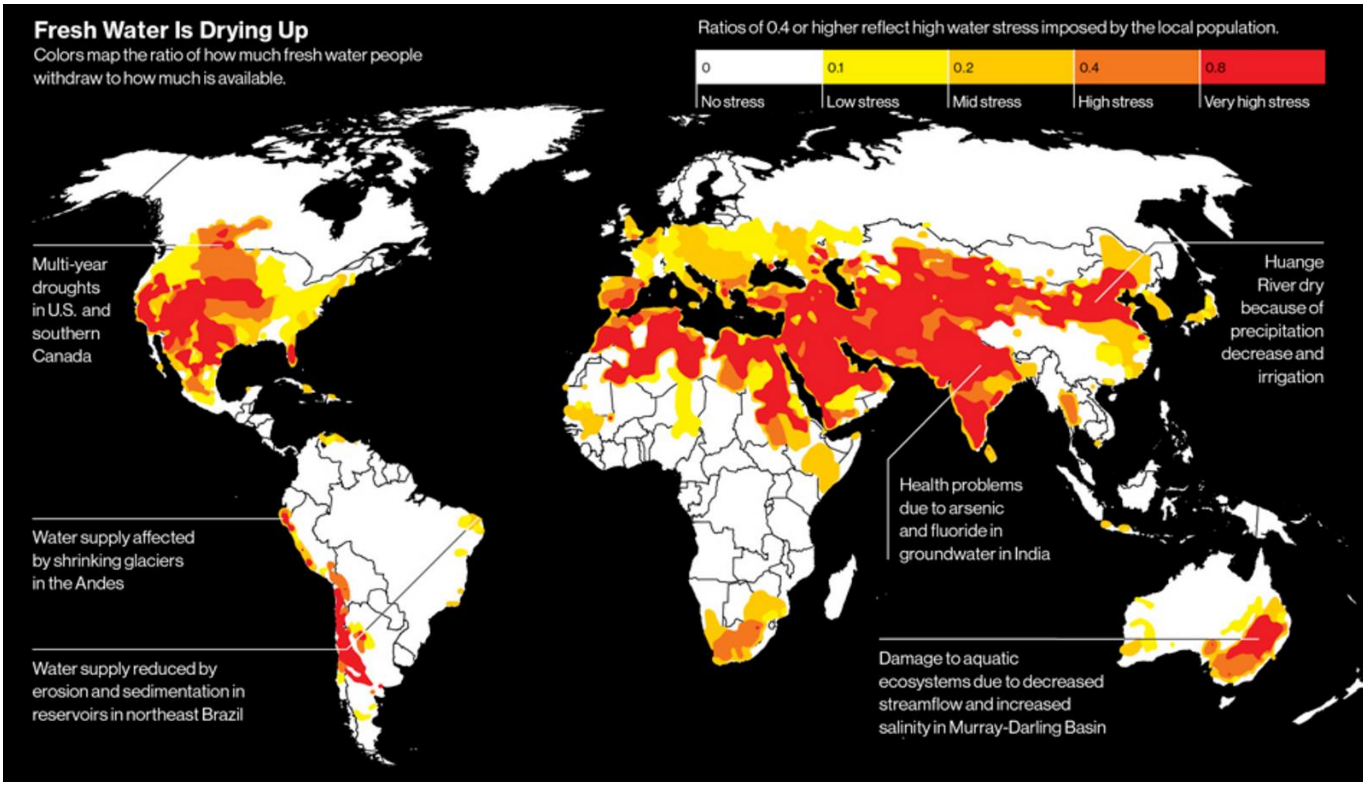


Figure 2.4.15a: Fresh water stress zones globally (Talbot, 2015).

Desalination technology may bring a new means for water supply to many locations with access to seawater or brackish underground water. Figure 2.4.15b provides an indication of the growing number of seawater desalination projects around the world, indicating a drive towards implementation of this technology to address growing concerns about fresh water supply. It should be noted that seawater desalination is still generally one of the most energy intensive operations compared to other alternatives as shown in Figure 2.4.15c (Talbot, 2015).

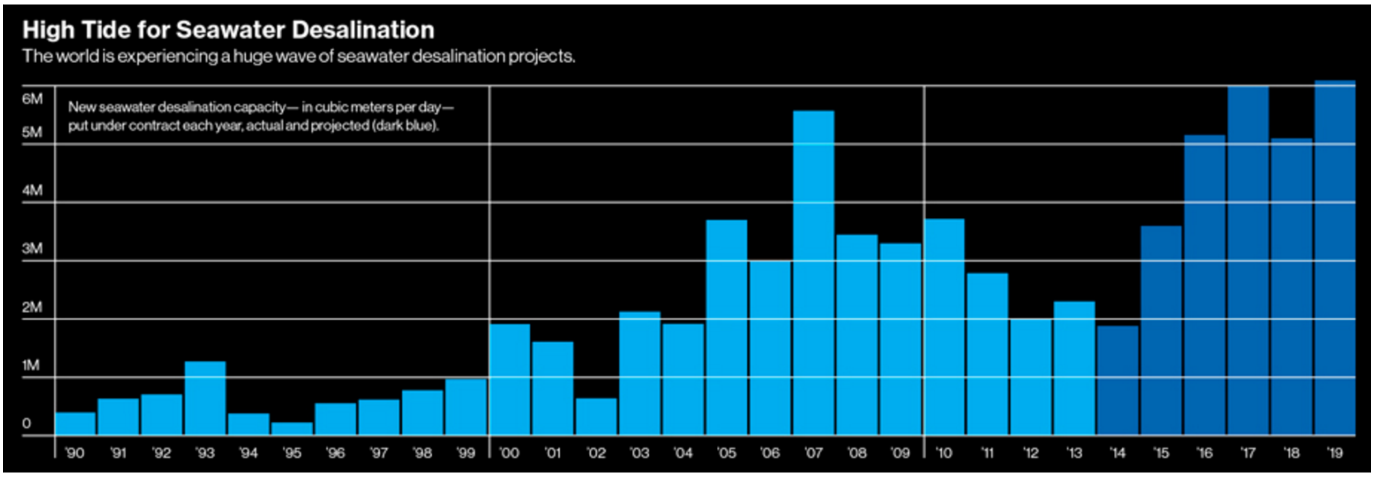


Figure 2.4.15b: Global seawater desalination projects trends (Talbot, 2015).

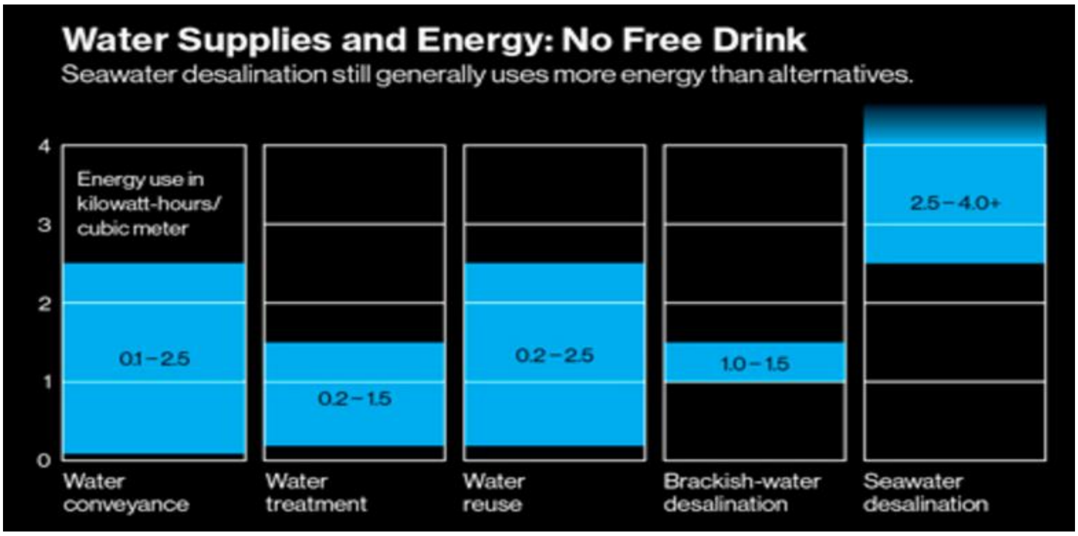


Figure 2.4.15c: Energy consumption indication for various water supply or treatment alternatives (Talbot, 2015).

Another technological development in water purification came from a team of engineers at Washington University in St. Louis. This purification process uses graphene and bacteria produced nanocellulose to create a water “biofilter” with two layers that uses sunlight to evaporate dirty water. On the top layer of the biofilter is graphene oxide filled nanocellulose and at the bottom is pure nanocellulose. Water moves up to the graphene layers through the pure nanocellulose and, since graphene converts absorbed sunlight to heat, the water between the two layers are evaporated. The result is collectable, clean and drinkable water (Ebsworth-Goold, 2016).

The synthesis process also allows addition of other nanostructured materials to the foam that will increase the rate of destruction of bacteria and other contaminants. The team of engineers believe that this could be a low cost and efficient way to clean drinking water as graphene production in itself is very cheap and cellulose can be produced in large scale. The biofoam used in the process is also light and inexpensive to manufacture, making it a viable tool for water purification as well as desalination (Ebsworth-Goold, 2016).

Significance of the study

With rising conflicts over resources the need to secure and sustain water supplies becomes crucial, especially for water intensive industrial-type operations such as mining. Operations that are located in water scarce zones will increasingly find the management thereof as a critical part of their operational plan. Technologies that could alleviate the dependence on water suppliers, or reduce conflict in demand for the scarce commodity, will inevitably become valuable.

2.4.16. Wearable Technologies

Mining companies have been searching for ways to benefit from technologies similar to the Apple Watch and Fitbit, which are wearable technologies that have been experiencing rapid adoption in the consumer markets. By incorporating computer and advanced electronic technologies into clothing, eyewear and other accessories (i.e. hats, gloves, watches etc.), companies could realise major advantages. Some examples include devices that track truck driver fatigue to reduce related incidents, or the real-time regulation of underground ventilation by tracking workers underground in order to save on energy consumption (DTTL, 2016). Some wearable devices can even signal for help if they detect that the wearer is in physical distress, allowing rapid response during emergencies (Vimeo, 2016).

Wearable technologies also open up major possibilities in the Virtual Reality (VR) and Augmented Reality (AR) field. AR enabled eyewear already provide some mechanics the ability to do maintenance on vehicles in a more efficient manner. Some AR applications are even able to provide clear-cut task assistance to the wearer, showing exactly how a specialist task should be completed and as a result improves efficiencies and reduces human error (Jacobs, 2015).

Significance of the study

Wearable technologies will continue to expand, similar to smartphone technologies. Along with the expansion of the IoT and mobile internet, wearable devices will also become more adept at performing a wider variety of tasks as well as to provide different kinds of assistance to the wearer. As computer devices become smaller, wearable technologies will also become more integrated with a wider variety of other technologies, bringing new devices that were previously unseen. This opens up major possibilities for technological assistance and brings a new means of an anytime, anywhere availability to different technologies.

2.5. Digital (Data, Information & Communication) Technologies

This section investigated Digital Technologies, including Data and Communication Technologies along with Information Technologies and integration systems as well. Before these technologies will be discussed, the scene will be set by McKinsey to identify the need for digital technology innovation in mining.

The mining industry has shifted its focus to improving productivity by "sweating" existing assets, but this strategy will go only so far. Despite the industry's booms and busts, the nature of mining has stayed the same for decades. Achieving a breakthrough on productivity performance demands rethinking how mining works. The potential to achieve such a breakthrough is now coming within the industry's reach through digital and technology innovations that could transform key aspects of mining (McKinsey, 2015).

Digital technologies that have long been in the works are now available and affordable enough to become operational at scale across the mining industry. Their applications include building a more comprehensive understanding of the resource base, optimising material and equipment flow, improving anticipation of failures, increasing mechanisation through automation, and monitoring performance in real time (McKinsey, 2015).

McKinsey (2015,) analysed global mining productivity across commodities, geographies and most mining companies and identified a declining trend of 3.5 percent (refer to Figure 2.5) over a decade (2004 to 2013).

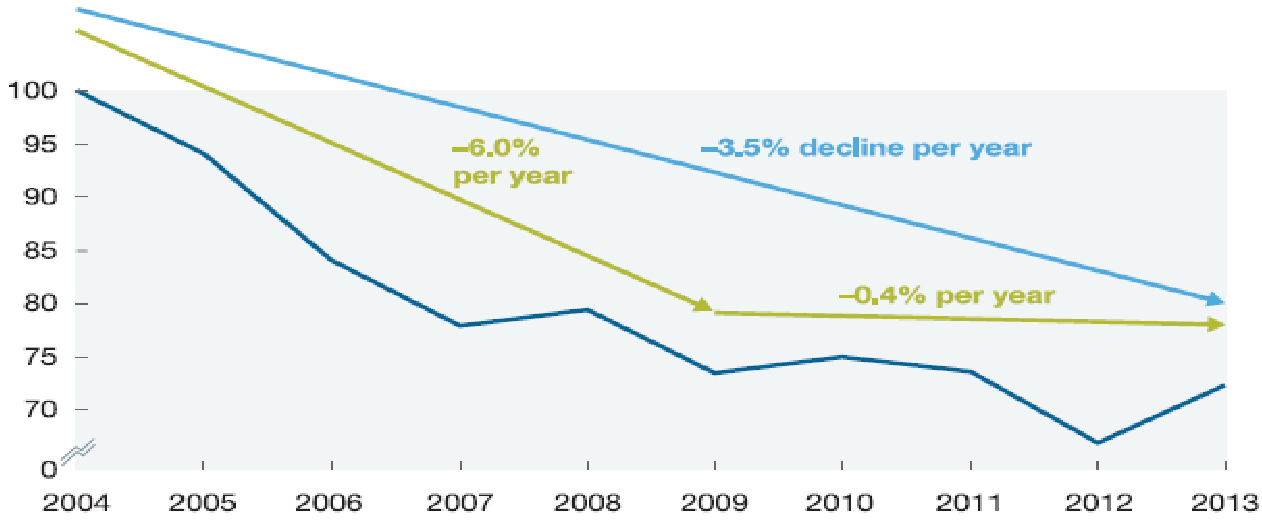


Figure 2.5: Global Decline in Mining Productivity between 2004 and 2013 (McKinsey, 2015)

There does however remain significant untapped potential for productivity improvement. One way to understand the order of magnitude is to compare mining to other industries such as upstream oil and gas, steel, and oil refining. Based on McKinsey's benchmarking, a global average was observed for overall equipment effectiveness (OEE) performance of 27 percent for underground mining, 39 percent for open pit mining, and 69 percent for crushing and grinding—compared with 88 percent for upstream oil and gas, 90 percent for steel, and 92 percent for oil refining (McKinsey, 2015).

McKinsey (2015), argues that digital technologies have the potential to unlock new ways of managing variability and enhancing productivity. Four main technology clusters were identified that experience large-scale (and accelerating) adoption throughout numerous industries, with the potential to add value to the mining industry as well. These can be described as follows:

- **Data, computational power, and connectivity**. Vast numbers of sensors are being embedded in physical objects, producing large volumes of data for analysis and enabling communications among machines. Embedding sensors is also becoming increasingly affordable and accessible. For example, smart grids can report power usage across millions of homes and sensors on remote deep sea oil wells cause warning signs to flash at the central control centre when problems arise. In 2015, more data was generated every day than what existed in total through 2003. Mining operations already produce huge amounts of sensor data, potentially enabling them to obtain a more accurate and consistent picture of the reality of operations than ever before.
- **Analytics and intelligence**. Advances in analytics, from machine learning to improved statistical techniques for integrating data, help turn vast data sets into insight about the probability of future events. Telecommunication companies, for example, use smart algorithms to predict customer attrition, turnover and defection. Retailers employ smart algorithms to aim offers at specific customers. Similarly, complex mining tasks such as geological modelling, scheduling, and predictive maintenance are increasingly entering the domain of smart statistical and optimisation algorithms.
- **Human–machine interaction**. Consumer smartphones and other mobile devices have transformed the way that people interact not only with one another but also with machines. Consumers rely on their smartphones for driving directions, booking taxis, and monitoring their health. Similar applications are also spreading rapidly in the industrial field. One example is “smart” glasses or goggles that feed instructions (through Augmented Reality or Virtual Reality technology applications) to workers working on an assembly line or to a worker carrying out repairs on equipment, improving operating disciplines. Another is work clothing that incorporates sensors transmitting data to managers about hazardous conditions and the physical condition of the workers themselves, improving safety outcomes (e.g. such as Deloitte's wearables).
- **Digital-to-physical conversion**. Advances in robotics are making equipment that is fully autonomous more affordable and effective. In manufacturing, the cost of industrial robots has fallen by 50 percent since 1990, while U.S. labour costs have risen 80 percent over the same period. Meanwhile technological advances in areas such as artificial intelligence are increasing the sophistication of robotics and expanding their productive applications. In mining, the use of tele-remote and assisted control equipment is becoming common, and deployment of fully autonomous equipment is taking hold in haulage, drilling, and other processes.

Taken together these technologies enable a fundamental shift in the way mining functions. These technological advances could bring new ways to harness the flow of information to reduce variability in decision making and to deploy more centralised, mechanised operations to reduce variability in execution (McKinsey, 2015). These four main clusters will be investigated in greater detail throughout the section, as well as other digital technologies that form part of or add to these clusters in different ways.

2.5.1 Automation & Automation of Knowledge Work

Automation is not limited to robotics in physical activities, but it also includes the automation of knowledge work. As such it is not just certain manufacturing jobs that will be replaced by robots and 3-D printers, but jobs requiring brainwork will also be replaced by other types of machines and computers. McKinsey Global Institute reports that computers could do the work of 140 million knowledge workers by 2025 (VanderMey, 2015).

Advances in artificial intelligence, machine learning, and natural user interfaces (e.g. voice recognition) are making it possible to automate many knowledge worker tasks. Many of which have long been regarded as impossible or impractical for machines to perform. For instance, some computers can answer "unstructured" questions (i.e. those posed in ordinary language, instead of precisely written as software queries), so employees or customers (without specialised training) can get information on their own. This opens up possibilities for major change in how knowledge work is organised and performed. Sophisticated analytics tools can then be used to enhance the talents of highly skilled employees. As more knowledge worker tasks can be done by machines or computers, it is also possible that some types of jobs could eventually become fully automated (McKinsey Global Institute, 2013).

McKinsey analysed the potential for automation (both for physical and knowledge work) of each of the occupations across the U.S. economy. In order to understand the potential impact and technical feasibility of automation on these occupations, the various constituent activities of each occupation were assessed individually. It was then found that 45% of activities people are paid to perform can be automated and 60% of all occupations could see 30% or more of their constituent activities automated. This analysis is based on currently available and demonstrated technologies (McKinsey, 2016).

When a given activity could be automated by adopting currently demonstrated technologies, then it is classified as technically feasible. Figure 2.5.1a demonstrates the technical feasibility (as a percentage) of various classifications of activities.

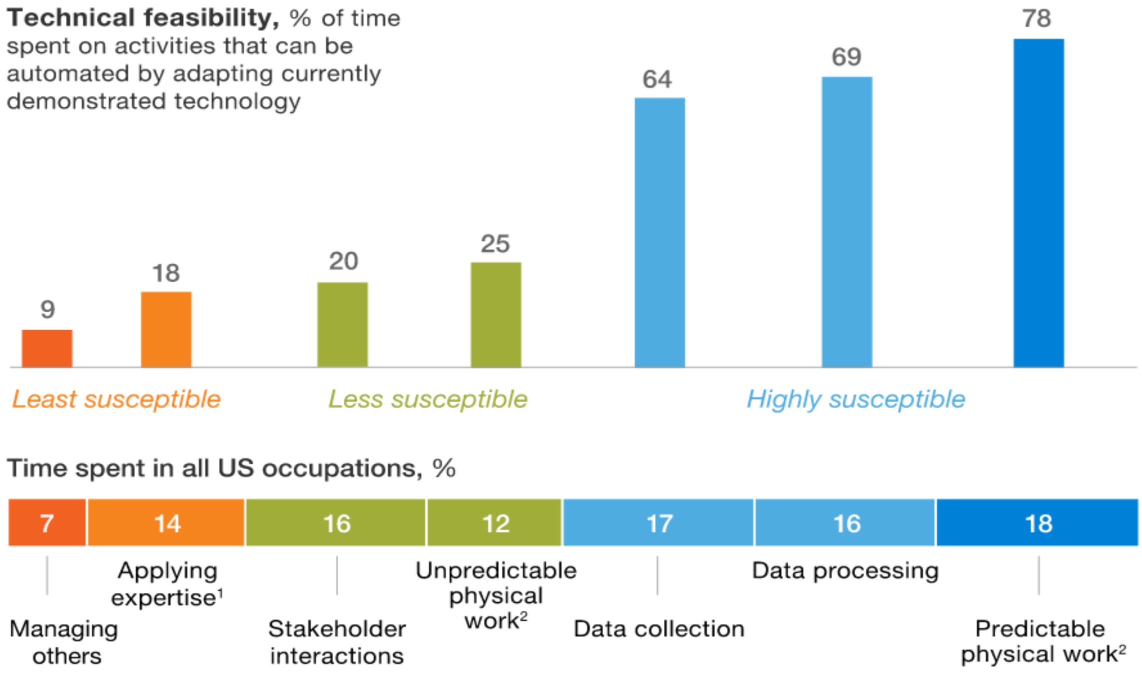


Figure 2.5.1a: Classification of activities in terms of technical feasibility of automation (McKinsey, 2016)

Notes from graph: (1) Applying expertise to decision making, planning, and creative tasks. (2) Unpredictable physical work (physical activities such as construction and forestry, and the operation of machinery) is performed in unpredictable environments, while in predictable work the environments are predictable (e.g. welding or soldering on an assembly line, food preparation, or the packing of objects).

In practice, automation depends on five factors (not merely technical feasibility alone). These are (McKinsey, 2016):

- Technical feasibility;
- Costs to automate;
- The relative scarcity, skills, and cost of workers who might otherwise do the activity;
- Benefits of automation beyond labour-cost substitution (e.g. superior performance, less human error);
- Regulatory and social-acceptance considerations.

The heat map in Figure 2.5.1b highlights the wide variation in how automation could potentially play out, both in individual sectors and for different types of activities within them.

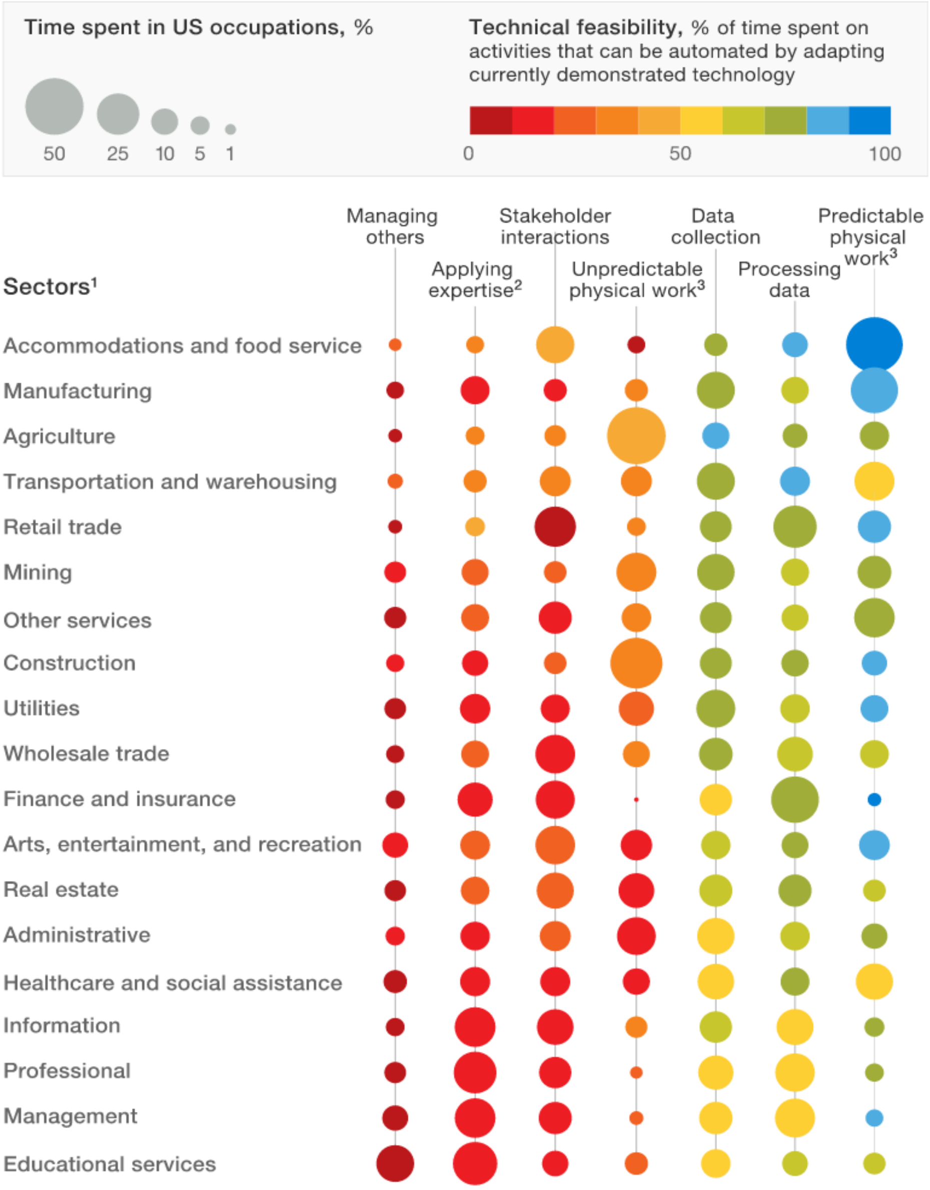


Figure 2.5.1b: Heat map indicating the potential for automation in various sectors (McKinsey, 2016)

Notes from graph: (1) Professional includes scientific and technical services, educational services includes private, state-government and local-government schools. (2) Applying expertise to decision making, planning, and creative tasks. (3) Unpredictable physical work as defined earlier.

Across these occupations in the U.S. economy, one-third of the time spent in the workplace involved collecting and processing data, which includes knowledge work activities that can be automated. A few examples include administering procurement, processing payrolls, calculating materials-resource needs, generating invoices and tracking flows of material. On the physical side, many repeat activities or processes can be automated, such as autonomous trucks in mining (McKinsey, 2016).

As technology develops, robotics and machine learning will enable greater potential for the technical feasibility of automation for various activities. New techniques, for example, are enabling safer and more enhanced physical collaboration between robots and humans in what are now considered unpredictable environments. These developments could enable the automation of more activities in sectors such as construction. Artificial intelligence, as another example, can also be used to design components in engineer-heavy sectors (McKinsey, 2016). Improved machine vision would also increase the potential for automation in unpredictable environments. It should be noted that the above research reflects a focus of technical potential for automation. The actual susceptibility for automation will reflect the interplay of the technical potential, the benefits and costs (or the business case), the supply-and-demand dynamics of labour, and various regulatory and social factors related to acceptability. Even so, these statistics reflect a great possibility of automation in all occupations and working environments. Automation could transform the workplace for everyone, including senior management. The rapid evolution of technology can also make harnessing its potential and avoiding its pitfalls especially complex (McKinsey, 2016).

Significance of the study

Understanding and taking account of the data and automation technologies that are emerging will be key for senior management in preparing for technological advances. Understanding the activities that are most susceptible to automation, from a technical perspective, could provide opportunities to rethink how workers engage with their tasks. Automation can bring different ways to freeing up valuable time to focus on core competencies that cannot be performed by robotics and computers, such as creativity, innovation, adapting to dynamic trends, leadership and human management.

2.5.2. Autonomic Platforms

The concept of autonomics can be described as the combination of automation and robotics, or taking automation a step further by basing it in machine learning. Nearly all traditional IT operations are candidates for autonomics, including anything that is workflow-driven, repetitive, or policy-based and that requires reconciliation between systems. Various approaches are defined by different names, such as robotic process automation (RPA), cognitive automation, intelligent automation, or cognitive agents. However, the underlying concept remains the same, which is applying new technologies to automate tasks and help virtual (remote) workers handle increasingly complex workloads (Dupress, 2016d).

Autonomic platforms combine two important IT trends, namely software-defined everything (SDE) and DevOps operating and delivery models. Refer to Figure 2.5.2 for an illustration of how these tie in together. SDE refers to the concept of “virtualization” of computing infrastructure that is then delivered as a service. Virtualization is a term borne from the ability to create different segments of a computer’s hardware resources that can be managed independently as a separate machine. With hardware assets such as servers, network switches, storage arrays, and desktop facilities being expensive, difficult to manage and often sub-optimised in usage it becomes beneficial to mitigate physical hardware installations. As such, virtualization allows the creation of software-based, logical abstractions of underlying physical environments in which IT assets can be shared. DevOps on the other hand is a way of organising and focussing various teams, by utilising tools and processes to eliminate some of the waste embedded in IT operating modes. Both SDE and DevOps are further accelerated by robotics, process automation and cognitive technologies (Dupress, 2016d).

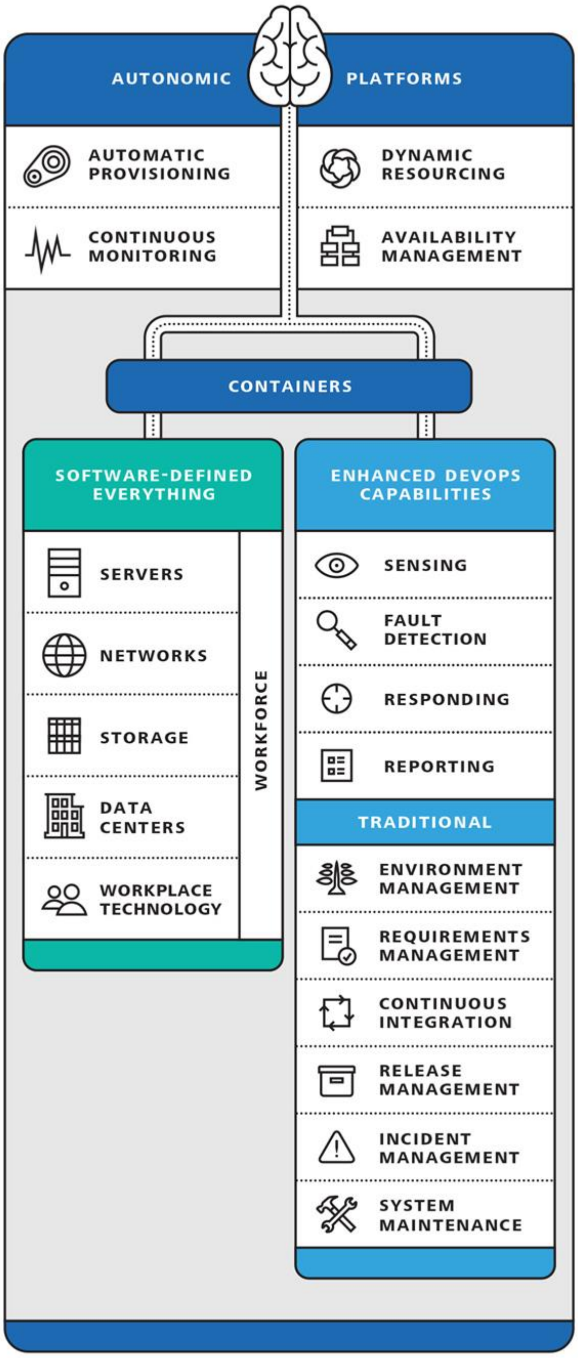


Figure 2.5.2: Autonomic platforms as laid out by Deloitte University Press (Dupress, 2016d)

Autonomic platforms increasingly make use of virtualised assets to reduce dependence on physical hardware. The improved mobility and deployment of IT services can increase the agility and responsiveness of IT within a business. Autonomic platforms can also provide the architectural support for next-generation solutions and operating environments that will be created with increased integration of IT (Dupress, 2016d).

Significance of the study

Automation and autonomic platforms are an essential part of digitisation. When more platforms can be created to allow automation and other IT services across a wider range of an enterprise's operations, then more digital integration and reduced costs (associated with hardware allocation and maintenance) can be achieved. These IT concepts are important to understand when striving towards increased implementation of IT into operations.

2.5.3. Advanced Analytics & Big Data

Data is a foundational component of digital transformation. Yet, few organisations have invested in the dedicated talent, platforms, and processes needed to turn information into insights. To realise the full potential that can be extracted from data, some businesses are adopting new governance approaches. Other adoptions include multi-tiered data usage and management models, and innovative delivery methods to enable repeatable results and scale. They are treating data analysis as a strategic discipline and are investing in industrial-grade analytics (Dupress, 2016b).

In Deloitte's 2015 global CIO survey, involving 1,200 IT executives, respondents identified analytics as both a top investment priority and the IT investment that would deliver the greatest business impact. In a similar survey of a broader executive audience, 59 percent of participants either included data and analytics among the top five issues or considered it the single most important way to achieve a competitive advantage (Dupress, 2016b).

Advances in distributed data architecture, in-memory processing, machine learning, visualisation, natural language processing, and cognitive analytics have unleashed powerful tools that can answer questions and identify valuable patterns and insights. The result is that a new approach to data is required, one in which the talent, data usage and management models, and infrastructure required to enable repeatable results and scale is deployed. By "industrializing" analytics in this way, companies can lay the foundation for an insight-driven organization that has the vision, underlying technology capabilities, and operating scale necessary to take advantage of data's full potential. This journey of analytics is displayed in Figure 2.5.3a along with the taxonomy of a strong data analytics program, in Figure 2.5.3b, that organisations may adopt (Dupress, 2016b).

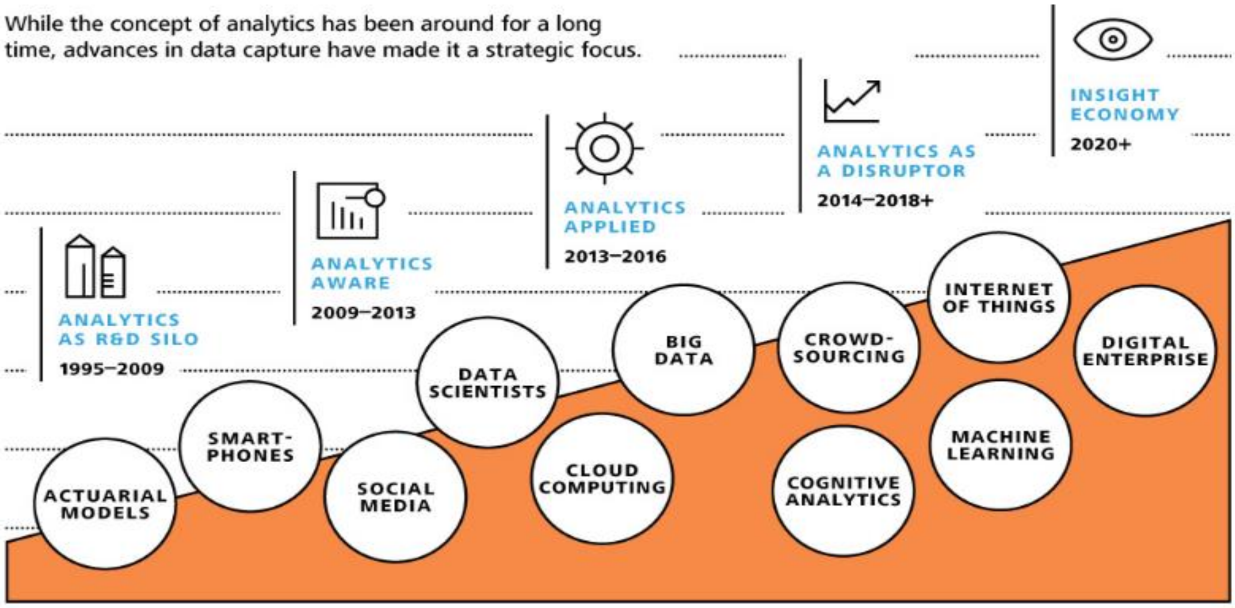


Figure 2.5.3a: The analytics journey (Dupress, 2016)

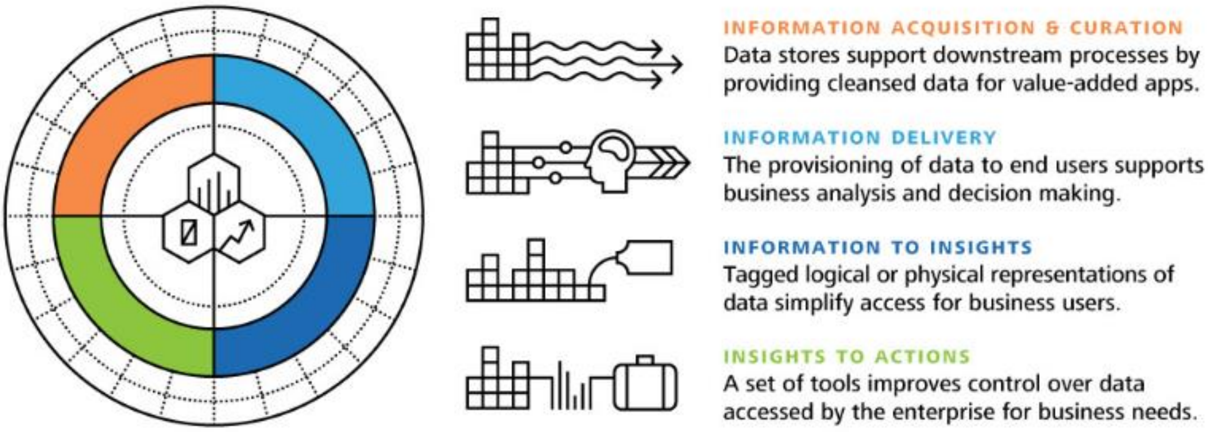


Figure 2.5.3b: Taxonomy of a strong data analytics program (Dupress, 2016)

Beyond enabling scale and predictability of outcome, “industrializing” analytics can also help develop a greater understanding of other possibilities from data and how to achieve it. Many data efforts are descriptive and diagnostic in nature, focusing primarily on what happened and why things happened the way they did. These are important activities, but they only form a part of the entire context. Predictive analytics broadens the approach by answering the next question, which is “what is going to happen?” Likewise, prescriptive analytics takes it one step further by helping decision makers answer the ultimate strategic question: “What should I do?” (Dupress, 2016b).

Analytics will become deeply, but invisibly, embedded everywhere. Organisations will face increased difficulty to manage how best to filter huge amounts of data (often termed Big Data) from the IoT, social media, wearable devices, sensors and other sources. Applying advanced analytics to an understanding of context could provide the preconditions for a world of smart machines. This foundation combines with advanced algorithms that allow systems to understand their environment, learn for themselves, and act autonomously. Prototype autonomous vehicles, advanced robots, virtual personal assistants and smart advisors already exist and will continue to evolve rapidly. This will ultimately usher in a new age of machine helpers, leading to a smart machine era that is likely to be the most disruptive in the history of IT (Gartner, 2014).

When looking at mining, global supply and demand factors lack the transparency companies often require to make decisions before disaster ensues in their operations. Companies now need more flexibility than ever before and the aim should be to hone the ability to scale production, labour and other inputs and outputs up or down in response to shifting economic trends. Predictive analytics can help organisations in this regard by identifying events that may shift commodity market fundamentals (DTTL, 2016). Smart planning and coordination of activities are required to mitigate variability caused by external forces. Disciplined execution is needed to eliminate variability in operations. The path to a step change in mining productivity will come through reducing and, where possible, eliminating the variability that has made mining unique (McKinsey, 2015).

Mining companies continue to refine their safety programs but statistics still remain dire worldwide. Companies often turn to data analytics to pinpoint the industry risks, organisational behaviours and internal cultures that are most likely to result in severe safety incidents. As this technology becomes more intuitive and less costly, it is enabling companies to implement safety programs focused on zero fatalities (rather than zero harm). Companies are able to better correlate the safety data they collect with other available data sets (e.g. production data, employee rosters, maintenance schedules, weather forecasts, vehicles telemetry etc.).

By correlating this data, companies can recognise safety incident patterns and employees that are particularly at risk. They are then in the position to adopt processes and procedures to minimise incidents and injuries (DTTL, 2016). Wearable technologies can also come into play here, to link to these data sets and provide warning signals to employees when computer analytics detect hazards.

In emergency situations, it can be exceedingly difficult to quickly learn who has been evacuated, who is still missing and where the missing persons were last seen. While this critical information is gathered, rapid response can be delayed and incorrect and potentially time-consuming decisions may be made that involves directing rescue teams and managing accountability activities. Safety efforts can be bolstered by new technological approaches that stretch the safety net beyond what training and procedures can provide (IBM, 2009).

To reduce the costs associated with safety, as well as other parameters such as maintenance and other cost-intensive programs is crucial to the profitability and survival of mining operations. However, to reduce these costs on a sustainable basis is futile if only component costs are examined. Using analytics, companies are able to (Deloitte Global Services Limited, 2014):

- Assess the costs of entire processes in order to uncover the underlying cost base and to identify exceptions and outliers.
- Improve decision-making and asset performance through the measurement of both financial and non-financial indicators that affect overall profitability.
- Transport data from a wide range of different sources to deliver on-demand reports. This would then enable the improvement of asset utilisation and reliability, it would also minimise downtime, streamline mine planning and optimise fleet resources.
- Companies can also use emerging metrics to manage operational costs, such as measuring the mineral content of each shovel load to determine whether or not it is below cut off grades.

Various companies have already begun using analytics to reduce the abovementioned costs, as well as operational and supply chain management costs. As data analysis becomes increasingly more sophisticated, opportunities for greater efficiency arise. From a talent management perspective, companies can now leverage vast sets of employee data to make more informed workforce planning decisions. They can use real-time information on the state of equipment to improve maintenance schedules and asset performance. They can consolidate various data inputs to streamline supply chains and enhance mine planning. They can continuously monitor mineral asset portfolios to pinpoint commodity and cost movements that can affect profitability. Using predictive project analytics, they can vastly reduce cost overruns to improve capital project outcomes. By harnessing big data in real time, some companies are even optimising global mineral processing from a single location. In time, operational excellence will likely hinge on an organisation’s ability to effectively interpret the massive stores of data it collects (Deloitte, 2015).

Finally, advanced analytics can aid production supervisors in determining the optimal material blend option and scheduling production to optimise mine/plant throughput. It can also benefit strategic procurement programs in that category management, strategic sourcing, supplier integration, procurement centres of excellence (COEs), and transaction optimisation can all work to reduce costs and wastes in the supply procurement process (IBM, 2009). This could be an automated system through the correct use of information technologies.

Significance of the Study

While most Information Technologies prove to be not only greatly beneficial, but also critical to all levels of an organisation, it is the integration of various technologies that is both the most difficult and the most lucrative. Business leaders need to pay special attention to how advanced analytics, huge volumes of generated data, the IoT, AI, machine learning and automation all tie in together. In doing this, the underlying component technologies will also play a critical role in the successful integration to reach a global automation and real-time analytics ecosystem that not only responds but also predicts and adapts to market and operational dynamics.

Enhanced Asset Management

In terms of asset management, mines will need to employ tracking technologies to better manoeuvre and monitor mining equipment and other assets. Assets should be instrumented, interconnected and intelligent, reporting their location, their status and other key metrics remotely and automatically. Capital-intensive mining business performance is tied to the availability, maintenance, financing and deployment of assets. Every moment that equipment are not utilised or the right equipment or transportation is not available, can have severe effects on productivity and profitability. Repairs and other unplanned maintenance activities result in two detrimental effects, namely additional (often high) costs as well as a loss in revenue due to the asses not producing. Such repairs are typically performed reactively after the asset is down, which results in the need for different asset management (IBM, 2009).

A system is required that encompasses the entire asset management life cycle (i.e. from needs analysis to disposal). It should take a wider view of asset classes (i.e. the way assets are categorised e.g. transportation, equipment, information technology, land) and how they each behave and contribute value differently. This approach will also improve how well each asset management activity is performed (IBM, 2009).

Through the use of data analytics and remote sensors, assets could become instrumented and intelligent, reporting their location, their status and other key metrics remotely and automatically. In order to achieve a desired zero unplanned maintenance environment, companies must first strengthen their asset management practices. Merely putting sensors onto all mining equipment and machinery is insufficient if the company lacks the means to analyse the data obtained from these sensors. With the right tools that give operations visibility into the health of the assets they are tracking, they can amass and analyse baseline data points to predict various outcomes. Some of which include things like regular failure points, asset wear-and-tear, required maintenance frequencies, shifting energy demands and optimal resource deployment. Ultimately this minimises maintenance costs and improves asset efficiency (IBM, 2009).

"Predictive condition monitoring" is used where systems using predictive data modelling trigger maintenance orders before equipment failures happen. The entire asset management lifecycle could be planned for, and analysed and managed on many different dimensions. A centralised asset management program could be deployed and used, leveraging sophisticated asset management practices and integrated asset management tools and technologies. Asset managers can then also employ more sophisticated maintenance schedules and reduce the time, expense and downtime that repairs entail (IBM, 2009).

Other resulting benefits from enhanced asset management include a better utilisation of assets to contribute to business value and productivity. It could reduce maintenance, repair and operations costs. Lastly, it could also improve finance strategies via smarter asset deployment, smarter purchasing/leasing decisions and ultimately improved return on capital employed (ROCE) (IBM, 2009).

Significance of the study

Enhanced asset management is a tangible application of data analytics to create real business value. This application of technology also fits in with an automation drive. Enhanced asset management can not only report critical information autonomously, it could also fit into a larger autonomous system that reacts to a detected issue by employing either the right employee for the job or the right robotics.

Data Integration & Visualisation

Mining companies collect masses of data through sensors, equipment monitors and other devices. To turn that data into intelligence, specific systems are needed. This involves more than the adoption of analytic programs. It also requires companies to integrate their operational systems (i.e. SCADA, PLC, DPC4) with their enterprise resource planning (ERP) platforms. Ultimately, the aim is to enable better decision making by adopting a common platform capable of sharing information across the extended enterprise in near real time. Rio Tinto's new data analytics excellence centre in Pune (India) is a good example of this. There the company will analyse the huge volumes of data captured by the sensors on its fixed and mobile equipment to better predict and prevent downtime events that could impact productivity or safety (DTTL, 2016).

IBM (2009) states that the traditional mining mind-set, is a "look and see" mentality. Aged experts rely on their intuition and gut feeling based on what they experience in the field. While sophisticated technology has permeated many of the operational aspects of mining, few have tied all of the information into comprehensive views of the mine(s) for insight-driven decision making.

The vision for information in mines interconnects all entities in the environment including instrumented assets and equipment, transportation, people, supplies and plans into integrated views. Called visualisation, this integration of information provides production and maintenance operations, analysts, field crew and other decision-makers with a real-time view of their entire operation via consolidated, synoptic interfaces. Alerts, alarms and other triggers enable a mine to be hyper-responsive to change and challenges. Advanced analytics help miners predict and plan for the future, not just react, but how this technology is conveyed to people is important (IBM, 2009). Technologies and concepts such as the ambient user experience and visual technologies such as AR and VR may come into play in order to both successfully and efficiently communicate analysis with decision makers.

To integrate many sources of data without reinstalling or replacing different systems across the mine, new technologies techniques may prove essential. These may further include using reference semantic models, industry standards, intelligent service oriented architecture (SOA) approaches and new, intuitive visualisation dashboards and interfaces. The management of the mine's operations also links to key business systems, such as enterprise resource planning (ERP) or sales forecasting, enabling the entire supply chain to be managed in synch across the enterprise (IBM, 2009).

Through the integration of both various data sources and technologies that perform advanced analytics and provide the required visualisation, great value can be obtained by any enterprise. Decision makers can have access to a timely and comprehensive set of facts and a single version of the truth. Assets and people can be instrumented with location-aware technology that provides real-time metrics on performance and status. Information can reflect the current business reality, delivered in real-time or right-time. Reporting and analysis of operations can be in real-time and predictive. Companies can spend more time "looking forward" instead of reporting on the past. Production operations and others can be able to visualise their entire mining operations via intuitive interfaces that provide synoptic and detailed views of performance, including alerts and events. A broad and rigorous set of key performance indicators can be defined and tracked throughout the enterprise.

Operational data from mines can interconnect and communicates with key business systems, enabling administration, finance, sales, service and other functions to respond to mining and supply chain events. Technology architecture can leverage new strategies such as service-oriented architecture (SOA) to become flexible, allowing new capabilities to be built and deployed rapidly (IBM, 2009).

Significance of the study

The visualisation and integration of data and various analytics performed on it, is a crucial part of allowing people to understand the IT component and be able to draw benefit from the potential it provides. As more intuitive interfaces and interaction with technology develop, so too may our ability to utilise potential benefits and to increase the value that can be gained from technology.

2.5.4. Artificial Intelligence & Machine Learning

Artificial Intelligence (AI) refers to the field of study to create computers that are capable of intelligent behaviour and that could divulge answers by analysing data, as well as having the ability to learn by itself from data analysis. Machine learning uses algorithms to analyse and learn from data and adapt accordingly. Machine learning is more specific in application and, as a result also more accurate since, it is a technology that has seen greater maturity than AI which is still in its growth phase (Skylads, 2015).

Artificial Intelligence (AI)

Artificial intelligence (AI) is becoming embedded in everyday life. It supports significant strides in everything from medical systems to transportation. As an exponential technology, it is expected to impact the world of work significantly. It is enhancing human intelligence, enabling individual and group decision makers to utilise great volumes of data in evidence-based decisions. It can also aid humans in complex work requiring creativity and judgment, and will likely increasingly substitute for routine labour (Dupress, 2015a). In anticipation for the exponential growth of AI, Silicon Valley has been preparing for AI integration into nearly all things considering computers. Tech leaders believe that AI will become essential to any form of data processing and analysis instead of being a useful extra (Hardy, 2016).

Since the first contact with the concept of AI in 1956, the field has developed along three vectors. The first, machine learning, emulates the brain's ability to identify patterns. The second, knowledge engineering, seeks to utilise expert knowledge in narrow domain and task-specific problem solving. The third, involves reverse engineering of the brain. Tools such as electroencephalograms (EEGs) and functional magnetic resonance imaging are used to identify what parts of the brain perform specialised tasks. Researchers then attempt to replicate those tasks in software and hardware using similar principles of operation. The hardware development that stem from this work is referred to as neuromorphic, or cognitive computing, chips that replicate some neural processes in the brain (Dupress, 2015a). Refer to the section on computer processing for more details.

The most intricate focus of AI (above machine learning) is to achieve true "intelligence". This spans wider than the ability to learn, but also to other more human-like features such as speech recognition and the ability to communicate. Looking further down the line, AI includes the ability to perform tasks and cognitive reasoning like humans do (Knight, 2016b).

Machine Learning

For machines to learn different tasks it takes time and various procedures. For example, for a machine with a two-pronged grip to learn to pick up something like a paint brush, it first has to view the brush from multiple angles and measure the depth to it. It can then attempt to pick the brush up and has to measure the right amount of force to apply in order to have a successful, yet non-destructive, grip. This learning process is similar to the learning phase humans experience during their childhood. For machines however, it is possible to pass this learning on to another machine and in effect reducing much of the time required for this learning process (Schaffer, 2016).

The Deep Learning algorithm is a powerful general-purpose form of machine learning. It uses a variant of neural networks to perform high-level abstractions such as voice or image pattern recognition. For example, Google is using Deep Learning with its Android phone to recognize voice commands and on its social network to identify and tag images. Facebook is exploring Deep Learning as a means to target ads and identify faces and objects (Dupress, 2015a). Another example of the application of Deep Learning is Google's AlphaGo, which beat 18-time world Go (a Chinese board game) champion Lee Sedol 4-1. Impressive as it were, many shortcomings with AI were also identified, among which is the fact that Deep Learning still requires more time to learn than a human does (Knight, 2016b).

Great progress is however being made for machine learning in general. Another sub-set of this technology, termed deep reinforcement learning, has been applied in a Japanese company called Fanuc. The company created a robot that can learn a new task, like picking widgets out of one box and putting them into another container, overnight. Come morning, the machine should have mastered the job as well as if it had been programmed by an expert. Robotics researchers are testing deep reinforcement learning as a way to simplify and speed up the programming of robots that do factory-type work (Knight, 2016c).

For smart machines and the digital mesh to be viable to organisations, they require intense computing architecture. In order to provide this, high-powered and ultra-efficient neuromorphic architectures are required. The underlying technology here is field-programmable gate arrays (FPGAs), which are integrated circuits that can be programmed in the field after manufacture. This technology provides significant gains, such as the ability to run at high speeds and with high energy efficiency. What this technology will allow, is the distribution of algorithms into small devices with low electrical power in the device mesh. Correspondingly this will deliver advanced machine learning capabilities into the tiniest IoT endpoints, such as cars, homes, wristwatches and even human beings (Gartner, 2015)

In mining, particularly in Australia, the move towards autonomous vehicles and automated technologies has already revolutionised operations. As the "intelligence" of these machines grows, they will be able to perform more and more complex tasks. Some of which include maintenance and repair activities on equipment and other machinery, hazardous processing activities and more. This will reduce labour costs and enhances productivity as a result. It is not unlikely for companies to ultimately operate fully autonomous mines, concentrating labour in centralised functional hubs rather than in remote regions (DTTL, 2016).

Advanced Machine Learning

In advanced machine learning, Deep Neural Nets (denoted as DNNs, which is an advanced form of machine learning particularly applicable to large complex datasets) is what makes smart machines appear "intelligent". DNNs enable hardware- or software-based machines to learn for themselves all of the features within the environment that they operate, from broad sweeping abstract classes of content to fine details. This goes beyond normal computing and information management to create systems that can autonomously learn to perceive the world independent of human input or assistance. The growing amount of data input sources and the complexity of information makes manual analysis uneconomic and infeasible. DNNs automate information classification and analysis tasks, making it possible to address key challenges relating to the Information of Everything (IoE) trend (Gartner, 2015).

Amplified Intelligence

One of the more promising applications of AI is not replacing workers, but augmenting their capabilities. When built to enhance an individual's knowledge and deployed seamlessly at the point of business impact, advanced analytics in conjunction with artificial intelligence can help amplify our own intelligence for more effective decision making (Dupress, 2015b).

Amplified intelligence is in its early days, but the potential use cases are extensive. Deloitte University Press (Dupress, 2015b), sets out various examples of use cases such as where: The medical community can now analyse billions of web links to predict the spread of a virus. The intelligence community can now inspect global calls, texts, and emails to identify possible terrorists. Farmers can use data collected by their equipment, from almost every foot of each planting row, to increase crop yields. Companies in fields such as accounting, law, and health care could let frontline specialists harness research, diagnostics, and case histories, which could arm all practitioners with the knowledge of their organisation's leading practices as well as with the whole of academic, clinical, and practical experience. Risk and fraud detection, preventative maintenance, and productivity plays across the supply chain are also viable candidates. Next-generation soldier programs are being designed for enhanced vision, hearing, and augmented situational awareness delivered in real time in the midst of battle. These range from maps to facial recognition to advanced weapon system controls.

Autonomous Agents and Things

Machine learning gives rise to a spectrum of smart machine implementations. These include robots, autonomous vehicles, virtual personal assistance (VPAs) and smart advisors, which are able to act in an autonomous (or semi-autonomous) manner (Gartner, 2015).

Advances in physical smart machines such as robots open up great potential in many areas, however, the software-based smart machines have both a more near-term and a broader impact. VPAs (e.g. Google Now, Microsoft's Cortana and Apple's Siri) are becoming smarter and are precursors to autonomous agents. The emerging notion of machine-based assistance feeds into the ambient user experience in which an autonomous agent becomes the main user interface. Therefore, instead of interacting with menus, forms and buttons on a smartphone, the user would speak to an app which functions as an intelligent agent (Gartner, 2015).

Significance of the information

While machine learning, and potentially other sub-sets of AI as well, can be harnessed in the working environment to achieve great gains, the broader impact of AI on everyday life needs to be assessed as well. It is likely that the growth of this technology will enable more possibilities in the world of information and physical technologies. The way people interact with these worlds may also impact the way they perform their tasks. With the increase in consumer available technologies and access to the internet, all levels of an organisation will have employees that bring with them their own set of technological assistance to the workplace. The use of personal smartphones for communication, setting up meetings and reminder, and sourcing information for use at work is potentially only the peak of the iceberg. Companies should remain aware of this growing opportunity as it may be exploited to improve worker efficiency, save on company costs and more. IT leaders should explore how autonomous agents and things can be used to augment human activity by assisting humans with their tasks in such a way that more time is freed up for activities specifically limited to human abilities. These kinds of technologies may be accessed through personal devices as well as company specific technologies.

2.5.5. Augmented Reality & Virtual Reality

Virtual reality (VR) makes it possible for a user to immersive himself within a computer generated environment, which can either be a manufacturing of an actual place or an imaginary one. In contrast, augmented reality (AR) overlays contextual information on the immediate physical environment the user sees. This way AR blends digital components (e.g. virtual elements such as text or 3D models) with real life. Both of these sensory (predominantly visual) technologies allow the deployment of technology in ways that were previously infeasible or even impossible (Dupress, 2016a).

The future of mobile is tilting increasingly towards wearable technologies, especially with the progressive adoption of AR and VR solutions in different markets. These technologies have the potential to reshape business processes, or fundamentally recast user experiences. In this regard, AR and VR offer user experiences built around natural models of interaction, such as posture, gesture and gaze. In this way the interaction with technology shifts away from a screen and towards the real and augmented, or a simulated, world around the user. This evolution of the interaction between human and computer technologies is displayed in Figure 2.5.5a. Looking at this evolution, the notion towards a profound impact on the interaction between man and machine (as we currently know it) can be seen (Dupress, 2016a).

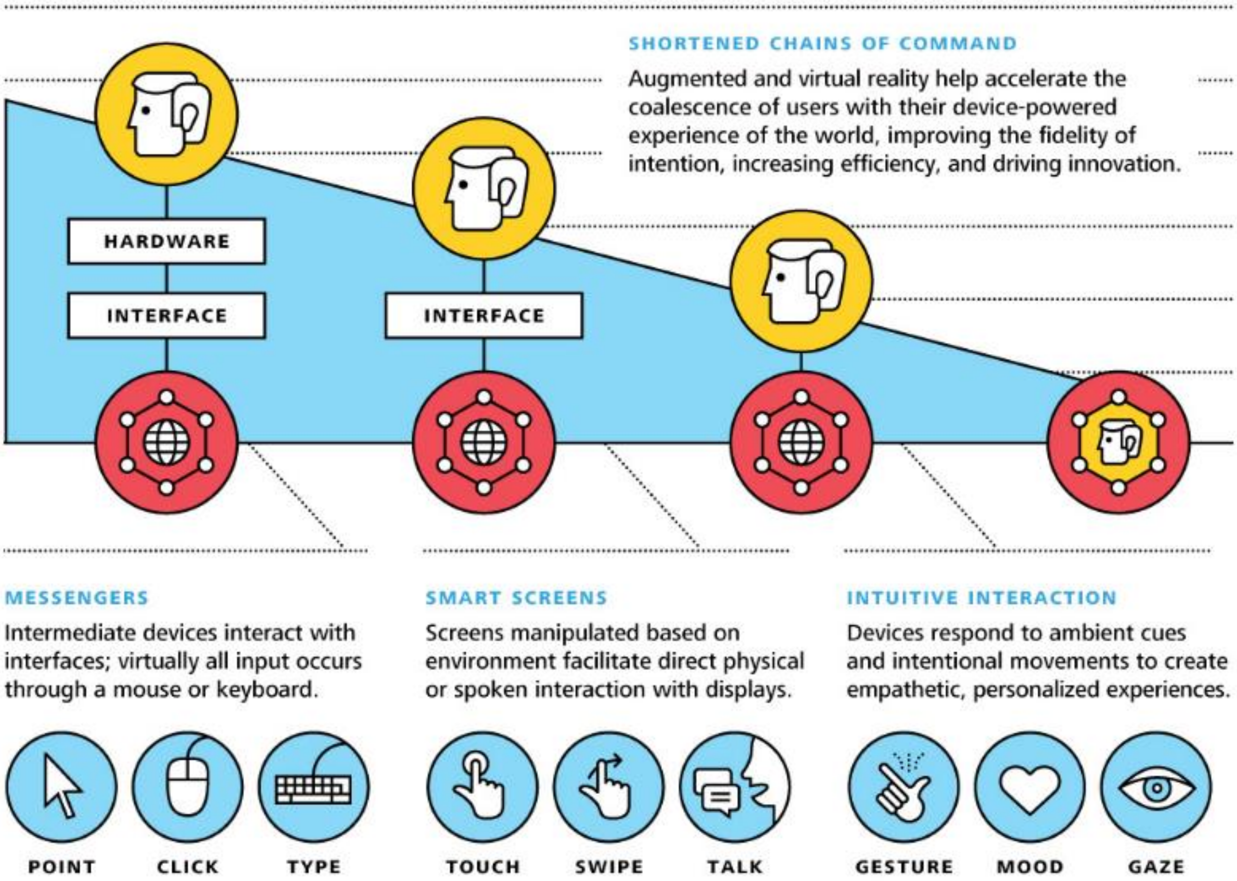


Figure 2.5.5a: The evolution of interaction with computer-based technologies (Dupress, 2016a)

This progress is taking place at a rapid rate, with various companies driving the development of both AR and VR. An example is Leap Motion's Orion, which allows developers to create virtual reality apps that incorporate a user's finger movements and not simply hand gestures alone. This motion control technology allows "finger-level precision", as shown in Figure 2.5.5b, which is a breakthrough in the accuracy of this technology type. This can be done with devices that allow the full immersion of a user into a virtual environment, such as with the Oculus Rift (Terdiman, 2016).

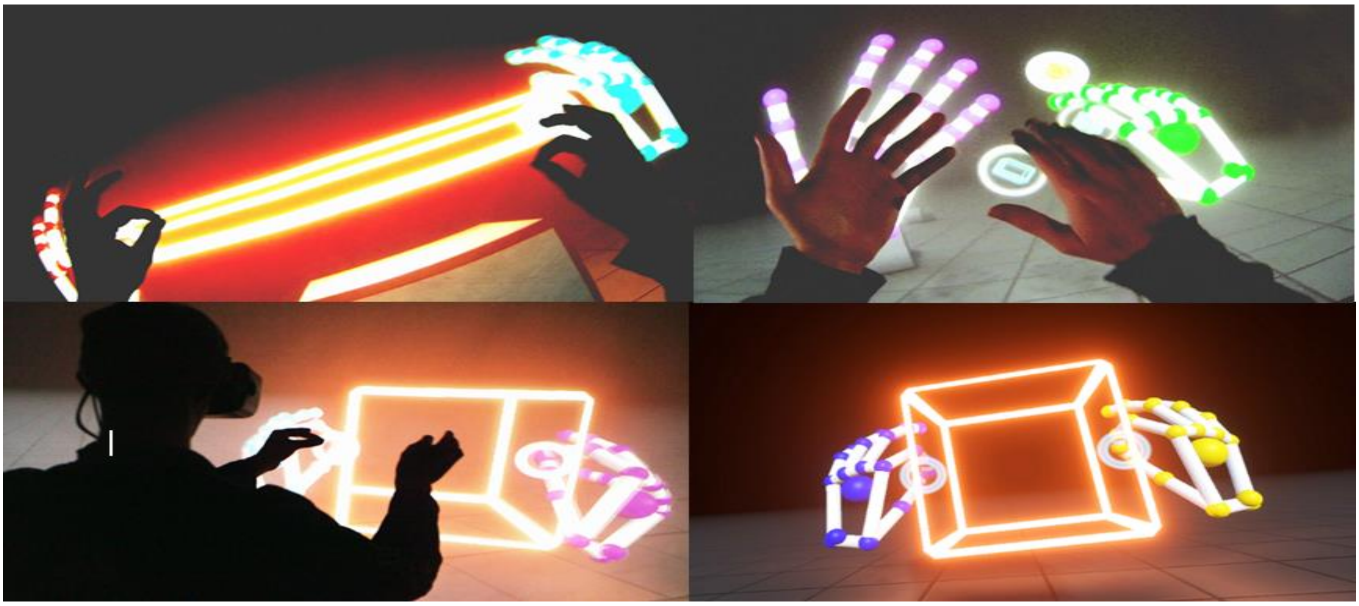


Figure 2.5.5b: Leap Motion's Orion allows finger-level precision control of virtual elements (Terdiman, 2016)

As for AR, it can be accessed through a variety of devices, ranging from smartphones and tablets to specialised AR-headgear (Head Up Displays, Eyewear, Head Mounted Displays etc.). Most of these do not deliver high quality displays or accuracy in appropriate depth perception. As a result, the AR field too is evolving towards hardware that will deliver more "intuitive reaction". In this regard a company called Magic Leap has been doing great amounts of R&D with major investment backing from large technology companies, including Google (Metz, 2015). Magic Leap aims to create a mixed reality, where the digital elements get blended into the real world the user finds himself in. The company places great focus on the neuroscience behind the understanding of how the human brain perceives light and how it is processed through the eyes to form a picture in the mind. Magic Leap wishes to tap into this natural brain function, by providing additional light inputs to create elements that are not present in reality but which can only be distinguished if designed to do so. Figure 2.5.5c is an example from Magic Leap, where a virtual robot appears to be held in a person's hand (Loizos, 2016).

Figure 2.5.5c: Virtual robot blended into the view of the real-world (Metz, 2015)

How these technologies can be used in practice is something of growing importance. Deloitte University Press (Dupress), provides examples of AR and VR applications throughout various industries, (Dupress, 2016a):

- **Communication and collaboration**: AR and VR may replace one-on-one human interaction in many environments. Both technologies offer IT opportunities that changes the way information is reported and shared and how people take action. On-site inventory inspection and viewing is possible for different products, parts and consumables. Engineering teams can collaborate in real time, on an international level, to test and refine a single design.
- **Training and simulation**: Both AR and VR will play an active role in retooling high-cost training and simulation environments. This type of application also allows the rehearsal of critical scenarios without the risk of real-world consequences. By creating parallel processes that leverage remote controls and robotics with the visual aid from AR or VR, employees could potentially even be removed from dangerous, real-world analogues altogether. Full-scale computer-rendered structures can also be created in a virtual environment, in which a person can get a sense of the size and implications of the model before physical construction commences.
- **Field and customer service**: AR and VR holds potential to be used in tandem with a variety of other technologies. For example, deploying augmented interfaces that pair with connected devices, sensing objects, and relational data can deliver task-specific information to workers in the field in context and on demand. Augmented solutions can overlay an engine's service hours, component temperature, and

service panel details into a mechanic's field of vision. Likewise, virtual solutions can immerse customer service agents in collaborative scenarios featuring perceptive conversations and problem-solving. Remote experts can see what field reps see and provide guidance as they perform maintenance or mechanical tasks. This will redefine the definition of remote collaboration as well as that of tele-presence and tele-work.

- **Customer experience and interactive marketing**: AR and VR offer potential new ways to interact with products and services. Immersion into replications of distant sites and structures is also possible.

Looking at VR in isolation, VR tools can be utilised to create immersive environments which provides enhanced visibility to large-scale designs. This capability could make it possible to simulate design decisions and consider the operational implications to layout, equipment placement, and other elements that impact factors such as operation and maintenance (Deloitte, 2016). VR therapy is also highly successful in transforming a user's mental and emotional state. Due to this trait, it could have wide range of applications in healthcare. Examples span from pain management, to paediatric care, and treating psychological conditions like PTSD and anxiety disorders. VR designed games have also proved helpful in treating burn victims, by drastically reducing their need for highly addictive narcotic medications to distract them from the pain (Smith & Pridgeon, 2016).

For training and teaching applications, VR has also found notable applications. An example is the creation of a Virtual Laboratory, which hosts around $10million worth of equipment. The virtual lab equipment can be used by students in the virtual environment with no real-life operating expenses or associated hazards, in order to conduct scientific experiments. When exposing students to 2 hours of learning, students using only the Virtual Laboratory simulations achieved 76% improved learning effectiveness compared to students that were exposed to traditional teaching methods. When combining the Virtual simulations with personal teaching and mentoring methods, an increase of 101% in learning effectiveness was measured (Bodekaer, 2016).

Both VR and AR technologies allow the users to bridge the language barrier in working environments. They further also remove the reliance on reading ability, due to their highly visual nature, coping for the lack of education in certain workforces and countries. Studies indicate that people that are exposed to immersive education (a teaching method that utilises immersive technologies such as VR, AR and other methods) also have better memory retention. An example from a study in the U.S. indicated an 80% increase in the learning curve for students during a test, where the teaching time required of certain concepts was reduced from 3 hours to 30 minutes (ImmersiveEducation, 2014).

In the construction and industrial industries, workers in the field regularly don protective goggles, vests, and helmets, along with tool belts and other items that help them perform specific tasks. Smart wearables, such as augmented and virtual reality tools, therefore, represent a natural progression. Companies are exploring applications of AR technologies for worker assistance. Examples include helping to train unskilled labour remotely to perform highly technical tasks, providing mobile monitoring capabilities that display system-status details in real time, and using smart helmets that are geotagged to provide location-relevant information to field workers (Dupress, 2016a).

In the long term, artificial intelligence and machine learning can help refine the information that field workers receive, and enhance the AR interface between people and data (Dupress, 2016a). Other potential AR applications related to the mining industry specifically were identified by Jacobs (2015), these included:

- Mine planning phase
- Solidified, visual milestone agreements
- Underground navigation
- Mine layout visualisation

- Incident/event recreation
- Historical mine site recreation
- Museum visits
- Selection & purchase of inventory
- Mine construction
- Training & simulation
- Crash tests
- Subsurface visualisation
- Maintenance and repair
- General task assistance
- Mine navigation
- Remote collaboration
- Production and safety
- Employee identification and monitoring systems
- Emergency management
- Search and rescue

Based on practical AR applications already in existence, Jacobs (2015) created the following conceptual applications for the mining environment:

- Navigational Aid & Operator Assistance;
- Maintenance and Repair Tasks;
- Provision of Real-Time Information;
- Drilling work (this application consisted of technologies in existence, although the AR application itself has not yet been demonstrated to a similar extent in another environment).

For navigational aid and operator assistance, some of the potential AR uses include guidance during equipment usage and the overlaying of information that could provide assistance for more effective decision making. Figure 2.5.5d shows an example of a mine with high dust (or similarly, high rain fall) conditions, where AR can be used to create a digital overlay of important objects, road boundaries and other vehicles which may otherwise not be visible. Figure 2.5.5e provides an example of operator assistance through the provision of different kinds of information to assist with decision making and to enhance the operator's interaction with the machine (Jacobs, 2015).

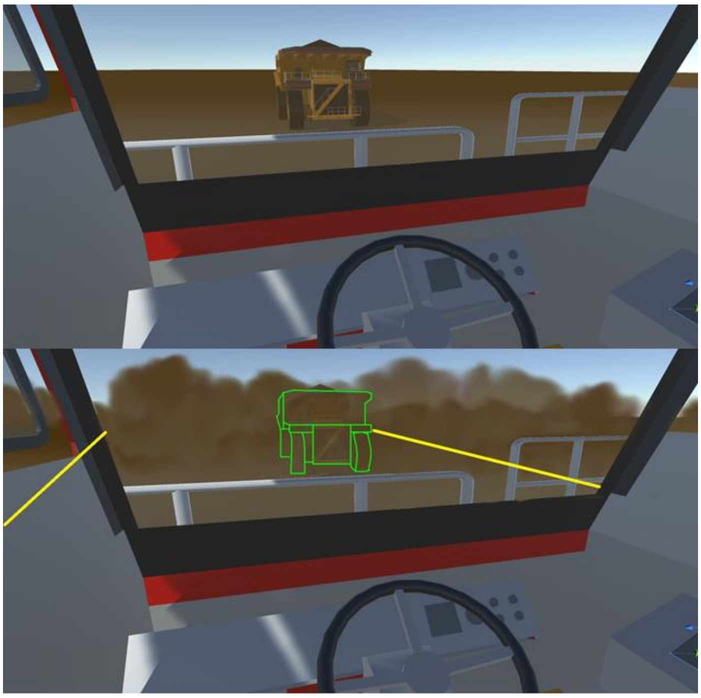


Figure 2.5.5d: An augmented outline of an approaching haul truck (Jacobs, 2015)

Figure 2.5.5e: Augmented overlays for operators (Jacobs, 2015)

Similar to major automobile companies that employ AR for maintenance and repair tasks, can AR technology be used to provide task assistance to mechanics and engineers that need to perform work on mining equipment and machinery (Jacobs, 2015). Figure 2.5.5f shows an example from BMW, who uses AR to provide step-by-step instructions to skilled mechanics when conducting work on certain automobile models. Figure 2.5.5g indicates a similar application from Continental.

Figure 2.5.5f: BMW uses AR to provide mechanics with step-by-step instructions (Driscol, 2013)

Figure 2.5.5g: AR task assistance from Continental (Continental, 2015)

The provision of real-time information refers to any scenario where informational inputs, while performing a task or activity, may prove beneficial to a user. Examples include guidance to perform pre-emptive inspections on equipment, machinery and other assets in order to prevent or reduce unplanned maintenance or breakdowns. Warning signals could also prove useful for safety applications, such as for approaching equipment or potential hazard identification. Figure 2.5.5h is an example of a warning pop-up on AR eyewear when a driver is following too close behind a loaded haul truck.

Figure 2.5.5h: Warning system through AR (Jacobs, 2015)

In terms of potential drilling applications, AR could firstly be used to eliminate the need to mark drill holes. Figure 2.5.5i shows a concept for overlaying a virtual drill pattern according to pre-set burden and spacing inputs. When combining drilling systems with directional drilling technology from the oil and gas industry (see Figure 2.5.5j for an example of a steerable drill head), AR could potentially also be applied to assist in improving drilling accuracy. Figure 2.5.5k is a representation of a real-time visualisation of a drill-head and rod underground, as drilling is taking place. By tapping into the information sent to the drilling machine from drill-head tracking technologies, a wearer of an AR device would be able to both see and steer the drill-head towards the desired destination (Jacobs, 2015.

Figure 2.5.5i: AR overlain drilling pattern concept (Jacobs, 2015)

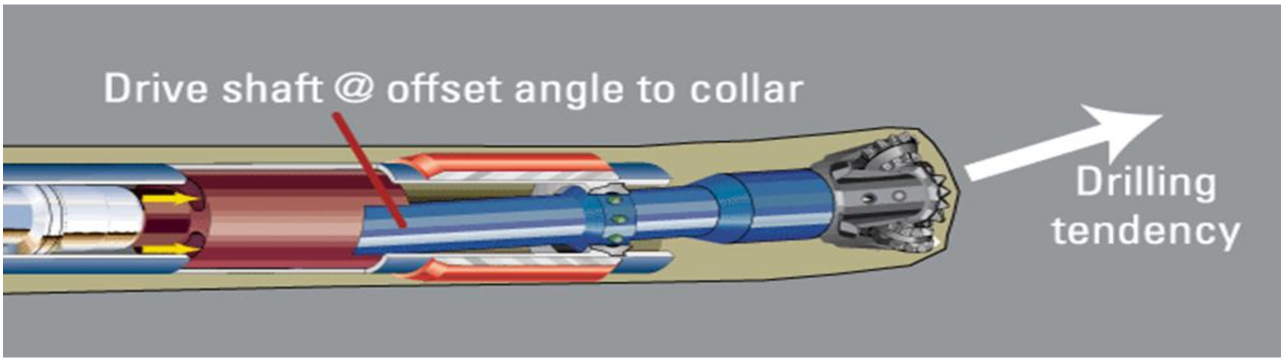


Figure 2.5.5j: Cross-section of drill-head used in directional drilling (Schlumberger, 2002)

Figure 2.5.5k: Concept for an augmented drill hole with indicated deflection on the drill head (Jacobs, 2015)

Many other potential applications exist for both AR and VR technologies. As these technologies mature and as they are increasingly able to synchronise with other technologies, so too will more applications become a reality (Jacobs, 2015). As a result, AR and VR should be an extension of an organisation's digital strategy, to apply new technologies to transform customer and stakeholder engagement and employee empowerment (Dupress, 2016a).

Significance of the study

AR and VR may bring an entirely different means to the way in which people interact with and use technology. This impact may span nearly all forms of technologies, both physical and digital. New technological applications may open up due to this potential coming change in the boundary between man and machine. This possibility alone may hold greater potential value than the mere use of AR and VR as standalone technologies. With that said, both of these technologies have demonstrated considerable value with numerous existing and potential applications. It should then also be borne in mind that both are still in the early phases of their adoption and technological growth curves, meaning that much more may still be achieved through their use.

2.5.6. Ambient User Experience

The Device Mesh creates the foundation for a new, continuous and ambient user experience. Immersive technologies creating immersive environments through AR and VR hold significant potential for human-to-human and human-to-machine interaction. This extends to the associated experience in doing so. The ambient user experience preserves continuity across boundaries of the device mesh, time and space. The experience seamlessly flows across a shifting set of devices and various interaction channels that blend the physical, virtual and also electronic environments as a user moves from one place to the next (Gartner, 2015).

As mobile apps play an increasingly strategic role and focus in work and private life, the leading edge hinges more and more on the provided experience to users. The focus for mobile applications will further shift more towards exploiting different devices (including IoT sensors), common objects (e.g. automobiles), or even factories. Designing these advanced ambient user experiences will be a major differentiator in software development in order to enhance both the experience when using the software, as well as the ease and efficiency benefits that come with it (Gartner, 2015).

Significance of the information

While this technology will not have a direct impact on mining, it will play a major role in the interaction of users with software (whether mobile, on machinery, robotics, augmented devices or autonomous equipment). This interaction will become more and more important when connecting more (if not all) devices, equipment, machines and other technologies together in the device mesh. It will also impact how people interact with both the devices and the information that they produce. As a result, the concept of ambient user experience will directly impact the way people use technology and therefore the efficiency and state of mind they attain from it.

2.5.6. Cloud Technology

With cloud technology any computer application or service can be delivered over a network or the Internet, with minimal or no local software or processing power required. In order to do this, IT resources (such as computation and storage) are made available on an as-needed basis. This means that when extra capacity or computing is needed, it is seamlessly added, without requiring up-front investment in new hardware or programming. The cloud is enabling the explosive growth of Internet-based services, from search to streaming media to offline storage and IT services. It also provides the background processing capabilities that enable mobile Internet devices to do things like respond to spoken commands to ask for directions. The cloud can also improve the economics of IT for companies and governments, as well as provide greater flexibility and responsiveness. Finally, cloud technology can enable entirely new business models, including all kinds of pay-as-you-go service models (McKinsey Global Institute, 2013).

The growth of cloud technology will change the magnitude of what small businesses and organisations can accomplish. IT capabilities and back-office services, that were traditionally only available to larger firms, will become available to a greater spectrum of smaller firms and institutions. The cost of the capabilities and services will further also drastically decrease (VanderMey, 2015).

In short, cloud computing allows elastically scalable, self-service, computing. The convergence of cloud and mobile computing drives the growth of centrally coordinated applications that can be delivered to any device. On the near term, the focus for cloud computing will be on synchronising content and application state across multiple devices and addressing application portability across devices. Over time, applications will evolve to support simultaneous use of multiple devices (Gartner, 2014).

Significance of the study

Through Cloud services, leading to other services and technology applications such as XaaS, Tele-Presence and tele-work (e.g. through the use of AR and VR), the very concept of urbanisation may be challenged. People would no longer need to cluster together in order to find employment, or at least to a far less extent than ever before. A single expert may be able to service multiple working environments from one location, e.g. a highly skilled artisan, engineer or other specialist may work on eight mines at the same time (especially with the advancement of robotics which could take over certain human tasks). This could help address some of the challenges associated with an aging workforce and a difficulty to attract new blood to an industry plagued by a stigma of being dangerous, dirty, and unpleasant and situated in remote locations.

2.5.7. Cloud Services: Everything as a Service (XaaS)

Cloud technology gave rise to various cloud-based services, which are IT services that can be rendered to various environments or organisations without the need for the required physical infrastructure. As such a variety of services and applications are emerging for users to access on demand over the Internet, instead of utilising such services and applications via on-premises means. The all-encompassing term for these cloud services is Everything as a Service (XaaS), which also includes Software as a Service (SaaS), Infrastructure as a Service (IaaS), Platform as a Service (PaaS), Banking as a Service (BaaS), Storage as a Service (STaaS), Desktop as a Service (DaaS), Disaster Recovery as a Service (RaaS), Communications as a Service (CaaS), Network as a Service (NaaS), Monitoring as a Service (SaaS) and other emerging cloud services (adapted from Stroud (2016) and Dixon (2014)).

Significance of the study

Cloud services will gain traction as IT becomes increasingly embedded into all business, NGO and governmental environments. Any business should remain aware of available offerings before attempting to create in-house IT services, applications or other developments. Successful exploitation of XaaS type offerings will not only save on hardware, personnel, facility and other infrastructure costs, it will also reduce reliance on in-house personnel and shift various IT risks to outside of the organisation.

2.5.8. Communication

A few communication based technologies were analysed that may provide the most value for mining operations in current times. These technologies were different in context and application, ranging from human-to-human, human-to-machine and vehicle-to-vehicle communications.

Language Translation

A company called Waverlylabs has been driving the R&D of a wearable device that could be used in conjunction with an app on a person’s smartphone, to translate different languages as people speak. The wearable device would look similar to a normal hearing aid that fits into the ear. This device would then speak into the user’s ear in a language of his/her choice after the words of another person have been translated. Although the prototype version experiences a slight delay as it uses the app to translate between languages before delivering the message, it may bring major positive impacts for communication (Waverlylabs, 2016).

Figure 2.5.8: Wearable prototype translating a conversation between a French and an English speaker (Waverlylabs, 2016)

Significance of the study

Using this kind of communication technology may greatly alter the way numerous organisations function that are spread across borders and that have to deal with multiple languages in their employees and surrounding stakeholders. This could bridge the language barriers that people and companies have to deal with, which would be greatly beneficial for various circumstances. Some of the effects that may surface are on training, human-to-human and human-to-machine interaction, negotiations and relations with stakeholders. Artificial intelligence and machine learning may further greatly add to the scope of use and to the growth of this technology as well.

Secure Messaging

The morals and standards that society places on (or associates with) different technologies, or the applications thereof, greatly affects development, adoption, effectiveness in usage and the effect these technologies are allowed to have on the private and working environments. This extends beyond the use of computers and smartphones, to the notion of answering phone calls during a meeting, using social media and the degree of comfort people feel in confronting or merely communicating with their employing companies. The opposite holds true as well, where people's opinions of certain technology usage are also shaped by their working environments. An example of this can be seen in the use of private social media that has gotten numerous people dismissed, for various reasons. This has led to a more reserved use of this type of technology (e.g. Facebook) by many people.

Another example is secure messaging, which initially had the reputation of being for people that had something to hide. However, since a series of high-profile hacks in 2014 laid bare the private lives of several celebrities (as well as thousands of civilians), there has been massive interest in messaging (voice, text, photo, and video) that is meant to be fundamentally secure from misuse or misinterpretation. A new set of products emerged to take up this challenge, including everything from personal data vaults, to secure encrypted calls, to video chats and messages that self-destruct after a short delay (Kalaher, 2015).

Significance of the study

These types of technologies will become increasingly important for general communication on high managerial levels in companies that wish to secure sensitive information. Cyber security covers numerous IT communications and information in a company, but many informal (and formal) communications happen on private devices regardless of rank within a company. Organisations may wish to secure these communications as well, whether from competitors, their own employees or from those with malicious intent.

Secure messaging, especially the kinds that alloy anonymity or that will self-destruct, will also increase the likelihood of employees communicating with, confronting or relaying information to their employing companies. This could provide companies with valuable information, e.g. of impending strikes or disruptions, unlawful actions, dangerous behaviour or the general worker moral.

Companies would do well to investigate the implementation of such practices into their other social media and cyber security practices, especially in a world that is increasingly becoming more connected and digital.

Voice Interfaces

One of the most intuitive interactions with technology (e.g. with computers and smartphones) is through voice communication. Voice interfaces are easier to use than even touch screens, and they also reduce the time spent learning a new interface (e.g. of a different smartphone make or model, not to mention various software packages or complex machinery), which can be time-consuming and frustrating. Voice interfaces can also majorly reduce the time spent using such technologies by eliminating the need for typing (Knight, 2016d).

Baidu, a company founded in 2000 as China's answer to Google (which is currently blocked in China), is the largest Internet search engine in the country. Baidu is particularly making progress with voice recognition technology, especially due to the fact that Chinese characters are too complex to effectively use smartphone screens for typing them out (there are around 50,000 Chinese characters, although only around 8,000 are generally used). These advances could benefit other languages as well to aid communications with the machines we interact with. Other major key players in the field further include Google, Apple, Nuance and Facebook (Knight, 2016d).

These companies are striving to combine voice recognition and natural language understanding, to create effective speech interfaces. The result is that voice commands may become reliable enough to be used for interacting with all sorts of devices. Robots, machinery and various appliances, could be easier to control and operate if a user could simply "talk" with them. Advances in machine learning are making voice control more practical in order to accomplish this. Voice recognition and command technologies have developed to the point where they are no longer limited to only a small set of predetermined commands. The technology can also work in a noisy environment or when speaking across a room (Knight, 2016d).

Significance of the study

Mining companies that deal with difficulties in training operators and other personnel, to use certain pieces of technology, may wish to push service providers to integrate voice command technologies into their interfaces. This would reduce the time spent, complexity and cost for teaching and training of employees. Voice interfaces may also open up a larger portion of trainable workers to become skilled in using certain technologies or machinery, especially for operations that have to make use of large unskilled or poorly educated labour. Language translation technologies may also be integrated with such a system to incorporate non-major languages that often make up the majority of mining workforces.

Car-to-Car Communication

Car-to-car or vehicle-to-vehicle communication, allows cars to broadcast their position, speed, steering-wheel position, brake status, and other data to other vehicles within a few hundred meters. Other vehicles can then use that information to build a detailed picture of what is unfolding around them. This could reveal hazards that even the most careful and alert driver, or the best sensor system, would miss or fail to anticipate (Knight, 2015).

Many vehicles currently on the road already have instruments that use radar or ultrasound to detect obstacles or vehicles. The range of these sensors is however limited to a few car lengths, and these detection technologies cannot "see" past the nearest obstruction. What the car-to-car communication technology does differently, is it uses transmitters with a dedicated portion of the wireless spectrum as well as a new wireless standard, 802.11p, to communicate with and authenticate each message from other vehicles. As such it creates a network that uses the computers aboard each other vehicle within the network to communicate. Messages (or readings) from the surrounding vehicles in its own network are then processed in order to analyse the surrounding environment (Knight, 2015).

Car-to-car communication may have a bigger impact than the advanced vehicle automation technologies that have been more widely heralded. Though self-driving cars could eventually improve safety and bring other benefits, they remain imperfect and unproven in the short term. Currently sensors and software are too easily influenced by poor weather, unexpected obstacles or circumstances, or complex city driving. Simply networking cars together wirelessly is likely to have a bigger and more immediate effect on road safety before autonomous vehicles become fully adopted (Knight, 2015).

Between 2012 and 2014, the National Highway Traffic Safety Administration and the University of Michigan conducted studies on the technology in the U.S. They then concluded that the technology, as it currently stands, could prevent more than half a million accidents and more than a thousand fatalities in the United States every year (out of over 5 million crashes and 30,000 fatalities a year in the U.S.). This improvement was measured as revolutionary when compared to the value of human life (Knight, 2015).

Significance of the study

This technology may improve overall road safety and reduce road related incidents and fatalities. When arguing that worker mind-sets when driving off-site is a reflection of their adherence to safety protocols on-site, then this type of technology may bring a change in the way people conduct themselves both when driving and working. For the mining operation context, the technology may also prove useful as a substitute or enhancement of more readily used Proximity Detection Systems (PDS) in order to improve safety.

2.5.9. Computing Everywhere

As mobile devices (smart and simple, i.e. smart phones and other wearable electronic devices) continue to proliferate, it is predicted that there will be an increased emphasis on serving the needs of mobile users in diverse contexts and environments, as opposed to focussing on a device alone (Gartner, 2014).

Mobile devices form part of an expanded, and expanding, computing environment that includes consumer electronics as well as connected screens in the workplace and public space. As such, the overall environment will need to adapt to the requirements of the mobile user as more data and more intense processing is needed in the blend between using a mobile device for private and for working purposes. This will impact user experience design, partly from which the ambient user experience was born, and it also led to the emerging strategic technology termed the device mesh (Gartner, 2014).

Significance of the information

Mobile devices play increasingly more prominent roles in the daily lives of people, whether in low ranking (or low skill-level) jobs or in high ranking managerial positions. These devices, often personal devices, are being used more and more for work (for communication, e.g. emails, texts, voice calls, for computing requirements, e.g. calculations, and for knowledge or information sourcing, e.g. doing Internet searches or downloading a company document onto a smart phone), for learning purposes (reading articles, the news, doing Internet searches etc.), as well as personal use (whether communicational or entertainment purposes etc.). It is important for companies to manage this and find ways to extract value from the opportunities that these technologies bring, e.g. Mobile Internet and the ability to become more connected, i.e. through the IoT and the device mesh. There lies potential for efficiency increases when managing the way people interact with mobile technologies and making it easier to use a central node that connects various environments.

2.5.10. Internet of Things (IoT)

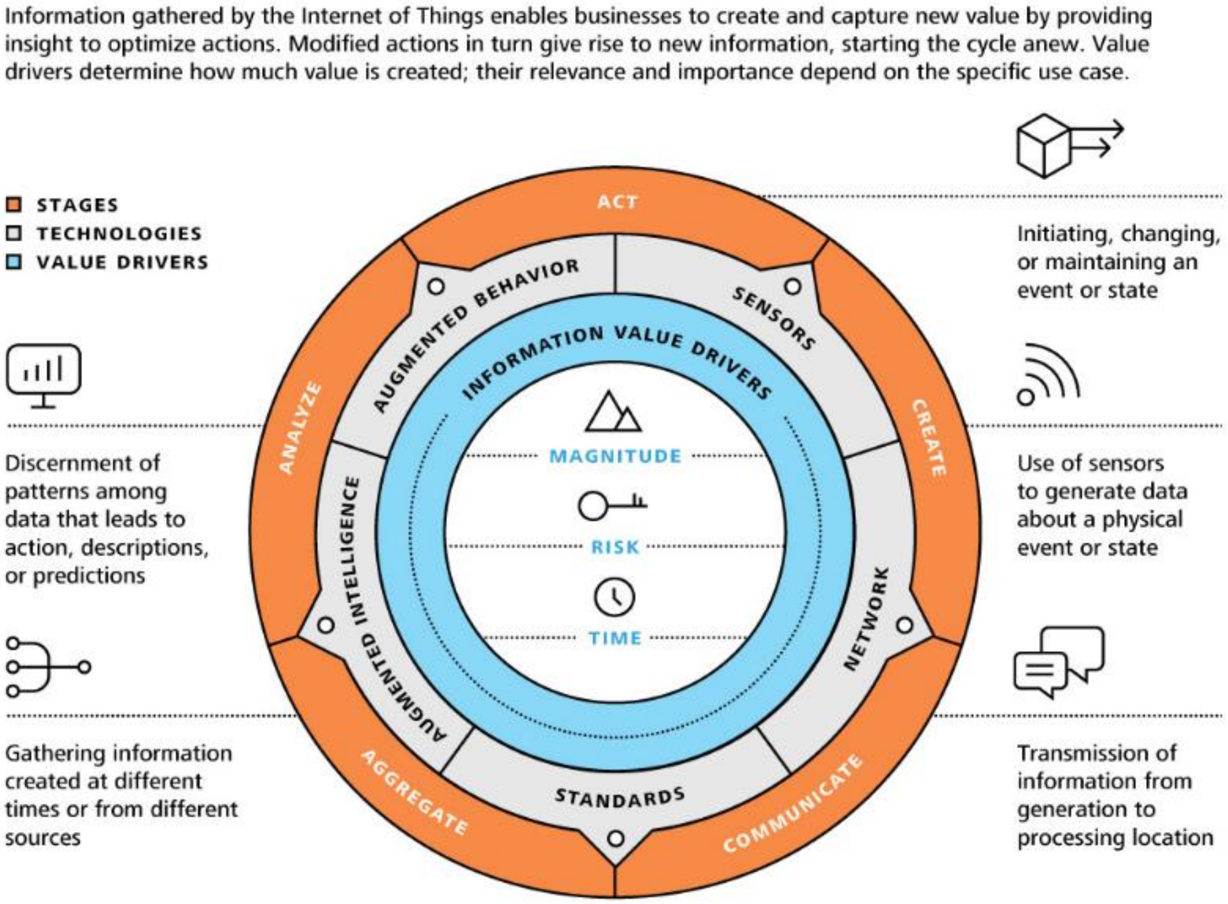
The Internet of Things (IoT) involves embedding sensors and actuators in machines and other physical objects to bring them into the connected world (namely internet connectivity). This allows the monitoring of the flow of products through a factory, measuring the moisture in a field of crops, and tracking the flow of water through utility pipes. The IoT allows businesses and public-sector organisations to manage assets, optimise performance, and create new business models. With remote monitoring, the IoT also has great potential to improve the health of patients with chronic illnesses and attack a major cause of rising health-care costs (McKinsey Global Institute, 2013). Going forward, more products and tools will be controlled via the internet and all kinds of data will be generated as a result. Sensors to collect these data, for processing and control purposes, will be able to obtain information on the health of machinery, the structural integrity of bridges, and even down to seemingly redundant information such as the temperatures in ovens (VanderMey, 2015).

Gartner, Inc. forecasts that 6.4 billion connected things will be in use worldwide in 2016, 30 percent more than in 2015, and that the number will reach 20.8 billion by 2020. In 2016, 5.5 million new things will get connected to network infrastructure each day. As the IoT grows, so too does the volume of data it generates. By some estimates, connected devices will generate 507.5 zettabytes (ZB, or 1 trillion gigabytes) of data per year by 2019, up from 134.5 ZB per year in 2014. Steps to implement IoT's component parts (namely sensors, devices, software, and connectivity), run the risk of being overwhelmed by the sheer magnitude of the digital data generated by connected devices (Dupress, 2016c).

Due to the wide variety of data formats existing in and resulting from the IoT, there is a surge towards adoption of Big Data Analytics techniques in order to not only cope with the information, but capitalise on it too. There is value in the information the IoT creates. IoT makes it possible to show companies when and where they are performing well, and with significant depth and accuracy. For this to happen, the information needs to be understood with great certainty and precision. This emphasises the importance of delving deep into insights, rather than adopting a generalist approach (Interquest Group, 2016).

IoT has powerful potential for boosting analytics efforts. Strategically deployed, analytics can help organisations translate IoT's digital data into meaningful insights. It can also drive opportunities to integrate and automate business processes in ways that were previously impossible. There is also a disruptive potential for reimagining business processes and, ultimately, rewiring business, government, and society. To realise that potential will mean to shift IoT applications' strategic focus toward not just sensing, but doing. As such, forward-thinking organisations are focusing their IoT initiatives less on underlying sensors, devices, and "smart" things, and more on developing approaches for managing data, leveraging existing infrastructure, and developing new business models (Dupress, 2016c).

One strategy involves harnessing the information created by the IoT ecosystem to augment worker capabilities, a process modelled in the Information Value Loop in Figure 2.5.10. Structures can be designed to enhance an individual's knowledge and natural abilities, and deployed at the point of business impact. As such, IoT in tandem with advanced analytics, can help amplify human intelligence for more effective decision-making (Dupress, 2016c).



Information gathered by the Internet of Things enables businesses to create and capture new value by providing insight to optimize actions. Modified actions in turn give rise to new information, starting the cycle anew. Value drivers determine how much value is created; their relevance and importance depend on the specific use case.

Figure 2.5.10: The Information Value Loop (Dupress, 2016c).

Companies may harness data-driven insights to augment or amplify operational activity in the form of transforming business processes, reimagining core systems and capabilities, and automating controls. Eventually, robotic process automation and advanced robotics will monitor events, aggregate sensor data from numerous sources, and use artificial intelligence capabilities to determine which course of action they can take to deliver the most desirable outcome (Dupress, 2016c).

As networks, servers, personal computers, mobile devices and various sensors become increasingly connected to the Internet and to each other, the application and integration of technology grows in potential. Along with a reduction in the costs to implement sensors, it becomes increasingly more feasible to collect data on a wide variety of mining equipment as well. This is empowering original equipment manufacturers (OEMs) to offer uptime guarantees designed to virtually eliminate all unplanned maintenance, provided that mining operations are able and willing to share operational data with suppliers. Considering the advantages of ensuring continued equipment uptime, some companies are exploring the feasibility of adopting cloud-based integrated IT platforms to facilitate collaboration with suppliers (DTTL, 2016).

A South African startup, called IoT.nxt, has developed software that allows nearly all devices to be connected and to share information. The software also creates a framework that moves business beyond islands of automation and towards a seamless horizontally and vertically integrated digital enterprise. The IoT.nxt platform creates enterprise wide data-connectivity between new data sources such as sensors or "things", less sophisticated legacy systems, enterprise systems, applications, machines and cloud services. This allows people and machines on any network, using any operating system, to connect and interact. Such a platform will allow greater interoperability and drive the IoT revolution (Jackson, 2016).

Organisations are encouraged to investigate how they can leverage different models to extract value from the IoT. Organisations should however not limit themselves to thinking that only the IoT (assets and machines) has the potential to leverage the four models classified as Manage, Monetize, Operate and Extend. These four basic usage models are created from the combination of data streams and services, by digitising everything. The four basic models can be applied to any of the four "Internets." For example, the pay-per-use model can be applied to assets (such as industrial equipment), services (such as pay-as-you-drive insurance), people (such as movers), places (such as parking spots) and systems (such as cloud services) (Gartner, 2014).

Significance of the study

The concept of the Internet of Things cannot be ignored in the coming digital age. It will form the source of nearly all operational data that needs to be fed into other technological and processing systems, such as advanced analytics and AI, to visualisation tools for amplified human intelligence. In the near future this may become a mandatory route for all operations that seek to survive the changing mining climate.

2.5.11. IoT Platforms

The IoT is an integral part of the digital mesh and ambient user experience, and the emerging IoT platforms are what make these technologies possible. IoT platforms also compliment the mesh app and service architecture by providing the connection between the back-end cloud technologies and the front end user interaction. IoT platforms constitute the work IT does behind the scenes from an architectural and a technology standpoint to make the IoT a reality. The management, security, integration and other technologies and standards of the IoT platform are the base set of capabilities for building, managing and securing elements within the IoT (Gartner, 2015).

Significance of the information

While IoT platforms do not have a direct impact on mining, it is a technology that will form a critical part of digital technologies and correspondingly also in the digital mine of the future. When attempting to exploit cloud and IoT technologies, it will be important to understand and correctly apply IoT platforms from an IT (or CIO) perspective.

2.5.12. Information of Everything (IoE)

There is not only one way in which IoT technologies will impact industries, there is also the vast quantities of data that is, and will continuously be, collected along the way. This data may hold massive value, subject to the ability to turn it into valuable information and/or knowledge. Similarly, on the broader scale everything within the digital mesh produces, uses and transmits data and information. The data and information goes beyond textual, audio and video information and further includes sensory and contextual information (Gartner, 2015).

IoE addresses this influx of data and information with strategies and technologies to link data from all these different data sources. Information has always existed everywhere (smart devices for example have been collecting some of these kinds of information since inception) but it has often been isolated, incomplete, unavailable or unintelligible. Advances in semantic tools such as graph databases as well as other emerging data classification and information analysis techniques will bring meaning to the often chaotic deluge of information (Gartner, 2015).

Significance of the study

IoE is a by-product of the information generated by the IoT. It is possible that much of the IoT's senseless data will become available through IoE incentives. Different entities could then make use of this sensible information. For example, instead of capitalising on current weather conditions as provided from the applicable sensors in the IoT, more value could be extracted if the broader sense of such weather sensor data is analysed. Such an analysis from the IoE would then be able to predict weather patterns and movements, as well as a predictive analysis of how it could impact current operations within a specific time period.

2.5.13. Mobile Internet

Internet-enabled mobile devices have dramatically altered the way of life for the people who own such devices, e.g. smart phones and tablets. The portion of Web browsing taking place on mobile devices is increasing and was projected to exceed wired internet use in 2015 already. Ubiquitous connectivity and an accelerated propagation of apps are enabling users to go about their daily routines with new ways of knowing, perceiving, and interacting with the physical world. The technology of the mobile Internet is further also continuously evolving, with intuitive interfaces and new formats (including wearable devices). The mobile Internet now has applications across businesses and the public sector, enabling more efficient delivery of many services and creating opportunities to increase workforce productivity. In developing economies, the mobile Internet could bring billions of people into the connected world and expand the integration of people and devices (McKinsey Global Institute, 2013).

Due to mobile access to the Internet, mobile technologies are transforming developing markets and opening access to critical services like education and healthcare. They are also improving financial inclusion and improving the efficiency of trade (McCallum, 2015). Currently more than two thirds of people on earth have access to a mobile phone. It is further expected that another two to three billion people are likely to gain access over the next decade. The result is that internet-related expenditures outpace even agriculture and energy, and it will continue to grow (VanderMey, 2015). This growth cannot be ignored and the advantages that come with mobile internet and smartphones need to be well investigated in order for business leaders to take advantage thereof.

Various projects are underway to increase access to the Internet across the globe, increase the speed of Internet access, or to harness the energy generated from the airwaves in mobile signals. Some may provide mobile Internet access and others will expand wired access which can in turn lead to more mobile Internet access as well (e.g. through WiFi). A few examples of such projects will now briefly be discussed.

Project Loon

Google has been sending hundreds of air balloons into the stratosphere, up to an altitude of around 20km. The balloons form a radio link to a telecommunications network on the ground and then beams down high-speed cellular Internet coverage to smartphones and other devices in a wide area beneath its own proximity. Google believes that these balloons (an example can be seen in Figure 2.5.13) can bring widespread economic and social benefits, by providing Internet access to the estimated 60% of people around the world who do not have online access. The balloons have mostly been launched into the Southern hemisphere, but the company aims to launch many more around the globe (Simonite, 2015).

Figure 2.5.13: Project Loon Air Balloon from Google (Solveforx, 2016)

Service providers could use the chunks of the airwaves they already own and put up ground antennas to link the balloons into their networks. Google expects cellular network providers to rent access to the balloons in order to expand their own networks and this has already seen adoption in various regions and countries (e.g. large adoption drive in India). Project Loon is also further along in terms of progress, compared to other projects such as Internet delivered by drones (Google and Facebook are working on such projects) or by satellite (an idea being pursued by SpaceX CEO Elon Musk) (Simonite, 2015).

5G Internet

5G (or fifth generation wireless technology) is currently under development. This technology is expected to provide a great advancement over current wireless technology (4G), by offering mobile Internet speeds that will allow users to reach expected download speeds of over 10 gigabits per second. This will allow the download of large files (such as entire company databases, models, movies, or other large-sized visuals) within seconds. Setting global standards for such a new era of Internet speeds will take lengthy negotiations, which are expected to persist until around 2019, after which rollout to various cities and countries can begin. Access to 5G Internet for commercial consumers is then expected to only become available well into the next decade. However, this technology will create possibilities for new types of mobile applications and widen the scope of what can be accomplished through mobile internet applications (Scott, 2016).

5G will further also greatly progress network expansion for the connection of all sorts of devices and sensors (within the IoT and Device Mesh). These kinds of networks require large quantities of data transfer as well as faster connection speeds to allow improved network efficiencies. The ultra-fast mobile Internet speeds from 5G will also greatly benefit autonomous vehicles and robotics, by allowing faster response times due to faster communication between devices (Scott, 2016).

Power from the air

Researchers at the University of Washington have demonstrated that Internet-connected temperature and motion sensors, and even a camera, can be powered by harnessing energy generated from nearby TV, radio, cell-phone, or Wi-Fi signals. The technology used to harvest this energy from airwaves is expected to reach commercialisation due to significant successes in transferring power wirelessly while allowing the devices to communicate back with the source. The technology allows a device to selectively reflect incoming signals in order to construct a new signal, while absorbing some of the energy from the signal being modified to power its own circuits (Harris, 2016). As this technology matures, wireless power supply to more electronic devices may become possible. As the technology stands currently, it can already provide power supplies to sensors for minor technology usages such as temperature and motion sensors (and possibly other IoT sensors as well). A device without its own power supply may also be powered for sending an SOS signal, to allow browsing the internet or to use a camera.

Data Transfer via Laser

Lasers form an efficient manner with which to transfer data over significant distances. Laser beams can hold a lot of information and propagate over great distances. They also don't require a dedicated spectrum like cellular networks, meaning they can be used to set up ad hoc data links to off-grid locations. Due to the fact that such a data transfer method uses line-of-sight light transmissions, more than one can also be installed within the same area without interference (Condlife, 2016).

The major problem with laser-based data transfer is however the fact that a beam of light becomes wider as it travels through space, making it difficult to focus the beam on a small receiver. Facebook is busy developing a system that is able to get around this challenge by using fluorescent materials, instead of traditional optics, to collect light from data-carrying laser beams. It is possible that the success from this project may bring mobile Internet access to remote locations, especially with Facebook's plan to use drones to beam the lasers between strategic locations (Condlife, 2016).

Significance of the study

The growth of mobile Internet, as a technology providing access to the Internet, is the key component in most IT-based technologies. It will enable the emergence of even more applications that require Internet access in order to perform some sort of task or provide certain information. Without the advancement in this field, IT itself may not reach its full potential. This includes all technologies that make up the digitisation drive, such as cloud technology, AR, VR, IoT, remote technologies, automation and many more. Companies that wish to exploit the benefits that come with the Internet need to remain aware of projects that may add value to remote locations. This extends beyond locations or areas that previously struggled with Internet connectivity to remote locations within warehouses and working environments as well.

2.5.14. Remote Operation

Remote Operation, as a culmination of technological application, has been highlighted as an integral part in the Mine of the Future initiative. In many ways, remote operations may best define the future of the mining enterprise. It requires the amalgamation of information, collaboration, smarter and leaner organisation, governance and workforce, visualization and business model innovation (IBM, 2009).

Remote operations expand the potential skilled workforce to reach a broader range of effective working environments, but it brings other benefits as well. By moving control centres to centralised locations, mining performance can be measured across sites and locations. Measurement processes can be standardised and universally adopted. Knowledge and experts can be shared across the enterprise more easily via collaboration. Collaboration also becomes more effective and possible within a wider scope of the total workforce. Procurement programs can be unified across the enterprise for greater synergies and cost control, and stakeholder relationships and production orders can be managed on a global scale (IBM, 2009).

When automation is then also applied, it allows mining sites across the enterprise to be managed centrally. This leads to increased synergies and advanced capabilities by unifying processes, information, control and knowledge (operational, economical, market etc.). A lean, centralised management function can then achieve improved control of the enterprise. The reduction of redundant management further reduces costs, while making governance and coordination more streamlined and effective. Leadership and staff can be located in optimal locations independent of mine sites, reducing travel time and costs as well as allowing faster travelling to any location when the need does arise. When appropriate, automated, robotic and remotely controlled equipment and transportation can be used to improve productivity, safety and to boost employee retention (IBM, 2009).

Other benefits that arise from remote operations include more expansive resource pools that are available at different costs structures. The mitigation of redundant expenses and other cost benefits further arise from improved automation and centralisation. Greater control can also be achieved over the entire enterprise, linking various components for organisational optimisation. Lastly, the unification of processes, information and knowledge lead to improved efficiency, prowess, speed and synergies for all systems and sub-systems related to the mining venture (IBM, 2009). Refer to the case study on Riot Tinto for more information on how Remote Operations have already been implemented successfully in mining.

Significance of the study

Remote Operations are the final destination of the application of technologies such as mechanisation and automation, and all of the associated technologies that constitute these two categories. The benefits that may be reaped from them are clearly defined within the study, and these are above and beyond the benefits that the individual technologies may bring within an operation as described within the rest of the literature study. Remote Operations may not necessarily form a technology that can be slotted in on a technology map, but it should be an end goal for a mining enterprise that aims for full implementation of automation and remote mining technologies.

2.5.15. Social Technologies: Social Networking & Digital Workforce Engagement

By using mobile and social technologies, mining companies can stay connected with mineworkers. This bridges the barrier between management and employees and could lead to companies obtaining valuable information from its workforce. This concept is not limited to traditional portals that allow employees to review internal memos or sign up for training programs. When companies use social media, wikis, widgets, blogs, tagging, rich media and mashups to deliver personalised messages in real time, they are encouraging collaboration. This in turn enhances productivity and unleashes creativity across the entirety of the organisation (DTTL, 2016).

For their part, NGOs, special interest groups and activists have more tools in their arsenal than ever before. Increasingly, these organisations work to sway public opinion through online communications, such as social media and campaigns geared to go viral. As activist organisations become more vocal, and more organised, they are also able to exert greater pressure on both governments and communities considering mining project approvals (DTTL, 2016).

Mining companies should “get serious about social”. Although most mining companies rely on some social media to engage with various stakeholders, they are not on the forefront of current emerging trends. This puts them at a disadvantage to organisations that are capable of mobilising full-scale social media campaigns to back up their own agendas or protests. Mining organisations need to get more active in this technology space by using social media to engage directly and share targeted information with their various stakeholders (DTTL, 2016).

Much of the information that gets disseminated about the mining industry’s environmental, social and governance performance takes the form of pictures, tweets and infographics. Simply put, public attention spans are diminishing and mining companies that want to tell their side of the story will need to do so a lot more clearly. That means considering ways to leverage mobile communications and social media in an effort to foster two-way dialogues with investors, industry analysts, community organisations, media and the public at large. It is also worth noting that mining needs to go beyond simply observing tweets and other social feeds, they must also get into the world of social media and engage with the wider stakeholder community (Deloitte, 2015).

Beyond using social media platforms to communicate with stakeholders, companies should leverage data analytics and ‘social listening’ tools to track what is being said about their organisations in real-time. Social listening provides companies with an early warning system that allows them to respond proactively. This can be achieved by alerting companies to reputational risks, community concerns or patterns that may signal social unrest (DTTL, 2016).

Significance of the study

This becomes important for all mining phases and companies are in a position to use the same social technologies to their benefit. Companies can create awareness campaigns of their intentions, the benefits they bring along with a mining operation, and their commitment to the affected communities and environment. This could aid the process of obtaining the relevant mining or exploration permits, or approval for Greenfields expansion projects. During the mining phase and post mine closure, the same applies to transparent communication with communities, NGOs, activists and special interests groups. Addressing issues as they occur often prevents exponential growth in the unhappiness of people and the influence it has on companies.

2.5.16. Software-Defined Applications and Infrastructure

Agile programming of everything, from applications to basic infrastructure, is essential to enable organisations to deliver the flexibility required to make the digital business work. Software-defined networking, storage, data centres and security are maturing. Cloud services are software-configurable through API (Application Program/Programming Interface) calls, and similarly applications have increasingly rich APIs to access their function and content programmatically. To deal with the rapidly changing demands of digital business and to rapidly scale systems up, or down, computing has to move away from static to dynamic models. Rules, models and programming code that can dynamically assemble and configure all of the elements needed from the network through to the application are needed (Gartner, 2014).

Significance of the study

This requirement impacted the emergence of the technology classification termed “Software-Defined Everything”, under Autonomic Platforms. It also refers to the kind of software needs and approach to service delivery that arises as the influence of IT expands on the business world. Notably, some of the software-defined applications and infrastructure can be delivered through Cloud Services. However not all of the emerging and ever increasing software needs can be answered by external means. As a result, companies should continuously investigate their IT capabilities and expand through lean principles in order to address rapidly rising shortcomings.

2.5.17. The Device Mesh & The Digital Mesh

The Device Mesh refers to an expanding set of endpoints that people use to access applications and information or to interact with other people, social communities, businesses and governments. The device mesh includes mobile devices, wearable technologies, consumer and home electronic devices, automotive devices and environmental devices (i.e. such as sensors in the IoT) (Gartner, 2015).

While devices are becoming increasingly connected to back-end systems through various networks, they have often operated in isolation from one another. As the device mesh evolves, it is expected that connection models will expand and that greater collaboration and cooperative interaction will occur between devices. Along with immersive and ambient user experience technologies, the device mesh propagates the merging of the physical and virtual worlds in the emergence of "the digital mesh" (Gartner, 2015).

Significance of the study

While this concept is still very new, it is an emerging trend in IT that will have a major impact on various ITs and electronic devices of all sorts as they become more connected. Organisations should remain aware of the growth of this technological concept as devices become more and more able to communicate with each other (even some that may seem to have no connotation to one another). This may open up various possibilities to exploit, while also opening up cyber security related threats.

2.5.18. The Digital Mine of the Future

Combining all of the data, information and communication technologies covered in the literature study, mining operations are able to move closer to becoming a digital operation that functions as a single system. This end-goal will be labelled *the Digital Mine of the Future*. This section will explore existing digital innovations in the mining industry, the applications of existing data and information technologies, as well as potential digital innovations that mining companies would do well to consider exploring in working towards the Digital Mine of the Future.

Globally most mining industries experience an aging workforce, making it difficult to sustain some of the required human resources. Mining companies have also been cutting costs for many years, decades in some instances, leaving them with limited resources to make adjustments. This hinders companies in seizing the opportunities in adopting new business and operational models to include new technologies. What companies can do however is to start by leveraging available digital tools and capabilities. These could improve operating efficiency, develop more accurate and agile planning, heighten vendor awareness and allow collaboration with business partners throughout the value chain (Accenture, 2015).

For operations to combat the rising costs for energy generation, the scarcer high-grade ores, declining commodity prices, and smaller profit margins, it is more important than ever before to make sense of the data that is already being generated. Productivity depends upon it and so will the digital mine of the future operations. To achieve this, companies need to formulate their business models and strategies around the technologies that could accomplish this (Hexagon Mining, 2015). These include for example Big Data and associated technologies to produce and make use of it (e.g. IoT, advanced analytics, machine learning, artificial intelligence, automation and computer-based algorithms etc.). Accenture (2015), added onto these technologies, as key digital technology enablers, with eCommerce, IoT, "Connected Everything", cloud technologies, Active Defence and social media/collaboration.

When operations and companies are able to better analyse and make sense of the data that mines inevitably generate (and find ways to generate more valuable and smart data), then significant gains can be realised. Within the data there is a smarter way to mine. By seamlessly integrating design, planning, and operations technology, mining operations can function both safer and more productively (Hexagon Mining, 2015).

Generally operational staff and managers are however increasingly being overwhelmed with huge volumes of data, from numerous sources, often in real time and sometimes in the form of reports that may be analysed too late. As data is collected and then distributed to various systems and sections in the mine, the data is replicated and altered before hours are spent reconciling and rationalising the information. This leads to multiple versions of the "truth", silos of data and practice, and spreadsheets that dominate as a planning and execution tool. The need for accurate data analytics to provide a single "truth" and distribute correct information to the correct receivers then becomes clear. A holistic view of the mine is vital, where data visualisation and interpretation is done with clarity and accuracy, and where timely reporting (that everyone understands) is achieved. The utilisation of this information should then preferably be automated or near real-time data analytics should be performed to ensure quick assessments and responses. This is vital to move mining to its next level of productivity and financial performance. Without this view of an operation, cost efficiency is not only lost, but escalating losses from under-informed decisions often send ripples downstream resulting in large monetary losses from unintended consequences (Hexagon Mining, 2015).

When operations and companies are able to connect people and sections across a mine, it becomes possible to also connect intelligence and processes, leading to enhanced efficiency in decision making and responses to variability in mining. Finding a way to assemble and present all the disparate data in a useful and understandable format, as per the perspective and skill of an individual receiver, is one of the biggest challenges faced by mining operations (Hexagon Mining, 2015). Exploring digital innovations may very well provide the answer to this challenge, especially when incorporating data integration and visualization principles.

By embedding the abovementioned digital technologies as an integrated whole across the entire mining value chain, McKinsey (2015) identified five areas of significant value creation. These five areas (as shown in Figure 2.5.18a) will now be discussed in more depth.

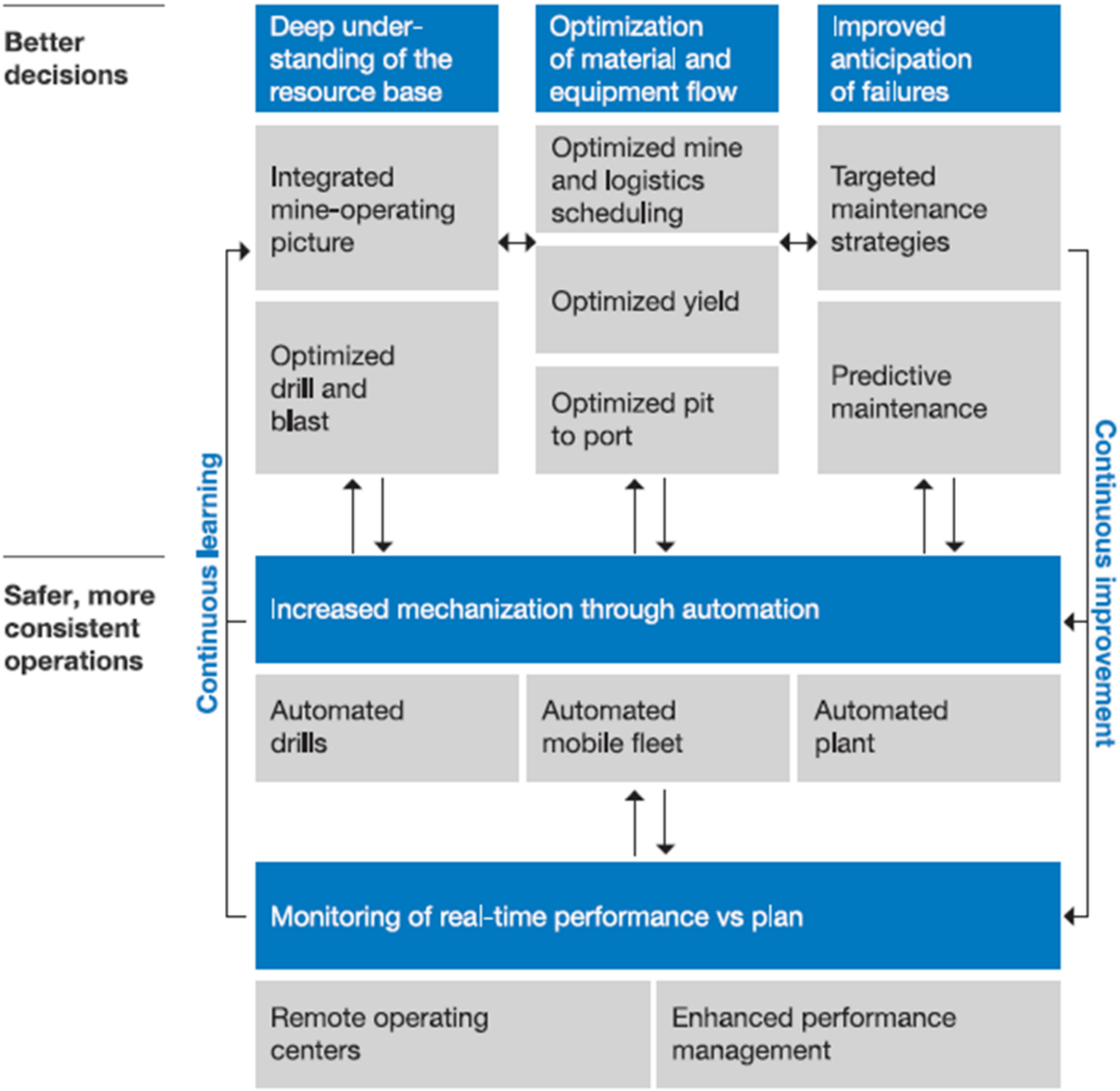


Figure 2.5.18a: Five Areas of Digitisation for Significant Value Creation (McKinsey, 2015)

Deeper understanding of the resource base: Operations can gain much better resource knowledge by combining orebody model information with blast hole drill data and online sampling. To make sense of exploration data, statistical techniques can be applied with the potential to improve the probability of discovery and help direct further drilling activities in order to maximise information gains. The integration of geological information into one better, universal "source of truth" helps to optimise drill and blast patterns, create an executable mine plan, and avoid quality issues at the source. With these enhancements, traditional activities such as core logging, face inspections, and manual plant assays will no longer be required. See Figure 2.5.18b for an explanation of the potential shifts resulting from enhanced understanding of the resource base (McKinsey, 2015).

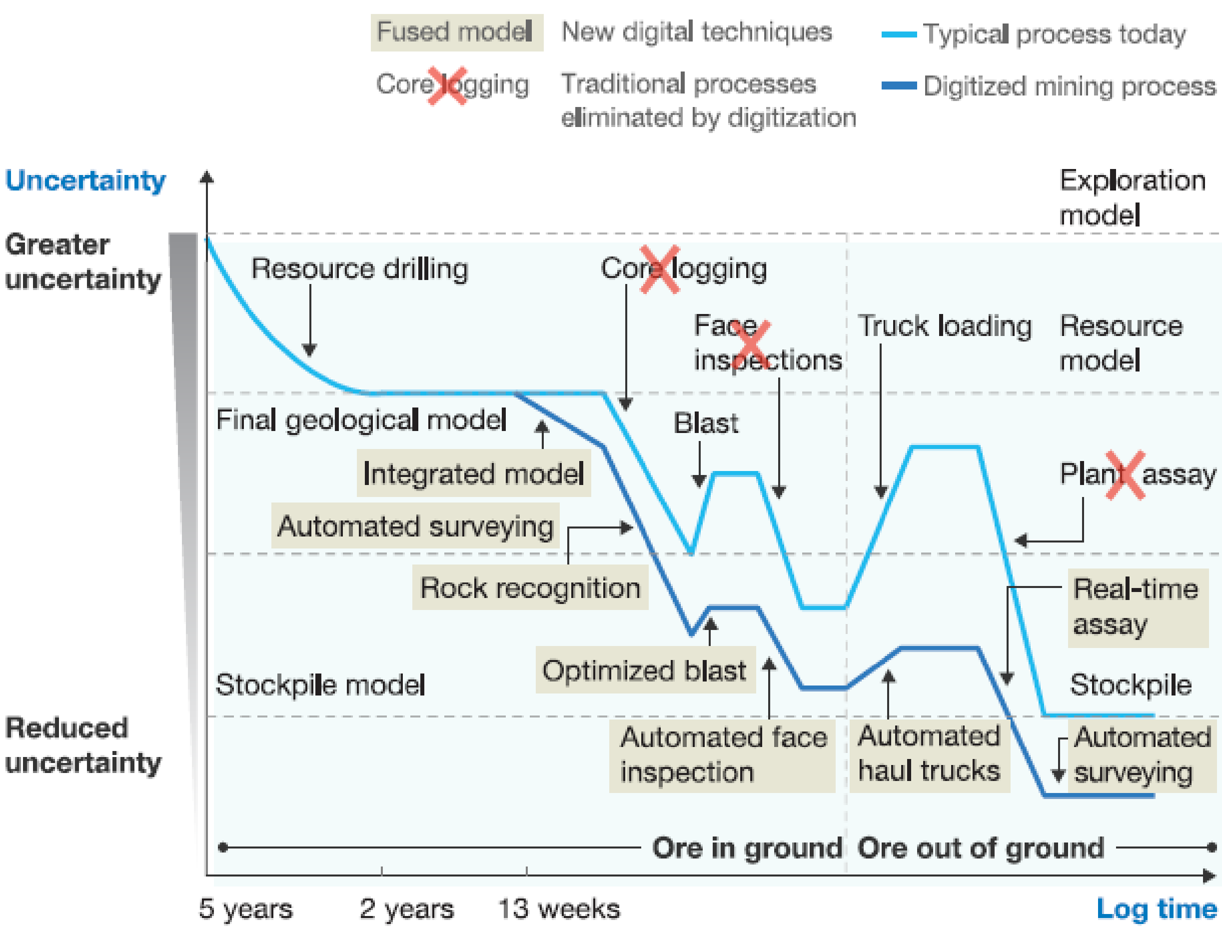


Figure 2.5.18b: Potential shifts in the mining process from an enhanced understanding of the resource base (Durrant-Whyte, 2015)

Optimisation of material and equipment flow: Mining supply chains can be described as interdependent systems of multiple pieces of fixed and mobile equipment. Tools and metrics such as Overall Equipment Effectiveness (OEE) are a sound basis for operational improvement, but fail to grasp the complexity of the combined system. Real time data and better analytical engines make the scheduling and processing decisions possible that maximise utilisation of equipment and yields. An example is combining traditional dispatch with smart algorithms to optimise machine movements for maximum efficiency. Another example is in processing plants, where it is suggested that many plant operators have blind spots in understanding the drivers of yield. By applying new mathematical techniques that look for hidden relationships between second-and-third-order variables, it was found that plant yields of gold, nickel, phosphate, and other processed minerals can often be improved by 3 to 10 percent within months (McKinsey, 2015).

Improved anticipation of failures: Mining companies typically collect huge amounts of data from drills, trucks, processing plants and even trains. Yet rarely is this information used to generate insight. In some cases, operations use less than 1 percent of the information collected from their equipment (see Figure 2.5.18c). Deploying this information to estimate the probability of failure of specific components or equipment, instead of using a traditional time-based approach, can help reduce maintenance spending and prevent unplanned interruptions to production (McKinsey, 2015).

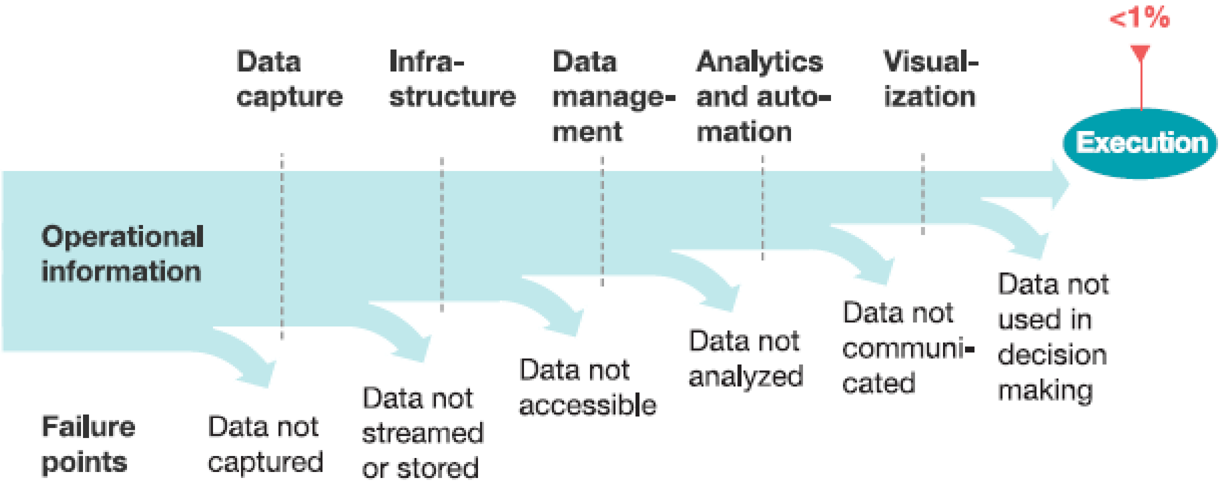


Figure 2.5.18c: Data usage of mining operations (McKinsey, 2015)

Increased mechanisation through automation: Automation offers the potential to reduce operating costs, improve operating discipline, and take people out of harm's way while reducing labour intensity. Some technologies, notably automated haulage and drilling, have moved into full-scale commercialisation. While others, particularly automated blasting and shovelling, are currently in testing. Analysis suggests that the economics of haulage are sound, reducing total cost of ownership by between 15 and 40 percent (depending on labour costs). Mining operations do need to manage several design choices around pit configuration, equipment configuration, and operational transitions in order to fully incorporate automated haulage. McKinsey's work on developing automated mining operations has identified opportunities to reduce the number of people working in areas considered most dangerous by more than 50 percent (McKinsey, 2015).

Monitoring of real time performance versus plan: One benefit of real time data is knowing the state and location of every piece of equipment in a mining operation at every second. This allows coherence monitoring to production plans and scheduling. Real time insight gives new meaning to operations performance management. This alters the focus on monthly output to focussing on variability and compliance to planning. Furthermore, connecting this real time feed to a central operating centre not only enables a real time response, but also moves control to a more sophisticated decision making capability. The central decision making can then take actions to optimise operations across the whole supply chain, rather than local silos. This capability can be deployed to improve safety outcomes, by detecting deviations from expected operating conditions, and to maintain high equipment utilisation and low operating cost in line with operating plans (McKinsey, 2015).

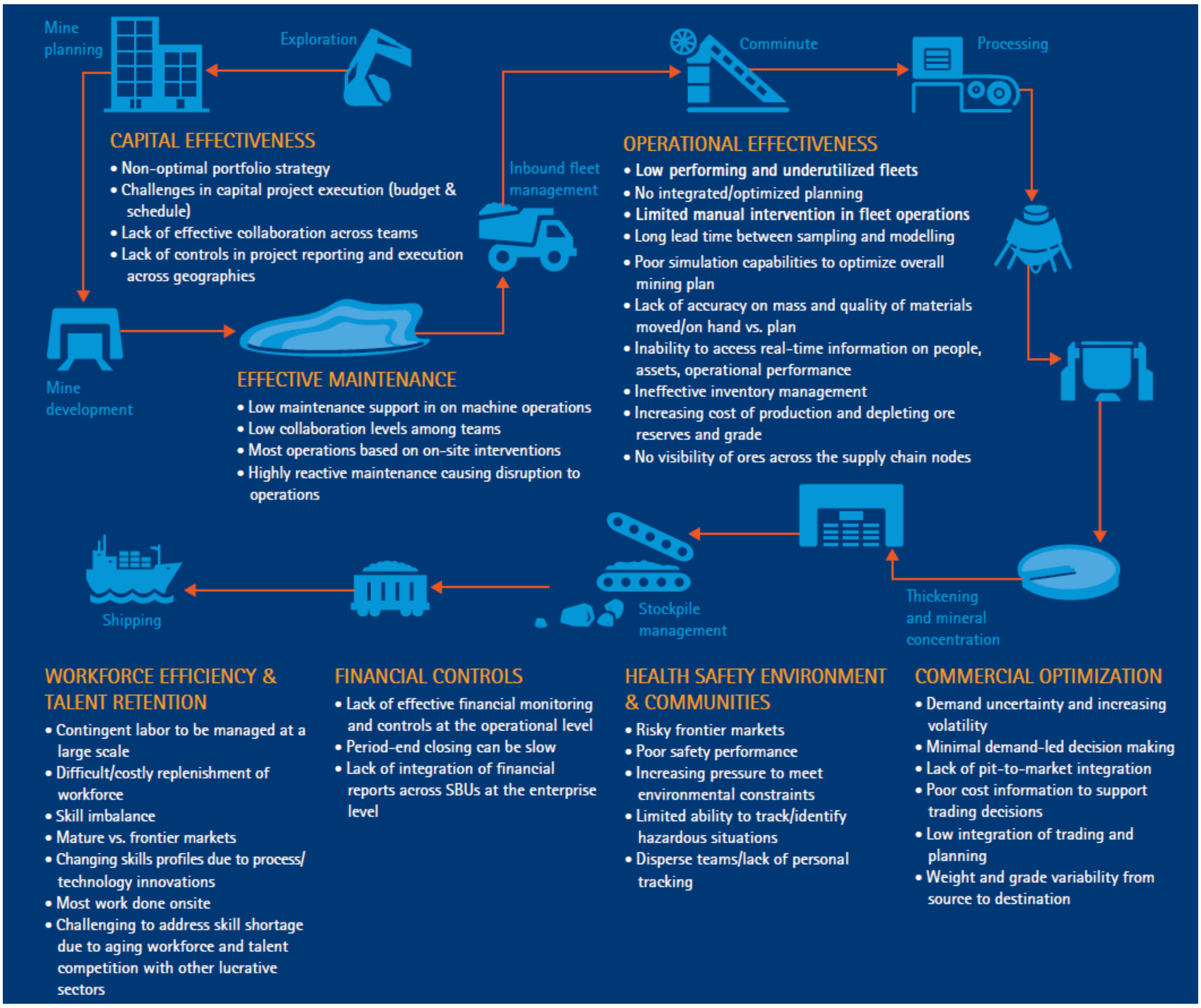
While each of these opportunities provide significant value, the full potential of all opportunities is only possible if they are pursued in an integrated manner. The reasons being, firstly, that the physical technologies required for automation provides the real time flow of information which forms the foundation for better insights. Investments in automation are best done concurrently with investments in systems and tools that build a foundation for better decision making. Secondly, these decisions will eventually be fed back to autonomous machines and not to human operators. The learning this would provide would prove valuable in working with machine learning algorithms and lead to continuous refining through iteration. Lastly, once part of the system exists on a digitised platform there are extended benefits (e.g. network effects) to extending it across the supply chain. The more data that becomes available to decision-making algorithms, the more effective they become (especially when applying and improving on artificial intelligence in such a system). The more operational activities that are systematised and recorded, the more they become valuable data in and of themselves. The broader the scope of the decision-making algorithms, the more they reflect the best whole-of-business outcomes for the operation (McKinsey, 2015).

As the volume and scope of data and analytics widens and further digital transformation is achieved, many other industry challenges may be turned into real business value. Table 2.5.18a lists potential benefits arising from specific industry challenges through increasing digitisation, as identified by Accenture (2015).

Table 2.5.18a: Potential Benefits through Digitisation in Addressing Mining Challenges (adapted from Accenture, 2015)

Mining Industry Specific Challenge or Focus Area	**Potential Benefits through increased Digitisation**
Effective capital project execution.	May allow more accurate planning and analysis, leading to projects being executed on time and within budget, and, more effective contractor management controls.
Excess capacity.	Improved modelling and business portfolio. Could rationalise controls and capital expenditure.
Exploration of new frontiers.	Opens up more autonomous solutions. Reduce intensity of, and reliance on, people.
Resources nationalism and going "Green".	Maximise safety. Optimise sustainability. Maximise stakeholder engagement via analytics on social networks/media and other collaboration tools.
Demand/price uncertainty.	Trading and planning operations can be integrated to maximise value.
Cost management and cash control.	Improve mine, plant, rail and port integration. Improve data capturing, modelling and analysis. Reduce transitioning within a mine, with remote access to information, leading to increased productivity. Improve CAPEX and OPEX management and reduce intensity (money spent). Improved cash flow and working capital.
Competition for talent.	Greater leverage of expertise to enhance problem solving. Improved training methods and improved support at the point of need. Change of the working environment, leading to greater attrition of the next generation workforce. Can address the aging workforce issue and problems with knowledge capturing, as well as the associated transfer of tacit knowledge.
Maintaining longer asset life cycle with low operating cost.	Longer asset life cycles and better return on assets. Improve the availability and utilisation of various assets. Improvement in safety in operating heavy equipment and machinery.
Increasing productivity.	Integrate the mine-to-port process. Create decision-oriented information out of increased data intensity (from geological information updated in real time, to real-time market events). Optimise available resources (and the use thereof) in alignment with market and shipment needs.

Accenture (2015), has further also highlighted chokepoints in mining (see Figure 2.5.18d) along with potential impacts of digital technologies across the mining value chain (see Table 2.5.18b).



CAPITAL EFFECTIVENESS

- Non-optimal portfolio strategy
- Challenges in capital project execution (budget & schedule)
- Lack of effective collaboration across teams
- Lack of controls in project reporting and execution across geographies

OPERATIONAL EFFECTIVENESS

- Low performing and underutilized fleets
- No integrated/optimized planning
- Limited manual intervention in fleet operations
- Long lead time between sampling and modelling
- Poor simulation capabilities to optimize overall mining plan
- Lack of accuracy on mass and quality of materials moved/on hand vs. plan
- Inability to access real-time information on people, assets, operational performance
- Ineffective inventory management
- Increasing cost of production and depleting ore reserves and grade
- No visibility of ores across the supply chain nodes

EFFECTIVE MAINTENANCE

- Low maintenance support in on machine operations
- Low collaboration levels among teams
- Most operations based on on-site interventions
- Highly reactive maintenance causing disruption to operations

WORKFORCE EFFICIENCY & TALENT RETENTION

- Contingent labor to be managed at a large scale
- Difficult/costly replenishment of workforce
- Skill imbalance
- Mature vs. frontier markets
- Changing skills profiles due to process/ technology innovations
- Most work done onsite
- Challenging to address skill shortage due to aging workforce and talent competition with other lucrative sectors

FINANCIAL CONTROLS

- Lack of effective financial monitoring and controls at the operational level
- Period-end closing can be slow
- Lack of integration of financial reports across SBUs at the enterprise level

HEALTH SAFETY ENVIRONMENT & COMMUNITIES

- Risky frontier markets
- Poor safety performance
- Increasing pressure to meet environmental constraints
- Limited ability to track/identify hazardous situations
- Disperse teams/lack of personal tracking

COMMERCIAL OPTIMIZATION

- Demand uncertainty and increasing volatility
- Minimal demand-led decision making
- Lack of pit-to-market integration
- Poor cost information to support trading decisions
- Low integration of trading and planning
- Weight and grade variability from source to destination

Figure 2.5.18d: Chokepoints in Mining (Accenture, 2015)

Table 2.5.18b: Potential Impact of Digital Technologies on the Mining Value Chain (Accenture, 2015), verbatim.

Area	Description	Key Benefits
Digital Mine	Increased sensoring, automation and data intensity across all mine operations to facilitate better integration and flow synchronisation. Applied analytics for better decision making. Mobility to decrease people movement, increase self-managed transportation means and reduce need for people on site. Increased operations managed remotely. Better tracking of people and anticipation of safety risks.	Decrease operating costs. Increase project/mine NPV. Increase revenue. 24/7 anytime, anywhere asset performance information. Increase paperless maintenance. Decrease cost per work order and downtime. Increase EBITDA (earnings before interest, taxes, depreciation and amortization), free cash flow and ROI (Return on Investment). Meet planned project close out expenditure and schedule.
Digital Sales & Marketing	Using analytics, achieve improved trading and mine planning integration by leveraging new	New sales opportunities/increase in revenue.

Area	Description	Key Benefits
	revenues and profitability opportunities based on updated market and plant-relevant information.	Improve profitability through better leverage of trading opportunities.
Digital Supply	Monitor stock across the value chain (both blend and quantity). Improved visibility of the stockyard. Increased automation of rail and fleet transport load and tracking. Applied analytics for improved sourcing. Use of deep market intelligence and analytics for improved supplier search and selection process supporting better negotiations and improving overall Total Cost of Ownership (TCO).	Optimise throughput. Reduce supply chain operational costs and working capital. Reduced sourcing costs/TCO.
Digital Capital Projects	Digital portfolio strategy that simulates financial and operations scenarios and evaluates bottlenecks and interdependencies. Use of big data and analytics for improved tracking and control of capital projects costs including material and contractors, as well as an improved integrated view of project execution. Improved data management across and post-project.	Reduce project lead-times/delays. Improve budget control and reduce overall project costs. Integrated project planning.
Digital Organisation	Leverage digital technologies to improve enterprise function efficiency through better visibility, financial performance and workforce collaboration/engagement. Move support functions to remote operating centres. Use of social networks to identify stakeholder-related risks and opportunities and better engage employees and local communities.	Decrease cost of hiring and training. Decrease travel and personnel costs. Increase talent retention. Improve employee and stakeholder satisfaction.

Capturing the value from digital innovations represents a fundamental shift in vision, strategy, operating model, and capabilities in the mining industry. In particular, much of the value creation in mining will shift from how well the operation moves material to how well it collects, analyses, and acts on information to move material more productively. The financial impact from digitisation is estimated to be significant, adding greatly to the mine modernisation drive when applied corrected. McKinsey's financial analysis indicates that the opportunity is substantial; with a potential economic impact of around $370billion per year worldwide in 2025. This would amount to 17 percent of the projected cost base of the industry globally in 2025. Table 2.5.18c contains details on the distribution of the estimated financial impact on the global mining industry resulting from increased digitisation.

Table 2.5.18c: McKinsey Global Institute estimates on the value at stake for mining from abovementioned digital innovations (McKinsey, 2015)

Applications	Description	Potential economic impact of sized applications in 2025

		($ billion, annually)
Operations Management	Deeper understanding of the resource base. Optimisation of material and equipment flow. Increase in mechanisation through automation. Monitoring of real-time performance vs. plan.	250
Equipment Management	Improved anticipation of failures. Reduced unscheduled breakdowns. Longer equipment life.	+100
Health and Safety	Minimised exposure to dangerous conditions.	+10
Equipment Supply	Improved purchasing analytics. IoT-enabled R&D into cost-efficient equipment design.	+5
Human Productivity	Augmented Reality (built on better human-machine interaction). Task-based activity monitoring.	+5
Total		**370**

McKinsey (2015) further stated that the key to unlocking this value will be to see innovation as an undertaking that encompasses all aspects of the business, rather than a technology effort. In truth, most of the technology challenge has been solved. This makes capturing the opportunity a management challenge for the next generation of industry leaders.

In striving towards exploiting the abovementioned opportunities McKinsey (2015) listed a number of factors/guidelines to consider that are believed to help drive success, verbatim:

- ***Is technology seen as an end in itself, or is this effort firmly grounded in value creation?***
  - *Miners must resist the temptation to pursue intelligence at the expense of value. It is difficult to set up a department that can integrate business problems and the practical application of technologies. The key to doing so is to have cross-functional teams that understand both mining operations and the technologies, and to integrate new technologies into operations and measure their impact.*
- ***Is technology seen as the next generation of bigger and better gear, or a more fundamental shift in the operating model?***
  - *Approaching technology as the next generation of gear to reduce direct head count could lead to missed opportunities to integrate real-time data with decision making. The task of integrating data into decision making across central planning and local sites, and across the full breadth of operations from pit to port, is making miners more akin to system engineers than movers of dirt. Mining companies must be able to get the systems-integration skill set right to maximize value creation.*
- ***How effectively are the people changes managed, both the shift in culture and the change in capability mix required to deploy new technologies?***
  - *From our work on big data across industries, we know that technology—data, analytics, and systems—is only part of the answer. Changes are needed in processes and people to most effectively implement technology and the new ways of working that it makes possible. Successful miners will set an integrated vision from data to systems to core processes to people capabilities, recognizing that new technologies only create value if they change the way people work and make decisions.*
- ***How well does management do at the start, balancing wins over 12 to 18 months to build momentum with a longer term vision of where the company is headed?***

  - *The concept of two-speed innovation—an agile approach to going after the most accessible big-ticket items, combined with a more measured approach to changing core systems and architectures—is now commonplace. The approach to applying new technologies in mining must follow the same principle. A priority is placed on achieving wins in the near term to show value and build the capabilities necessary to extract value from technology. At the same time, the legacy control systems, IT systems, and data architecture of many mining companies need a comprehensive transformation to support deployment of the new technology at scale. Successful players will find ways to do both.*
- ***How well does the organization adapt to the new set of opportunities?***
  - *At many mining companies, there is often no executive designated as the clear owner of innovation. Furthermore, going after this opportunity with the existing capability set or by using the current scorecards, metrics, and budgets will likely result only in a continuation of the status quo. To make these changes happen, mining companies must adapt their organizations by creating clear ownership among the top executive team, refining the organizational design to create meaningful senior roles for people with technical skills, and redesigning the annual planning and performance management process to create space for innovation.*

Mining has always been marked by uncertainty and variability, from the resource estimates to equipment performance and the weather. The key for the next era in mining is to accept that these facts are inevitable, but, with the right investments companies have the opportunity to reduce or even eliminate uncertainty. Over time, mining work will evolve toward knowledge-based jobs that solve the same challenges as today but do so through different means (McKinsey, 2015).

Accenture (2015) outlined a proposed path and approach towards mine digitalisation (see Figure 2.5.18e), for mining companies to consider when striving towards creating and implementing information technology based innovations in order to achieve the described digital mine of the future.

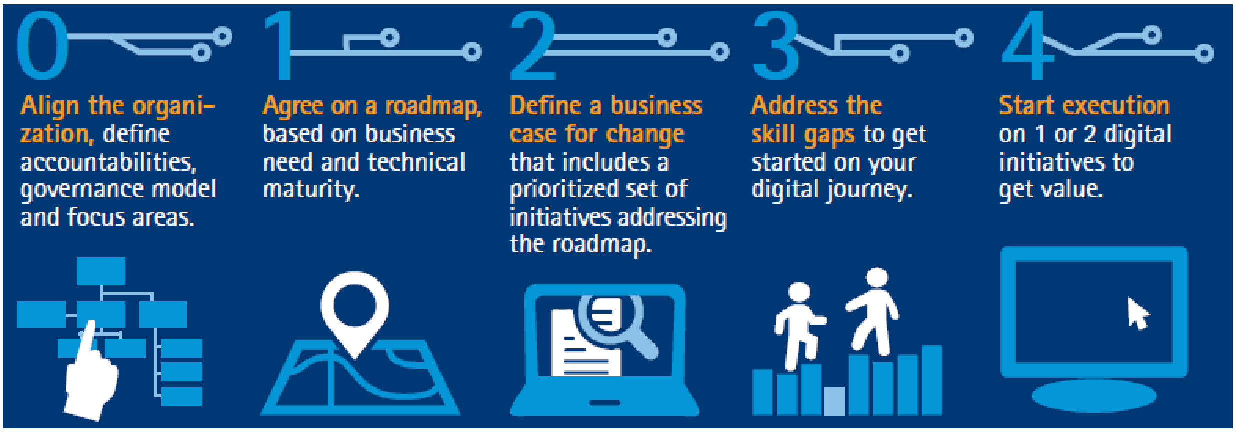


Figure 2.5.18e: The Path and Approach for Digitalisation (Accenture, 2015)

Significance of the study

The definition of digitisation is turning analogue information into digital information. The description used when talking about digitation across a business or industry is similar to this transfer of a resource from one form to another with more value. In its simplest form, digitisation is about turning data into value adding information or at least reducing the loss in value from under-utilisation of available data. Mining businesses need to 'mine' data as they mine their commodities. Data has to be extracted, refined and turned into a value adding resource that could benefit the business. This section serves to provide insight into the value of the digital technologies (data, information and communication technologies) identified within the literature study, as well as how they may be applied. The application and cross-integration of these technologies clearly hold potential value, especially when integrating all digital applications across the entire value chain and reducing the creation of silos within a business.

2.6. Cyber Risks & Security

Increased digitisation through the expanding integration of digital technologies, such as cloud computing and the mobile Internet, could raise productivity and quality in education, health care, and public services. At the same time, some of these technologies could bring unwanted side effects. The benefits of the mobile Internet and cloud computing are accompanied by rising risks of security and privacy breaches. Objects and machines under the control of computers across the Web (i.e. the Internet of Things and the Device Mesh) can also be hacked, exposing factories, refineries, supply chains, power plants, and transportation networks to new risks (McKinsey Global Institute, 2013).

Due to this, cyber security is rising on the corporate agenda. As the IoT evolves and network connectivity expands, greater cyber risks are opening up. If mining companies want to take advantage of the benefits that technology brings, they need to plan for the risks that come with these technologies. Cyber criminals are using increasingly sophisticated tactics to target both organisations and individuals by engaging in corporate espionage, attempted blackmail campaigns or malicious efforts to cause damage by hacking assets (e.g. autonomous vehicles and entire network systems) (DTTL, 2016).

Notably, the type of information at risk varies from financial performance data and technologies used to streamline processes, to areas where a company may be looking to mine or transactions it is considering entering into. The costs of a potential breach are considerable as well, ranging from damage to a company's reputation and profits to serious safety and security impacts. As these risks expand, mining companies will come under greater pressure to tighten their processes and controls around safety and security in a bid to better protect all of their critical assets. This ranges from the well-being of their people to their physical facilities and data (DTTL, 2016).

One approach to combat cyber threats is to employ risk monitors. By monitoring 'noise' (i.e. indications of potential unrest, unhappiness or threats) on the Internet from so-called "hacktivist" groups or other threat agents, operations can gain insight into potential attacks. This way it is possible to identify indicators that may signal an imminent protest action, cyber-attack or company being targeted for corporate espionage. Whilst this type of monitoring cannot protect organisations from every unknown threat, it can help pinpoint dangerous situations before they escalate. This may enable companies to detect, prevent and respond to emerging risks (DTTL, 2016).

Organisations can also conduct various risk assessments. In the context of cyber risks it is imperative to track which external parties have access to the company's data and what controls are in place to prevent the unauthorised distribution of confidential data. Third-party contracts must include security requirements that are regularly enforced with audits. At the same time, vulnerability assessments should not be confined to suppliers. Insiders often present the greatest risk to corporate security, and should be monitored as well (DTTL, 2016).

Emerging technologies to consider in order to combat the growing cyber risks can be classified as "adaptive security architecture". These technologies aim to detect and respond to threats in improved manners, as well as use more traditional blocking and other prevention measures against cyber-attacks. Application self-protection, as well as user and entity behaviour analytics, will help fulfil the adaptive security architecture (Gartner, 2015). A technology that is especially in the forefront of cyber risk reduction is "blockchain technology". Block chains are the technology underpinning the cryptography of Bitcoin (a crypto currency) and it is considered to have the potential to revolutionise the world economy. The reason for this future impact prediction stems from the ability of block chains to provide genuine privacy protection through its advanced security algorithms. This technology may also play a major role in the fight against cyber-attacks due to its ability to prevent hacking (Tapscott, 2016).

Digital currencies, including crypto-currencies, will thrive and play increasingly larger roles in transactions, banking and governments. Various governments are exploring frameworks and systems to regulate and manage digital currencies, which will make their ubiquity in everyday financial vernacular more profound. Ecuador's Congress recently approved a reform to create a digital currency, the New York State Department of Financial Services is considering establishing virtual currency exchanges, and the UK government is calling for information about the benefits and risks of digital currencies. It is expected that digital currencies will be used interchangeably with legal tender, resulting in a frictionless, agile, universal payment system that will expand beyond the current banking ecosystem (Tay, 2015).

The significance of the information

As with any new strategy implementation or shift in operating models, so too are there risks associated with the application of new technologies. It is important for businesses to be aware of these risks and analyse them appropriately in order to extract value from their technology strategy and not imbue more risk into the organisation.

In order to combat risk, humanity continuously develops countermeasures. An example is the use of Blockchain technology which could revolutionise transactions of all kinds, leading to improvements in trust and reductions in fraud, corruption and malpractice. Since mining companies often deal with 3rd world countries in trying to obtain mining licences, the price to pay sometimes exceed the physical monetary value of the mining rights themselves. This technology could drastically impact these kinds of transactions, leading to enhanced security and transparent dealings with reductions in "grey area" deals.

As mining organisations strive for increased mechanisation, digitisation and automation, it will become imperative to incorporate cyber security as a risk management tool into an organisation's operational risk management strategy.

2.7. Case Studies

The following case studies serve to provide examples of technological adoption and advances from different industries. These case studies aim to show what kinds of successes have already been achieved regarding the identified technologies (and especially combinations thereof) in the literature study.

2.7.1. Recent Technological Advances in Mining

It is important to be aware of existing technologies, innovations and other practices so as to learn from it, exploit it and to avoid re-inventing the wheel. For this purpose an overview of recent technological advances, along with previously identified technologies that may be applied to mining, were investigated. While not all technologies could be included in this study, the ones discussed in this section are worth looking into for further analysis. It should perhaps be noted that the description of "recent" is not bound to any specific timeframe. The reason is that when the technological advancement of different countries is compared, e.g. between Australia, Canada and South Africa, then the definition of recent advances often becomes vague. What may be new to the South African mining industry may have already been implemented for a decade in Canada.

There is no doubt that substantial innovation has taken place during the history of the mining industry. Open pit mining, block caving, long wall mining, draglines, sulphide flotation, and metal leaching are some notable examples of breakthroughs that have dramatically changed productivity and reduced operating costs. Additionally, most productivity or cost efficiencies in recent decades have also been driven by the incremental improvement of existing technology such as larger, longer-lived, and more efficient shovels, haul trucks, the LHD, larger crushers, grinding mills, flotation cells and better chemistry to improve processing recoveries (Bryant, 2015).

Above these well-known innovations there are also some of the emerging technologies that were investigated in the literature study that have already seen implementation, to some extent, in certain mining operations. The following examples, as highlighted by Deloitte Touche Tohmatsu Limited (2014), serve to lend credibility and insight to applications for these technologies that have already begun to unfold:

- *"Technologies that make it safer to operate underground mines: Such as collision detection systems, atmospheric monitoring, driverless trucks, automated drills, automatic longwall shearers, and ground control vibration tools.*
- *Autonomous trucks and trains, advanced robotics and control systems, and remote operating centres. A number of mining companies are well-advanced with programs of this nature.*
- *Data analytics solutions that deliver real-time information on equipment activity, safety performance, asset utilisation and other critical metrics to help miners uncover the true costs of their operations, improve efficiency and enhance on-site safety.*
- *Mobile internet and cloud technologies that allow workers to connect to enterprise applications no matter where they're located, enhancing data accuracy and worker productivity.*
- *Intelligent software systems that perform knowledge-work tasks, helping to improve mine safety and streamline operations.*
- *Energy storage devices and physical systems that store energy for later use, allowing miners to access power as required.*
- *3D printing techniques which can help miners solve the problem of sending replacement parts to remote mining sites.*
- *The use of advanced materials that improve equipment strength, conductivity, functionality and self-healing, which can extend the expected life and performance of mining equipment while reducing the downtime and costs associated with on-going maintenance.*

- *The evolving "internet of things" designed to data-enable a myriad of devices. In addition to enhancing data collection and monitoring, this technological trend can help mining companies use resources more efficiently by, for instance, improving the way they control water and energy use*."

Many influential people in the mining industry believe that the industry is on the verge of an explosion of further game-changing technology. Other technologies among the front-runners that are believed to hold great potential include (Griffith, 2015).

- Lasers that can cut rock or soften it enough to allow cutting (this could drastically impact drill and blast practices within the next few years);
- 3D point-cloud geo-spatial technology for real-time profiling of excavations;
- Automated robotic equipment that can detect geological structures remotely.

An example of more recently adopted technologies from other industries include the tunnel boring machines (TBMs) used in civil engineering. TBMs can vastly reduce reliance on explosives and reduce over-break in excavations. Until recently these machines were too large for mining environments, but some innovators have been incorporating the underlying technology to build smaller machines. Much R&D is taking place on this subject and underground mining operations should investigate how they could apply the technology beneficially (Deloite & Touche, 2014).

Other recent considerable innovations internationally in mining include (DTTL, 2016):

- AutoHaul, an autonomous rail transport system from Rio Tinto.
- The VAMOS (viable alternative mine operating system) project, which is exploring an underwater robotic mining prototype.
- EDS (enhanced drill systems), which rely on high-precision geolocation systems to provide equipment operators with continuous navigation and guidance, in order to increase the productivity of blast hole drills.
- Progress towards replacing diesel with lower carbon fuel sources.
- Sensors to monitor fixed and mobile assets

The implementation of robotics in mining provides further progress towards technological advancement. An example of robotic machinery in mining is the ultra-low profile mining machine from CMTI Consulting in South Africa (See Figure 2.7.1). This machine, called the MT100, is currently in development and will be implemented at Sibanye Gold's Burnstone gold mine in Balfour, South Africa. The MT100 has a sweeper and dozer attached and is battery-driven with a battery life of 7 hours. It is equipped with a drill rig and mechanical breaker for non-explosive mining or a multi-drill rig, which can drill four holes simultaneously for conventional blasting. The MT100 can further also be equipped with a laser scanner while being operated from a gulley up to 100m away. With its highly manoeuvrable track-based wheels it can reach a maximum height of 420mm. The multi-track concept, where four tracks are individually driven, further also allows the machine to swing around a centre point to enable it to negate vertical obstacles as high as 400mm (Solomons, 2016).

The benefits from implementing this robotic mining machine are described by Solomons (2016) as follows:
"The MT1000, powered by means of a trailing cable with the patented multi-drill attachment, can drill four holes simultaneously. The principle behind this is that the holes can be drilled as quickly and as accurately as possible at the right angles. This enables a 30 m panel to be drilled in just one hour, while it currently takes five rock-drill operators between five and six hours to do the same amount of work."

Figure 2.7.1: CMTI Consulting's Ultra Low-Profile Mining Machine, the MT100 (Solomons, 2016)

2.7.2. Anglo American Platinum

According Chris Gritth, CEO of Amplats, at the 2015 Mining Indaba, verbatim:
"Amplats have already, for a number of years, been on a modernisation journey within the company with game changing technological advances such as:

- *The Anglo American Platinum converting process which was commissioned at Waterval smelter a decade ago to greatly reduce our sulphur dioxide emissions by some 95%;*
- *The full mechanisation of our Bathopele mine. A bord and pillar operation utilising low profile equipment and operating at three times the productivity of our conventional mines. Recently we have introduced the next generation of equipment and approximately 10% of the production is delivered by extra-low profile machines. The technology drive continues with the expansion of extra low profile equipment and testing of ultra-low profile mechanised remote controlled mining equipment.*

To name a few of the innovations:

- *We are presently replanning our Twickenham mine to be the first hard rock mechanised mine to operate with extra-low and ultra-low profile mining technology. The trial project we have in place at Bathopele mine currently show promising results for application at Twickenham.*
- *Our Unki Mines, and Joint Ventures of Mototolo and Kroondal also already operate trackless bord and pillar mines.*
- *Installation of the new nickel tank-house technology at our base metal refinery in Rustenburg that has improved the work environment by reducing ambient tank house acid mist emissions.*
- *We were the first company to use large scale 3 MW ISAMillTM technology which is a fine-grinding technology to improve PGM liberation and downstream extraction resulting in 3% additional recovery.*
- *The use of proximity devices to control the safe movement of locomotives, personnel censors, other sensory and lighting technology and in-stope netting are all technologies that have already greatly improved safety.*
- *Although a much more difficult nut to crack, is the hard rock cutting projects currently under way at our operations. A number of these are collaboration projects between Amplats, Impala and Joy Global for activated disk cutting in stoping, and Amplats and Atlas Copco for a reef borer, and Amplats and Sandvik for compression cutting in stoping. These projects are all underground and on trial. Also with Atlas Copco*

we are developing a machine that uses disk cutting, for high rate access tunnels. This trial machine will be available for testing at Twickenham mine in the latter party of 2015."

2.7.3. Anglo American Plc

According to Cutifani (2013), Anglo American is actively involved to provide a lead in the development of technologies such as:

- Low-temperature super conducting quantum interference device (SQUID) exploration technology;
- Underground hard-rock cutting machines that take the human element out of potentially hazardous working areas (with two remote-controlled machines cutting rock in our platinum mines as we speak);
- Automated vehicles (Anglo has 2 ADTs that have been automated with a kit system – the only ones currently running in the industry); and,
- Underground mapping and positioning.

Furthermore, areas identified by Anglo American plc as important in terms of collaboration for future innovation are (Cutifani, 2013):

- Collision avoidance;
- Automation;
- Underground cutting.

2.7.4. A Petroleum Company

IBM (2009), verbatim, describes the benefits of information integration through an example of "*a Norwegian petroleum company that deployed an integrated information framework with the goal of identifying the methods, technology and work processes needed to integrate its operations. Previously plagued by unconnected systems and a lack of shared information, the company deployed an integrated industrial-semantic model based on a linkage of key oil and gas standards to create a flexible information integration and interoperability framework. Within this framework, nearly any system's data, regardless of its format, is accessible where it's needed most.*

Using data from wireless sensors, which monitor subsurface conditions (such as the pressure and temperature at different points in the field, as well as the movement of gas or oil deposits), the solution will provide the company's engineers with the information they need to know when, where and how much to pump. Getting data feeds from its sensors in real time will give the company the means to make decisions for production optimization on the spot, without having to wait weeks or months to gather and synthesize information. The program has been a key enabler of their preventative maintenance strategy, which is designed to identify potential maintenance issues before they become critical and cause shutdowns. Algorithms will process this data to determine when proactive (or condition-based) maintenance should be performed."

2.7.5. Ford

Deloitte Touche Tohmatsu Limited, 2016, describes The Ford Motor Company as a salient case in point for applying innovation to achieve operational excellence and improving productivity gains (Verbatim):

"*In 2006, the company lost over US$12 billion following a collapse in consumer demand. Between 2011 and 2014, however, Ford realized annual profits ranging from US$6.2 billion to US$8.3 billion. Whilst this turnaround has been attributed to many factors, a recent study suggests that the most pivotal steps included the company's willingness to:*

- *Reimagine the collective bargaining process by working with its union to develop a shared vision for success;*

- *Offer generous voluntary separation packages, ranging from an early retirement program that covered healthcare costs to educational programs that paid college tuitions;*

- *Take control of their end-to-end supply chains by bringing suppliers into their ecosystem to reduce costs;*

- *Place greater emphasis on low frequency, high consequence safety issues rather than all safety incidents;*

- *Encourage a culture of problem resolution rather than placing blame;*

- *Embrace emerging technologies, such as robotics, self-driving vehicles, connecting vehicles to the cloud, and hybrid and electric vehicle development*."

2.7.6. Gold Fields

Holland (2015), CEO of Gold Fields has highlighted the need for mining to:

- Embrace digital mining and full integration of Big Data, advanced analytics and new software technologies;
- Strive for a "mining on demand" system and ability to run agile production schedules;
- Convert conventional mining practices to mechanisation and automation; and,
- Embrace energy and water efficiency with reduced environmental impact.

Holland (2015), further also highlighted technology focus areas that could potentially address many issues relating to the entire mining process as shown in Table 2.7.6a (note that the table does not give a one to one relation between a highlighted challenge and technology).

Table 2.7.6a: Mining Challenges and Focus Areas with Corresponding Technologies (Holland, 2015)

Challenges/Focus Areas	**Technologies that could address this**
Exploration	
Size and qualities of discoveries are declining Reducing the cost of exploration Increasing the chance of exploration success Deeper ore bodies without surface outcrops	**Airborne Gravimetry** – Electromagnetic surveys that provide greater coverage and depth **3D Seismics** – High-resolution 3D geology model **Directional drilling** – drilling holes from a single site in different directions
Mining and Extraction	
Increased mining depth Narrower ore bodies Improved safety Grade reduction necessitates high volumes Increased remoteness of mining operations	**Advanced analytics** and modelling **Geographic Information Systems** **Real-time tracking** of equipment/people **Advanced mine planning** – understanding the dependencies **Precision drilling**

Rising labour costs Escalating energy costs	**Back-filling** of waste to boost extraction ratio **Automation** **In-pit crushing and conveying** **Remote hauling** trucks and loaders Hard-rock, **non-explosive continuous mining** **AI and Robotics** – learn from the military **Underground technologies**: Remote pillar mining; Large-scale block caving; Raise boring
Processing	
Refractory ore bodies Lower grades, which reduce recoveries Increasing environmental controls Increasing water scarcity Increasing electricity costs	**In-pit crushing and conveyance** **Predictive** equipment maintenance **monitoring** **High pressure grinding rolls** **Transmission sorting** of ore through X-ray, density assessment **High pressure leaching** – when conventional leaching does not liberate the metals Environmentally friendly **bio-leaching** Real-time, accelerated **rock sorting technologies** **Flexible closed-belt conveyor** – adaptable to bends and changes in elevation
Energy	
Rising energy costs Energy supply constraints and disruptions Carbon emission standards and regulation Stringent water emissions standards Increasing water scarcity Mine closure and rehabilitation	Increased **energy efficiency** Use of **renewable energy** forms **Underground water treatment systems** – no need to pump water to surface **Water treatment solutions** (e.g. RO plants) **Energy storage** systems

Holland (2015) further also highlights the importance of collaboration and the identified best-of-class technologies through partnering with OEMs (for the South African mining industry context). Table 2.7.6b shows various mining processes with corresponding OEM partners, as identified by Gold Fields, which are busy with R&D into applicable technological solutions.

Table 2.7.6b: OEM Partnerships and Tech Innovations (Holland, 2015)

Mining process	**OEM Partner for Tech R&D**	**Description of identified applicable technology**
Exploration	GEOSOFT freedom to explore	Computer algorithm that automatically detects patterns in exploration data indicative of mineralisation.
Drilling	CATERPILLAR SANDVIK Atlas Copco FLANDERS Listen. Innovate. Serve.	All major OEMS offer products with various levels of automation. Other firms specialise in retrofitting existing drills for automation.
Blasting	AEL Mining Services	The charging process can be automated, with the required amount of explosives being entered beforehand.
Loading	HITACHI CSIRO	OEMs that are developing autonomous excavators.
Hauling	HITACHI CATERPILLAR KOMATSU	Komatsu and Caterpillar have commercial offerings of remotely operated hauling equipment. Hitachi conducting field trials.
Other support equipment	HITACHI CATERPILLAR KOMATSU	All major OEMs are developing remote solutions for support equipment like dozers, shearers, etc.
Underground equipment	SANDVIK	OEMs have developed, tested and implemented a number of automated drilling products, for UG and surface use.

Gold Fields has also established partnerships with Mine Vision Systems and The Cyest Corporation in order to implement sensors and 3D vision and mapping software. Applications from these technologies include mapping and inspection, operator safety (advanced obstacle detection and warning systems), stockpile monitoring, geological monitoring, enhanced tele-remote systems and fleet tracking (real time monitoring underground) (Holland, 2015).

Through the use of drones and underground sensors Gold Fields can capture visual images and convert them into data files for use in mine software. The captured data can then be analysed for various mining applications. The way data is captured and processed can be altered to achieve better results for geology, geo-technical, material movements and reconciliation. Soon the company will also be able to automate geology mapping, ground support design and LHD controls, amongst others (Holland, 2015).

Gold Fields is also looking at innovative ways to economically optimise South Deep through advanced analytics and simulation, the scope is (Holland, 2015):

- Determine Maximum Potential – Scientifically determine the capacity of the mine's full value chain.
- Formulate Improvement Plan – Assist in the development of improvement initiatives.
- Generate Stakeholder Buy-in – Develop an advanced visualisation of South Deep, that coveys the complexity of the mining process, and helps communicate and catalyse the right action at all levels.
- Discreet Event Simulation – Advanced simulation of the sequence of activities and equipment interactions simulating the underground value chain.
- Carbon$_{14}$ – Validate and improve the medium and long term mining schedule by modelling the interaction of different mining activities as a function of mine layout, efficiencies and other factors.
- Value Driver Tree Modelling – Modelling of how operational drivers link to value to guide and demonstrate what interventions need to be pursued to achieve the required financial results.
- Advanced Visualisation – Using an advanced gaming platform to create a high fidelity visualisation of the ore body and the associated mining methods

Holland (2015), further stated that technology will give the mining industry the edge to fundamentally change cost structures and make mines safer. In the short term extraction and exploration will likely see the biggest advances through automation and digitisation technologies. However, partnerships with OEMs and IT companies will be critical if mining is to benefit from the latest technologies. Also, human resource and mine management will have to change to reflect new operating practices and technologies.

2.7.7. Hexagon Mining

This section will investigate drives towards creating the digital mine of the future and serves to identify examples of digital innovation in the mining industry. The example used for various data and information technologies to serve as an example for digital innovations as well as examples of existing products, is adapted from Hexagon Mining (2015). "*By focusing on business intelligence and business analytics, Hexagon Mining aims to help its customers to identify lost time that's non-productive (e.g. breaks, crew stand-down times, lunches, and equipment breakdowns).*

Hexagon Mining Athena is an effort to mastering big data in mining. The program imports, validates, analyses, and stores data from multiple input sources to a single data repository. It then presents the data in dashboard views that are easy to use and understand. The sources of data can be extremely varied, such as fleet management systems (FMS), drill rigs, on-board fragment analysis cameras and general mine planning systems. In the future, dashboards for safety, and slope stability will also be added.

Analysing and merging this data can answer questions like, "why are my shovels not meeting their production targets?" There could be several answers to this specific question, but one answer may be that the rock is not being fragmented efficiently, making it harder to dig.

It's a critical benefit for managers to be able to understand what is going on in their operation across multiple areas of the mining value chain. Being able to track poor shovel performance back to a sub-optimal blasting process, for example, can give managers the confidence to change projects, improve practices, and track the results.

Hexagon Mining Athena is central to plans for connecting with enterprise resource planning (ERP) systems. Athena's interchange data structure will allow customers to not only connect 'down' and 'over' to data sources, such as FMS, but also to connect 'up' to ERPs, such as SAP.

Understanding the problem is one thing, fixing it is another. Hexagon Mining is tackling this as well. MineSight's short-term scheduling product, Atlas, will soon be able to import actual FMS information automatically so that the mine plan is evolving. The value here is the productivity rate of excavators. This is related to the rock hardness and the blast's effectiveness. So if productivity is falling behind plan, the Atlas schedule will be updated on the fly, allowing engineers to predict problems before they happen and hopefully solve them.

This cycle of plan, do, act, check is repeated through all of Hexagon Mining's operational tools, such as MineSight Axis for grade control and the "soon to be released" MineSight Blast for drill and blast design management. The drill and blast cycle is integral to Hexagon Mining's vision. MineSight Blast will bring precision and dependability to one of mining's most challenging steps. Incorporating a modern design interface, MineSight Blast will design and manage drill and blast patterns interactively on screen while storing all of the design (and actual) information in a SQL database. Drawing upon visualisation and automation software, together with MineSight's Axis product, Hexagon Mining will focus on tracking grade and rock fragmentation.

This part of the mining cycle is too important to get wrong as poor fragmentation has major implications for crusher energy, refining and the whole mining process. Get crushing and grinding right the first time and mines really save energy costs and decrease the hit on the local energy grid. Hexagon Mining is looking to close that loop via Leica's drill fleet management machine guidance, and MineSight's drill and blast modules.

Another example is Hexagon Mining Live Terrain, which integrates the disparate data from surveying and measurement sources for a streamlined workflow. Those sources will include total stations, UAV, scanners, Lidar, and mobile mapping. HxM Live Terrain assembles other technologies, from Leica equipment to Intergraph software, and combines it with "data truthing" and processing software, to build a database of all relevant data, ranked by fidelity. Customers can select the area for which they need the latest terrain surface, and Hexagon Mining Live Terrain will deliver it. This provides a much-needed tool for rationalizing a critical source of data for the mine – the topography surface as it is continually measured and mined. Hexagon Mining expects Live Terrain to be a huge benefit for a variety of users; from mine planning, to fleet management, to environmental, slope monitoring, reconciliation, autonomous mining, and regulatory.

By eliminating silos, and sharing an open platform, Hexagon Mining believes it will be an attractive proposition to the industry, no matter what mine planning or fleet management systems are being used.

With a 360º vision, Hexagon Mining, will offer the competitive edge needed by productive mines. Mine planning, design, fleet and production management, optimisation, fatigue monitoring, and collision avoidance software will be seamlessly linked for a comprehensive flow of data across all operations. Fleet management, for instance, represents a huge opportunity for mines to minimise energy consumption, reduce carbon footprints, and save money."

2.7.8. Rio Tinto

Rio Tinto, in Western Australia, chose a mine as a test bed for innovation. Testing included automated trucks, automated drills and blasts and automated logistics applications (e.g. driver-less trains and autonomous haulage systems) (IBM, 2009). The initiative was termed 'The Mine of the Future™', a programme that creates next-generation systems and technologies to drive Rio Tinto to become a global leader in fully integrated, automated mining (Rio Tinto, 2014).

The aim of the Mine of the Future™ initiative is to:

- Improve employee safety;
- Increase productivity;
- Lower energy consumption; and
- Reduce environmental impact.

Rio Tinto (2014) stated that "*innovation is the key to solving the increasing challenges posed by geology, legislation, economics and the need to keep our employees safe. We use it to identify, develop and implement smart step-change technologies that significantly improve how we work. Mine of the Future™ is also mastering the delicate relationship between human and machine. The energy and ideas of our talented people unlock new possibilities, and we nurture and reward innovative thinking*."

Mine of the Future™ was launched in 2008 and has since trialled and implemented various autonomous systems within the mining cycle's operation phase. Figure 2.7.8 shows the timeline for these technological advancements in Western Australia's Pilbara region.

Figure 2.7.8: Mine of the Future Innovation and Automation Implementation Timeline (Rio Tinto, 2014)

According to Rio Tinto (2016) and Rio Tinto (2014), some of the innovative advances in the Mine of the Future™ initiative include:

- **Automated drilling system (ADS)**: In 2008, the automated drilling system was successfully trialled at West Angelas mine in preparation for deployment across our Pilbara operations over the next few years. The automated blast-hole drill system enables an operator to use a single console at a location remote from the machinery to operate multiple drill rigs from multiple manufacturers. It is much safer for the operators and it maximises precision and equipment utilisation.
- **Autonomous haulage systems (AHS)**: Rio Tinto is the world's largest owner and operator of autonomous haulage system trucks. They have 69 autonomous trucks in operation at the Pilbara sites moving high grade ore and the number of trucks is set to grow in coming years. Implementing autonomous haulage means more material can be moved efficiently and safely, creating a direct increase in productivity. These driverless vehicles deliver their loads more efficiently, minimising delays and fuel use, and are controlled remotely by operators who exert more control over their environment and ensure greater operational safety.
- **AutoHaul®**: AutoHaul® continues to progress and, once operational, it will be the world's first fully-autonomous heavy haul, long distance railway system. A key part of Rio Tinto's long-term operating strategy, AutoHaul® operations will provide the additional capacity required to meet increasing production without investment in additional trains. Throughout 2015, AutoHaul® fitted locomotives have been trialled on the network to test on-board systems, signalling, safety mechanisms and communications with the Operations Centre in Perth. In 2016, AutoHaul® development will continue including submission of regulatory approvals, completion of full system functionality, improvement of system performance and reliability and gradual integration into operations.
- **Operations Centre**: The Operations Centre in Perth is a state-of-the-art facility that enables all Rio Tinto's mines, ports and rail systems to be operated from a single location. This greatly increases opportunities for shared experience and overall system improvement. It incorporates visualisation and collaboration tools to provide real-time information across the demand chain, and will allow the optimisation of mining, maintenance and logistic activities across the Pilbara in a way never before possible. It increases efficiency, improves reliability, decreases variability and allows the business to better identify and improve performance across the supply chain.
- **Mine Automation System**: The system function to integrate data and centralise mine operations. The Mine Automation System acts like a computer's central processing unit, integrating all automated elements of a mine and optimising efficient and effective operation. It produces real-time models based on data from key elements such as equipment, geology, and control and planning algorithms used to coordinate vehicle fleets.
- **RTVis™**: The RTVis™ software interprets complex datasets and creates a user-friendly 3D display of a mine that is easily and quickly understood by pit controllers, geologists, drill-and-blast teams, mine planners and supervisors. It allows them to make informed decisions while working remotely from the machines. It enables clearer data models, better decisions and safer conditions.
- **Excellence Centres**: Excellence Centres unite experts with those from partner organisations, and give them access to real-time data from operations around the world so they do not have to be on site. These centres allow teams to make better decisions, enhance productivity, and reduce costs. They also improve the safety and wellbeing of employees by reducing the need to travel to mine sites to share expertise and excellence.

2.7.9. Schlumberger Water Services

Schlumberger Water Services had undertaken a 6-year programme assessing the adaptation of oil and gas (O&G) drilling and geophysical characterisation techniques to a range of mining applications. Focus was particularly placed on dewatering of open pit mines. Conventional dewatering systems generally use vertical boreholes that target hydraulically productive zones within an orebody. The drilling and completion of these vertical dewatering boreholes are often complicated by mine planning constraints, where optimum hydrogeological targets are not accessible from the reachable or practical drilling locations. Since the boreholes are often located within the operating open pit, they can interfere with the mining operation and the ability to carry out significant dewatering ahead of mining is limited (Rowland *et al*, 2016).

Dewatering Well Placement Technology (DWPt) is Schlumberger's next-generation mine dewatering solution aimed at addressing the limitations of conventional dewatering systems. This is to be achieved through placement of permanent, high-performance dewatering wells in optimum orientations beneath an open pit by using large-diameter directional drilling technology commonly used in the oil and gas industry. Ideally, well collars are located outside of the mine operating areas, resulting in improved compatibility between the dewatering system and mine plan. Recently drilled and constructed pilot directional dewatering wells in hard rock mining environments in the USA and Mexico have demonstrated that DWPt offers significant benefits. These benefits included better groundwater inflow control and value addition to mining operations, compared to conventional open pit mining dewatering practices (Rowland *et al*, 2016).

Robust and effective dewatering systems can be vital for maintaining slope stability and safety, as well as to minimise stripping ratios. Effective dewatering removes groundwater from operating areas, leading to a reduction in wear- and tear-related costs on mining equipment, along with a reduction in haulage costs by reducing the haulage of wet material (Dowling & Thys-Evans, 2015).

Other negative impacts on mining operations from poor or ineffective dewatering may include (Rowland *et al*, 2016):

- Wet drilling and blasting. Requires more expensive blasting agents and it could also lead to reduced fragmentation efficiency;
- Wet working benches. Increases equipment wear and introduces additional safety risk factors;
- Inundation of the pit floor and slow mine advancement;
- Reduced geomechanical performance of pit slopes that, in some cases, leads to the design of more conservative slope angles resulting in higher strip ratios and deferral or loss of ore.

As part of the proof of concept, two directionally placed dewatering wells have been successfully implemented at Morenci for the Garfield open pit mine dewatering programme. For the first well the borehole was steered underneath the centre of the planned pit on a pre-planned directional trajectory. A measured depth of approximately 700 m was attained. The well also intercepted hydrogeological targets and hydrogeological compartments as planned. After completion, the well was equipped with an oilfield-style high-lift, slim-hole electrical submersible pump system designed to minimise well drilling and construction hole diameters while permitting high production pumping rates for variable head pressure conditions. The well initially produced between 150 m^3/h and 160 m^3/h, which was at the high end of the planned production, and is five to ten times greater than the previously installed conventional, vertical in-pit wells (Rowland *et al*, 2016).

The well was immediately commissioned into the active dewatering programme and during the first year operated at 96% availability. The combination of the high production rate and high availability meant that it effectively produced up to two orders of magnitude more groundwater than any of the pre-existing in-pit vertical wells. The new well system exceeded the combined groundwater production from the rest of the dewatering system, comprised of six vertical production wells. Monitoring data showed a distinct acceleration in the rate of the groundwater level reduction in the open pit (Dowling and Rhys-Evans, 2015).

The success of the various pilot programmes at Morenci with Freeport McMoRan led Kumba Iron Ore to approach Schlumberger Water Services to conduct a technical feasibility study (TFS) for the evaluation of directional well placement to improve dewatering effectiveness at their Sishen operation in South Africa (Rowland *et al*, 2016).

The Sishen iron ore mine, Kumba Iron Ore's flagship operation, is currently the largest open pit iron ore mine in Africa, and one of the largest open pits mines in the world at almost 14 km in length (Kumba Iron Ore, 2016). Sishen currently consists of four operating areas that have been excavated to near or below the natural groundwater surface (Schlumberger Water Services, 2014). As a result of the relatively shallow pre-mining groundwater level, dewatering activities have been ongoing since the beginning of mining operations, with a series of vertical in-pit and perimeter pumping wells targeting productive geological formations within the mine area (Schlumberger Water Services, 2014). The groundwater regime and rate of mining require that dewatering pumping occurs on a continuous basis. The abstraction rate of the overall mine dewatering system is approximately 1 800 m^3/h as of November 2015, from a total installed capacity of approximately 2 130 m^3/h (Nel & White, 2015).

A full technical feasibility study was then conducted on the use of directional well placement to replace or enhance the existing system. A cost-benefit analysis was carried out to compare the current dewatering method, based on the use of vertical in-pit wells, against the associated cost with developing a DWPt dewatering programme. On top of this, a number of intangible benefits associated with the DWPt approach were also identified. The cost benefits of these were not calculated, however, their value was considered in the assessment of the DWPt application. These intangible benefits (which are applicable to other operations as well, e.g. at Kolomela), included (Rowland *et al*, 2016):

- Improved in-pit safety, resulting from reduced personnel movements in the pit relating to dewatering activities and also due to less in-pit dewatering infrastructure;
- Simplified mine planning, resulting from the removal of the need to incorporate in-pit dewatering infrastructure and maintenance;
- Improved dewatering, further leading to:
  - More efficient and lower costs for blasting. The reduced block size resulting from more effective blasting will in turn lead to a reduced need for crushing, grinding, and potentially drying of material to reduce double hauling;
  - Reduced mining equipment maintenance due to lower humidity levels;
  - Reduced acid rock drainage generation at the mining front;
  - Improved ore transportation efficiency due to a reduction in the volume of water carried in the ore;
  - Installing dewatering infrastructure that will remain in use after backfilling of the pit, thus supporting on-going site-wide dewatering.

The results of the trade-off analysis indicated that although the estimated CAPEX for continued vertical well dewatering was less than the proposed DWPt plan, the cost differential was offset by the estimated cost saving related to more efficient dewatering. In particular, the resulting reduction in wet mining and water haulage was also considered as a large potential cost saver (Rowland *et al*, 2016).

2.8. The Technological Mine of the Future Initiative

This section aims to provide insight into the potential future that may be created through technological integration into the mining cycle. The scenarios, needs and potential applications discussed are derived from initiatives such as Rio Tinto's Mine of the Future™, the Digital Mine of the Future, as well as other aspects as identified by various authors, organisations and other institutions. The technologies investigated in the literature study also serve to give insight into how these future initiatives may be reached through a technology strategy. When looking at the Technology Map created in Chapter 3, these (futuristic) aspects should be borne in mind regarding the potential use and impact from the technology focus areas as identified throughout the mining cycle.

Mining in the future will use fewer workers for manual jobs and more qualified operator experts for product and process optimisation, maintenance planning and environmental control. These experts will need to interact with each other to cover the complete mining cycle. A central mine control room will be the objective for future solutions, from which operator experts may even be able to control several mines at once (Sjöström & Carlsten, 2012).

In order to make intelligent, informed decisions in a consistent way, all data from all the sub-operations within the entire mining process and sub-processes are needed. This data needs to be real time data as it is of limited use if the data is of a historical nature (i.e. typically in report formats). All data must be available for online use in order to perform proper analysis and make value adding decisions (Sjöström & Carlsten, 2012). Through the use of the IoT (and the Device/Digital Mesh as an expansion on IoT), all devises, equipment and machinery can be linked to a single central unit from which operator experts can make informed human-based decisions. Advanced computer analytics can then also be applied for machine and information technology based decisions.

When presenting information, obtained from data analysis, to people for a decision making process, it should be noted that people do not have the time to seek out the information relevant to them. They need specific information regarding the types of decisions they are set to make. Providing vast amounts of undifferentiated information (not user role specific) backfires and is costly as well as counterproductive (Sjöström & Carlsten, 2012).

Furthermore, with rising constraints and pressure from stakeholders, "being green" will need to be more than a marketing campaign for mining companies. New technologies and programs that are able to manage consumables such as carbon, water and fuel from end to end, as well as providing new capabilities in performing trade-off analysis on productivity vs. environmental impact should be applied. These programs may further extend to footprint management, ecosystem risk management, waste management, tailings placement management, mine closure, rehabilitation, and stewardship management (IBM, 2009).

Although technology can certainly improve operations in the mining field, its true benefits can be realised when it is applied to a "platform" approach that encompasses all major phases of the operation. These may include mine development, drilling and extracting, processing, transportation, the provision of utilities and more (Bryant, 2015). In some cases, elements of the production platform may already exist. The general characteristics of the proposed approach by Bryant (2015) are as follows, verbatim:

- *"Increased energy efficiency (reduced waste);*
- *Continuous rather than batch operations;*

- *Less movement of equipment;*
- *Increased preventative maintenance and self-healing;*
- *Increased reliability and availability;*
- *Faster operation;*
- *Automation and remote operations to reduce labour costs;*
- *Flexible vs. fixed;*
- *Less waiting and queuing;*
- *Increased instrumentation and monitoring;*
- *Rapid mobilization;*
- *Scalability;*
- *Removal of less to zero waste;*
- *Able to mine lower grade resources at low cost."*

Feeding information to a central control centre, performing advanced analysis on the information, and making informed decisions in real-time on a dynamic environment for all aspects of the value chain and mining cycle as a whole, should further also be automated as far as possible. In striving towards this end goal of a 'global automation mining system', there are also incremental benefits along the way as seen throughout the literature study for various phases and activities (e.g. production, transportation, knowledge work of people etc.) Another way automation represent potential value, as highlighted by Deloitte Touche Tohmatsu Limited (2014), is in the optimisation of energy use, for instance:

- Using conveyors and similar electric technologies, instead of using trucks, to move ore.
- Harnessing gravity to move ore and waste down a mountain (at no energy cost) while at the same time generating electricity to power other processes.
- Using collision detection and atmospheric monitoring technologies to enhance the safety of underground mining operations.
- Adopting automated drills, automatic longwall shearers, autonomous trucks and trains and remote operating technologies for a global autonomous transport fleet system.

With this in mind, some of the suggested areas where technology may play a role as key enablers in the Mine of the Future initiative include (Bryant, 2015):

- Restoring agility and flexibility in the value chain;
- Shifting from a cost reduction mind-set to one of value creation;
- Increasing production and productivity;
- Reducing and eliminating waste;
- Reducing the need for people, especially at remote sites and underground;
- Improving ore body knowledge and the planning process;
- Improving recovery rates;
- Aligning the organization around strategic and tactical goals;
- Increasing the robustness of business, competitor and industry intelligence.

In summary IBM (2009) sketches a scenario to imagine information integration, visualisation, and collaboration in the future, verbatim: "*In the future, we can imagine scenarios where information integration, visualization and collaboration wildly improve business performance. For example, imagine an unexpected machine failure deep in the mine site. Sensors on the machine alert an intelligent control room thousands of miles away and provide diagnostics and performance metrics to a Remote Control Room production supervisor. The production supervisor then assembles a virtual team of experts to discuss the problem via multiple monitors in his control room. Experts from different mines across the globe are connected in real-time, as well as a maintenance repair person on the ground and a team of technical support experts from the equipment's manufacturer. Together, they discuss options and devise an approach to solving the problem. Recommendations and documented past fixes are sent from the Intelligent Analytics knowledge repository to onsite repair technicians*. *The collaboration system informs other business users such as Finance and Sales of the machine downtime who are then able to adjust their production forecasts and to contact customers if need be. The event and solution are logged into the collaboration and knowledge system so that future problems can leverage this expertise*."

REFERENCES

Accenture. 2015. *The Future of Mining is Digital*. [ONLINE] Available at: https://www.accenture.com/t20151207T214527__w__/us-en/_acnmedia/PDF-1/Accenture-The-Future-of-Mining-is-Digital-Infographic.pdf. [Accessed 06 April 2016].

Anderson, C. 2014. *Agricultural Drones: Relatively cheap drones with advanced sensors and imaging capabilities are giving farmers new ways to increase yields and reduce crop damage*. [ONLINE] Available at: https://www.technologyreview.com/s/526491/agricultural-drones/. [Accessed 11 May 2016].

Bodekaer, M. 2016. *This virtual lab will revolutionize science class*. [ONLINE] Available at: https://www.technologyreview.com/s/534976/nano-architecture/. [Accessed 07 March 2016].

Bourzac, K. 2015. *Nano-Architecture: A Caltech scientist creates tiny lattices with enormous potential*. [ONLINE] Available at: https://go.ted.com/CyGv. [Accessed 05 July 2016].

Bradley, D. 2010. *TR10: Green Concrete*. [ONLINE] Available at: http://www2.technologyreview.com/news/418542/tr10-green-concrete/. [Accessed 20 March 2016].

Brewster, S. 2016. *This $40,000 Robotic Exoskeleton Lets the Paralyzed Walk*. [ONLINE] Available at: https://www.technologyreview.com/s/546276/this-40000-robotic-exoskeleton-lets-the-paralyzed-walk/. [Accessed 22 July 2016].

Bryant, P. 2015. *Clareo: The Case for Innovation in the Mining Industry*. [ONLINE] Available at: http://www.ceecthefuture.org/wp-content/uploads/2016/01/Clareo_Case-for-Innovation-in-Mining_20150910_lo.pdf. [Accessed 14 January 2016].

Conlife, J. 2016. *Facebook Plans to Beam Internet to Backwaters with Lasers*. [ONLINE] Available at: https://www.technologyreview.com/s/601936/facebook-plans-to-beam-internet-to-backwaters-with-lasers/?utm_campaign=socialflow&utm_source=facebook&utm_medium=post. [Accessed 10 August 2016].

Continental. 2015. *Continental's portfolio of diagnostic tools is keyed to the needs of authorized workshops*. [ONLINE] Available at: http://www.continental-corporation.com/www/pressportal_com_en/themes/press_releases/3_automotive_group/interior/press_releases/pr_2015_04_15_diagnoseportolfio_en.html. [Accessed 27 July 2016].

Chamber of Mines of South Africa. 2015. Presentation from Chamber of Mines of South Africa – Next Generation Mining: Research for Mining Phakisa.

Copenhagen Business School. 2013. Automation, labour productivity and employment — a cross country comparison.

Cronimet. 2015. *PV-diesel hybrid power system*. [ONLINE] Available at: http://www.cronimet-mining.com/en/energy/intelligent-energy-solutions/case-study-south-africa/. [Accessed 29 April 2016].

Cutifani, M. 2013. A CRITICAL IMPERATIVE – INNOVATION AND A SUSTAINABLE FUTURE WORLD MINING CONGRESS, MONTREAL CANADA.

Davidse, A. 2016. Personal correspondence – Mining Innovation Leader, Deloitte Canada.

Deloitte. 2014. The Internet of Things Ecosystem: Unlocking the Business Value of Connected Devices.

Deloitte. 2014b. Tracking the trends 2014: The top 10 issues mining companies will face this year. [ONLINE] Available at: http://www2.deloitte.com/content/dam/Deloitte/global/Documents/Energy-and-Resources/dttl-er-Tracking-the-trends-2014_EN_final.pdf. [Accessed 11 February 2016].

Deloitte Touche Tohmatsu Limited. 2014. *Mining spotlight on: Remaking mining*. [ONLINE] Available at: http://www2.deloitte.com/content/dam/Deloitte/global/Documents/Energy-and-Resources/gx-er-remaking-mining.pdf. [Accessed 26 January 2016].

Deloitte. 2015. *Tracking the trends 2015: The top 10 issues mining companies will face this year*. [ONLINE] Available at: https://www2.deloitte.com/content/dam/Deloitte/fpc/Documents/secteurs/energie-et-ressources/deloitte_etude-tracking-the-trends-2015-en.pdf. [Accessed 10 February 2016].

Deloitte Global Services Limited. 2014. Deloitte Global Services Limited, London -*Mining spotlight on: Sliding productivity and spiralling costs*. [ONLINE] Available at: http://bionanouni.wdfiles.com/local--files/teaching-im010-horario-2014i/Deloitte_14-Mining-Spotlight-On_Sliding-Productivity-and-Spiraling-Costs.pdf. [Accessed 29 January 2016].

De Graaf, W. 2016. Personal correspondence with senior lecturer and blasting expert at the Department of Mining Engineering at the University of Pretoria.

Dixon, J. 2014. *X as a service (XaaS): What the future of cloud computing will bring*. [ONLINE] Available at: http://www.cloudcomputing-news.net/news/2014/aug/18/x-as-a-service-xaas-what-the-future-of-cloud-computing-will-bring/. [Accessed 08 August 2016].

Doblin. 2015. *Ten types of innovation*. Doblin, the innovation practice of Deloitte Consulting LLP. [ONLINE] Available at: https://www.doblin.com/ten-types. [Accessed 02 February 2016].

Douglas, A. D. 2014. *Status of communication and tracking technologies in underground coal mines - Theses and Dissertations in Mining Engineering, Paper 13*. [ONLINE] Available at: http://uknowledge.uky.edu/mng_etds/13. [Accessed 15 August 2016].

Dowling, J. & Rhys-Evans, G. (2015). *Oilfield directional well placement technology used for mine dewatering*. Mining Magazine. May 2015. p. 28.

Driscoll, S. 2013. *Imponderable Things (Scott Driscoll's Blog): Comparison of Augmented Reality Glasses, Google Glass, Meta, castAR*. [ONLINE] Available at: http://www.imponderablethings.com/2013/09/minority-report-and-terminator-vision.html. [Accessed 7 June 2015].

DTTL. 2016. Tracking the trends 2016: The top 10 issues mining companies will face in the coming year. Deloitte Touche Tohmatsu Limited. Annual report. United Kingdom.

Du Plessis, J. J. L. 2016. Personal correspondence with professor and senior lecturer at the Department of Mining Engineering at the University of Pretoria.

Dupress. 2015a. *Exponentials*. [ONLINE] Available at: http://dupress.com/articles/tech-trends-2015-exponential-technologies/. [Accessed 29 July 2016].

Dupress. 2015b. *Amplified intelligence*. [ONLINE] Available at: http://dupress.com/articles/tech-trends-2015-amplified-intelligence/. [Accessed 29 July 2016].

Dupress. 2016a. *Augmented and virtual reality go to work*. [ONLINE] Available at: http://dupress.com/articles/augmented-and-virtual-reality/?id=gx:2el:3dc:dup3036:awa:cons:tt16. [Accessed 26 July 2016].

Dupress. 2016b. *Industrialized analytics - Data is the new oil. Where are the refineries?* [ONLINE] Available at: http://dupress.com/articles/data-assets-and-analytics/?id=gx:2el:3dc:dup3040:awa:cons:tt16. [Accessed 28 July 2015].

Dupress. 2016c. *Internet of Things: From sensing to doing*. [ONLINE] Available at: http://dupress.com/articles/internet-of-things-iot-applications-sensing-to-doing/?id=gx:2el:3dc:dup3035:awa:cons:tt16. [Accessed 29 July 2016].

Dupress. 2016d. *Autonomic platforms: Building blocks for labor-less IT*. [ONLINE] Available at: http://dupress.com/articles/bi-model-it-on-autonomic-platforms/?id=gx:2el:3dc:dup3038:awa:cons:tt16. [Accessed 08 August 2016].

Durrant-Whyte. 2015. *Rise of the Machines*. Maurice Lubbock Memorial Lecture, Oxford University. Oxford, United Kingdom.

Ebsworth-Goold, E. 2016. *Dirty to drinkable: Engineers develop novel hybrid nanomaterials to transform water*. [ONLINE] Available at: https://source.wustl.edu/2016/07/dirty-to-drinkable/. [Accessed 08 August 2016].

Els, F. 2016. *Breakthrough aircraft to transform remote mining*. [ONLINE] Available at: http://www.mining.com/breakthrough-aircraft-to-transform-mining-economics/. [Accessed 04 August 2016].

ERASynbio. 2014. Next steps for European synthetic biology: a strategic vision.

ESPAS. 2015. European Strategy and Policy Analysis System (ESPAS): Global Trends to 2030: Can the EU meet the challenges ahead? [ONLINE] Available at: http://europa.eu/espas/pdf/espas-report-2015.pdf. [Accessed 03 April 2016].

European Commission. 2010. Space Exploration and Innovation Space Policy and Coordination Unit.

European Internet Foundation. 2014. The Digital World in 2030.

Everdell, C. 2015. *Frogdesign – Tech Trends 2015*. [ONLINE] Available at: http://www.frogdesign.com/techtrends2015/. [Accessed 14 April 2016].

Feulcellenergy. *How do Fuel Cells Work?* 2013. http://www.fuelcellenergy.com/why-fuelcell-energy/how-do-fuel-cells-work/. [Accessed 15 September 2016].

Frost & Sullivan. 2016. *TOP 50 EMERGING TECHNOLOGIES: GROWTH OPPORTUNITIES OF STRATEGIC IMPERATIVE - Multi-billion dollar technologies ready to propel industries and transform our world*. [ONLINE] Available at: http://ww2.frost.com/news/press-releases/frost-sullivan-reveals-50-emerging-technologies-set-transform-industries-and-propel-growth-opportunities-across-globe. [Accessed 19 April 2016].

Gartner. 2013. *Gartner Says the Internet of Things Installed Base Will Grow to 26 Billion Units By 2020*. [ONLINE] Available at: http://www.gartner.com/newsroom/id/2636073. [Accessed 29 April 2016].

Gartner. 2014. *Gartner Identifies the Top 10 Strategic Technology Trends for 2015*. [ONLINE] Available at: http://www.gartner.com/newsroom/id/2867917. [Accessed 31 May 2016].

Gartner. 2015. *Gartner Identifies the Top 10 Strategic Technology Trends for 2016*. [ONLINE] Available at: http://www.gartner.com/newsroom/id/3143521. [Accessed 31 May 2016].

GenomeAtlantic. 2015a. *Genomics: A transformative tool*. [ONLINE] Available at: http://transformers.genomeatlantic.ca/files/Genome%20Atlantic%20Mining%20Report.pdf. [Accessed 28 April 2016].

GenomeAtlantic. 2016b. *Genomics applied to the energy and mining sectors and industry | Genome Atlantic Transformers*. [ONLINE] Available at: http://transformers.genomeatlantic.ca/genomics-energy-industry. [Accessed 28 April 2016].

GenomeCanada. 2016a. *Mining | Genome Canada*. [ONLINE] Available at: http://www.genomecanada.ca/en/why-genomics/genomics-sector/mining. [Accessed 28 April 2016].

GenomeCanada. 2016b. *Energy | Genome Canada*. [ONLINE] Available at: http://www.genomecanada.ca/en/why-genomics/genomics-sector/energy. [Accessed 28 April 2016].

Gershgorn, D. 2016. *RESEARCHERS ACCIDENTALLY MAKE BATTERIES LAST 400 TIMES LONGER*. [ONLINE] Available at: http://www.popsci.com/researchers-accidentally-make-batteries-last-400-times-longer. [Accessed 15 September 2016].

Gibbs, S. 2016. *World's first passenger drone cleared for testing in Nevada*. [ONLINE] Available at: https://www.theguardian.com/technology/2016/jun/08/worlds-first-passenger-drone-testing-ehang-nevada. [Accessed 21 June 2016].

Giges, N. 2014. *Top 10 Materials for 3D Printing*. [ONLINE] Available at: https://www.asme.org/engineering-topics/articles/manufacturing-processing/top-10-materials-3d-printing. [Accessed 09 June 2016].

Griffith, C. 2015. Modernisation – a vital step in building a sustainable mining industry in South Africa. Mining Indaba 2015 Speech.

Hardy, Q. 2016. *Silicon Valley Looks to Artificial Intelligence for the Next Big Thing*. [ONLINE] Available at: http://www.nytimes.com/2016/03/28/technology/silicon-valley-looks-to-artificial-intelligence-for-the-next-big-thing.html?partner=IFTTT&_r=1. [Accessed 29 July 2016].

Harris, M. 2016. *Power from the Air: Internet devices powered by Wi-Fi and other telecommunications signals will make small computers and sensors more pervasive.* [ONLINE] Available at: https://www.technologyreview.com/s/600773/10-breakthrough-technologies-2016-power-from-the-air/. [Accessed 10 August 2016].

Heber, A. 2013. *12 technologies set to transform mining*. [ONLINE] Available at: https://australianmining.com.au/Features/12-technologies-set-to-transform-mining/. [Accessed 05 February 2016].

Hexagon Mining. 2015. *Mining Big Data Guide: The digital mine of the future*. [ONLINE] Available at: http://www.hexagonmining.com/downloads/Hexagon_ch_MiningBigData.pdf. [Accessed 06 April 2016].

Holland, N. 2015. *GoldFields: The Gold Mining Company of the Future*. [ONLINE] Available at: https://www.goldfields.co.za/pdf/presentations/2015/gold_fields_mine_of_the_future_28102015.pdf. [Accessed 18 May 2016].

IBM. 2009. *Envisioning the Future of Mining*. [ONLINE] Available at: https://www.ibm.com/smarterplanet/global/files/ca__en_us__oil__smarter_natural_resources_future_of_mining.pdf. [Accessed 17 February 2016].

ImmersiveEducation. 2014. *PRELIMINARY PROGRAM: 4th European Immersive Education Summit (EiED 2014)*. [ONLINE] Available at: http://immersiveeducation.org/PROVISIONAL/EiED-2014-PRELIMINARY-PROGRAM.xlsx. [Accessed 30 June 2016].

International Federation of Robotics (IFR). 2014. *Industrial Robot Statistics*. [ONLINE] Available at: http://www.ifr.org/industrial-robots/statistics/. [Accessed 30 June 2016].

Interquest Group. 2016. *You can't have IoT without IoE*. [ONLINE] Available at: http://www.interquestgroup.com/corporate/news/you-cant-have-iot-without-ioe#.V06Bffl95qN. [Accessed 01 June 2016].

ITER. Date unknown. *Plasma Confinement in a Tokamak*. [ONLINE] Available at: https://www.iter.org/sci/PlasmaConfinement. [Accessed 21 July 2016].

Jacobs, J. 2015. *A CRITICAL INVESTIGATION INTO THE POTENTIAL OF AUGMENTED REALITY APPLICATIONS IN THE MINING INDUSTRY*. Dissertation submitted in partial fulfilment for the degree B.Eng (Hons) (Mining Engineering), in the Department of Mining Engineering at the University of Pretoria, South Africa.

Jackson, T. 2016. *IoT.nxt plots Internet of Things "revolution" from SA*. [ONLINE] Available at: http://disrupt-africa.com/2016/06/iot-nxt-plots-internet-of-things-revolution-from-sa/. [Accessed 21 June 2016].

Kalaher, P. 2015. *Frogdesign – Tech Trends 2015*. [ONLINE] Available at: http://www.frogdesign.com/techtrends2015/. [Accessed 14 April 2016].

Knight, W. 2014. *Agile Robots: Computer scientists have created machines that have the balance and agility to walk and run across rough and uneven terrain, making them far more useful in navigating human environments*. [ONLINE] Available at: https://www.technologyreview.com/s/526536/agile-robots/. [Accessed 06 March 2016].

Knight, W. 2015. *Car-to-Car Communication: A simple wireless technology promises to make driving much safer*. [ONLINE] Available at: https://www.technologyreview.com/s/534981/car-to-car-communication/. [Accessed 11 August 2016].

Knight, W. 2016a. *Google is selling off a company working on the most advanced problems in robotics, but that doesn't mean it doesn't have robot dreams*. [ONLINE] Available at: https://www.technologyreview.com/s/601085/google-hasnt-given-up-on-robots/. [Accessed 06 March 2016].

Knight, W. 2016b. *Five Lessons from AlphaGo's Historic Victory*. [ONLINE] Available at: https://www.technologyreview.com/s/601072/five-lessons-from-alphagos-historic-victory/. [Accessed 29 July 2016].

Knight, W. 2016c. *This Factory Robot Learns a New Job Overnight*. [ONLINE] Available at: https://www.technologyreview.com/s/601045/this-factory-robot-learns-a-new-job-overnight/. [Accessed 29 July 2016].

Knight, W. 2016d. *Conversational Interfaces: Powerful speech technology from China's leading Internet company makes it much easier to use a smartphone*. [ONLINE] Available at:

https://www.technologyreview.com/s/600766/10-breakthrough-technologies-2016-conversational-interfaces/. [Accessed 11 August 2016].

Kumba Iron Ore. 2016. *Operations*. [ONLINE] Available at: http://www.angloamericankumba.com/our-business/operations.aspx. [Accessed 10 July 2016].

LaMonica, M. 2013. *Additive Manufacturing: GE, the world's largest manufacturer, is on the verge of using 3-D printing to make jet parts*. [ONLINE] Available at: https://www.technologyreview.com/s/513716/additive-manufacturing/. [Accessed 26 February 2016].

Larsen, L. 2014. *The 10 Best Technology Advances of 2014*. [ONLINE] Available at: https://www.pastemagazine.com/blogs/lists/2014/12/the-10-best-technology-advances-of-2014.html. [Accessed 20 March 2016].

Loizos, C. 2016. *Magic Leap says it will debut its product . . . "hopefully soonish"*. [ONLINE] Available at: https://techcrunch.com/2016/07/12/magic-leap-says-it-will-debut-its-product-hopefully-soonish/. [Accessed 27 June 2016].

Markoff, J. 2016a. *Want to Buy a Self-Driving Car? Big-Rig Trucks May Come First*. [ONLINE] Available at: http://www.nytimes.com/2016/05/17/technology/want-to-buy-a-self-driving-car-trucks-may-come-first.html?partner=IFTTT&_r=1. [Accessed 24 May 2016].

Markoff, J. 2016b. *A Drone Start-Up Explores Underwater*. [ONLINE] Available at: http://www.nytimes.com/2016/06/27/technology/a-drone-start-up-explores-underwater.html?partner=IFTTT&_r=0. [Accessed 01 July 2016].

McCallum, D. 2015. *Frogdesign – Tech Trends 2015*. [ONLINE] Available at: http://www.frogdesign.com/techtrends2015/. [Accessed 14 April 2016].

McKinsey and Company. 2014. Strategic principles for competing in the digital age. [ONLINE] Available at: http://www.mckinsey.com/business-functions/strategy-and-corporate-finance/our-insights/strategic-principles-for-competing-in-the-digital-age. [Accessed 05 May 2016].

McKinsey Global Institute. 2013. *Disruptive technologies: Advances that will transform life, business, and the global economy*. [ONLINE] Available at: https://www.sommetinter.coop/sites/default/files/etude/files/report_mckinsey_technology_0.pdf. [Accessed 28 January 2016].

McKinsey. 2015. *How digital innovation can improve mining productivity*. [ONLINE] Available at: http://www.mckinsey.com/industries/metals-and-mining/our-insights/how-digital-innovation-can-improve-mining-productivity. [Accessed 11 March 2016].

McKinsey. 2015b. *Technologies that could transform how industries use energy*. [ONLINE] Available at: http://www.mckinsey.com/business-functions/operations/our-insights/technologies-that-could-transform-how-industries-use-energy. [Accessed 06 June 2016].

McKinsey. 2015c. Greening the future: New technologies that could transform how industry uses energy. McKinsey & Company. Global Editorial Services.

McKinsey. 2016. *Where machines could replace humans—and where they can't (yet)*. [ONLINE] Available at: http://www.mckinsey.com/business-functions/business-technology/our-insights/where-machines-could-replace-humans-and-where-they-cant-yet. [Accessed 25 July 2016].

McKinsey. 2016b. *Renewable energy: Evolution, not revolution*. [ONLINE] Available at: http://www.mckinsey.com/industries/oil-and-gas/our-insights/renewable-energy-evolution-not-revolution. [Accessed 14 September 2016].

Mearian, L. 2016. *Scientists can now make lithium-ion batteries last a lifetime*. [ONLINE] Available at: http://www.computerworld.com/article/3060005/mobile-wireless/scientists-can-now-make-lithium-ion-batteries-last-a-lifetime.html. [Accessed 15 September 2016].

Mendo, J. 2013. *MINING OF THE FUTURE, What is next?* CETEM, Sustainability. [ONLINE] Available at: http://www.cetem.gov.br/images/palestras/2013/sustentabilidade/jose_mendo.pdf. [Accessed 07 March 2016].

Metz, R. 2015. *Magic Leap: A startup is betting more than half a billion dollars that it will dazzle you with its approach to creating 3-D imagery*. [ONLINE] Available at: https://www.technologyreview.com/s/534971/magic-leap/. [Accessed 27 June 2016].

Mines Rescue Services. 2016. *Mines Rescue Services - South Africa*. [Online] Available at: http://www.minesrescue.co.za. [Accessed 22 August 2016].

Ministry of Labour. 2015. Final Report (vol. 1): Mining Health, Safety and Prevention Review. Ministry of Labour. Toronto (Ontario), Canada.

Mining Indaba & Monitor Deloitte. 2016. *Innovation State of Play | Mining | Deloitte Southern Africa*. [ONLINE] Available at: http://www2.deloitte.com/za/en/pages/energy-and-resources/articles/innovation_in_mining.html. [Accessed 04 May 2016].

Ministry of Labour. 2015. *Final Report (vol.1): Mining Health, Safety and Prevention Review from Ministry of labour, Toronto, Ontario (Canada)*. https://assets.documentcloud.org/documents/2475228/mining-final-report.pdf. [Accessed 06 June 2016].

Nel, E. & White, T. 2015. *Groundwater Report, November 2015*. Kathu, South Africa: Kumba Iron Ore Limited. Pp 21.

Parkinson, G. 2016. *Solar and wind energy's stunning cost falls to continue*. http://reneweconomy.com.au/2016/solar-and-wind-energys-stunning-cost-falls-to-continue-25263. [Accessed 15 September 2016].

PDAC & Deloitte. 2015. *Innovation state of play: Mining edition 2015*. [ONLINE] Available at: https://www2.deloitte.com/content/dam/Deloitte/ca/Documents/energy-resources/Innovation_State_of_Play.PDF. [Accessed 04 February 2016].

Pickering, R. & Young, C. 2016. *Controlled foam injection: A new and innovative way non-explosive rockbreaking technology to replace drilling and blasting in mining*. Paper presented at the: New technology and innovation in the Minerals Industry Colloquium. Southern African Institute of Mining and Metallurgy, Emperors Palace.

Radimovic, G. & Kim, K. 2008. *Feasibility study of RFID/Wi-Fi/Bluetooth wireless tracking system for underground mine mapping – Oklahoma*. Incorporating Geospatial Technologies into SMCRA Business Processes, March 25 – 27, Atlanta, GA.

Rathore, I. & Kumar, P. 2015. *Unlocking the potentiality of UAVs in Mining Industry and its Implications*. International Journal of Innovative Research in Science, Engineering and Technology. Vol. 4, Issue 3. [ONLINE] Available at: http://www.rroij.com/open-access/unlocking-the-potentiality-of-uavs-in-miningindustry-and-its-implications.pdf. [Accessed 02 May 2016].

Reilly, M. 2016. *In an amazing video, the newest generation of the humanoid Atlas walks on uneven terrain, squats to pick up boxes, and puts up with abuse from its human creators*. [ONLINE] Available at: https://www.technologyreview.com/s/600884/the-latest-boston-dynamics-creation-escapes-the-lab-roams-the-snowy-woods/. [Accessed 08 March 2016].

Rio Tinto. 2014. *Mine of the Future*^{TM} *- Next-generation mining: People and technology working together*. [ONLINE] Available at: http://www.riotinto.com/documents/Mine_of_The_Future_Brochure.pdf. [Accessed 28 March 2016].

Rio Tinto. 2016. *Mine of the Future*^{TM}. [ONLINE] Available at: http://www.riotinto.com/australia/pilbara/mine-of-the-future-9603.aspx. [Accessed 13 September 2016].

Rivard, L. 2014. Dassault Systemes GEOVIA: Special Report on Mining Innovation: Mine owners focus on technology to control costs. [ONLINE] Available at: http://www.geovia.com/sites/default/files/campaigns/GEOVIA_SpecialReportMiningInnovation.pdf. [Accessed 04 March 2016].

Roland Berger Strategy Consultants. 2011. The Trend Compendium 2030.

Rowland, A., Bester, M., Boland, M., Cintolesi, C., Dlowling, J. 2016. *Adapting oil and gas drilling techniques for the mining industry with dewatering well placement technology*. Paper presented at: New Technology and Innovation in the Minerals Industry Colloquium. Southern African Institute of Mining and Metallurgy. Emperors Palace.

Rotman, D. 2014. *Microscale 3-D Printing: Inks made from different types of materials, precisely applied, are greatly expanding the kinds of things that can be printed*. [ONLINE] Available at: https://www.technologyreview.com/s/526521/microscale-3-d-printing/. [Accessed 26 February 2016].

Salesses, P. 2015. *Frogdesign – Tech Trends 2015*. [ONLINE] Available at: http://www.frogdesign.com/techtrends2015/. [Accessed 14 April 2016].

Schiffbauer, W.H. & Mowrey, G.L. *Preliminary assessment of communication systems for underground mines for normal and emergency operations*. The National Institute for Occupation Safety and Health, Office of Mine Safety and Health.

Schlumberger Water Services. 2014. *Pre-feasibility assessment of the use of dewatering well placement technology at the GR35 Pit, Sishen Mine*. Report no. 53810R1v1. Johannesburg, Gauteng, South Africa: Schlumberger Water Services. Pp 62.

Schaffer, A. 2016. *Robots That Teach Each Other: What if robots could figure out more things on their own and share that knowledge among themselves?* [ONLINE] Available at:

https://www.technologyreview.com/s/600768/10-breakthrough-technologies-2016-robots-that-teach-each-other/. [Accessed 29 July 2016].

Schlumberger. 2002. Horizontal drilling seminar: ADCO – November 2002.

Scott, M. 2016. *What 5G Will Mean for You*. [ONLINE] Available at: http://www.nytimes.com/2016/02/22/technology/what-5g-will-mean-for-you.html?partner=IFTTT. [Accessed 10 August 2016].

Sensefly. 2016. *Drones for Mining*. [ONLINE] Available at: https://www.sensefly.com/applications/mining.html. [Accessed 26 July 2016].

Shalal, A. 2014. *Lockheed sees buyer for hybrid cargo airships in 2015*. [ONLINE] Available at: http://www.hybridairvehicles.com/news-and-media/lockheed-sees-buyer-for-hybridcargo-airship-in-2015. [Accessed 29 April 2016].

Simonite, T. 2015. *Project Loon: Billions of people could get online for the first time thanks to helium balloons that Google will soon send over many places cell towers don't reach*. [ONLINE] Available at: https://www.technologyreview.com/s/534986/project-loon/. [Accessed 10 August 2016].

Sjöström, S. L. & Carlsten, K. G. 2012. *Mining in the Future – A FULLY INTEGRATED PROCESS*. [ONLINE] Available at: https://library.e.abb.com/public/190bb579fdadaf5dc1257b26003816ed/NordicSteel_2012_mining%20in%20the%20future.pdf. [Accessed 21 May 2016].

Skylads. 2015. *What is the difference between machine learning and artificial intelligence?* [ONLINE] Available at: http://www.skylads.com/rtb-blog/what-is-the-difference-between-machine-learning-and-artificial-intelligence. [Accessed 28 July 2016].

Smith, C. & Pridgeon, B. 2016. *Frogdesign – Tech Trends 2016*. [ONLINE] Available at: http://frogdesign.com/techtrends2016/. [Accessed 14 April 2016].

Solomons, I. 2016. *New ultralow-profile mining machine operated successfully for 500 hours at SA mines*. [ONLINE] Available at: http://www.engineeringnews.co.za/article/locally-manufactured-mining-machine-trialled-successfully-2016-02-12. [Accessed 10 July 2016].

Solveforx. 2016. *Balloon-powered internet for everyone*. [ONLINE] Available at: https://www.solveforx.com/loon/. [Accessed 10 August 2016].

STAC. 2014. *The Future of Europe is Science*. Report of the Science and Technology Advisory Council.

Stroud, F. 2016. *Everything-as-a-Service (XaaS)*. [ONLINE] Available at: http://www.webopedia.com/TERM/E/everything-as-a-service_xaas.html. [Accessed 08 August 2016].

Talbot, D. 2015. *Megascale Desalination: The world's largest and cheapest reverse-osmosis desalination plant is up and running in Israel*. [ONLINE] Available at: https://www.technologyreview.com/s/534996/megascale-desalination/. [Accessed 18 May 2016].

Tay, V. 2015. *Frogdesign – Tech Trends 2015*. [ONLINE] Available at: http://www.frogdesign.com/techtrends2015/. [Accessed 14 April 2016].

Terdiman, D. 2016. *New Technology Brings Finger-Level Precision To VR*. [ONLINE] Available at: http://www.fastcompany.com/3056709/startup-report/new-technology-brings-finger-level-precision-to-vr. [Accessed 26 April 2016].

TIA. 2012. *The Mining Sector Innovation Strategies Implementation Plan*. [ONLINE] Available at: http://www.tia.org.za/CMS/uploaded_docs/TIA%20Mining%20and%20Minerals%20Innovation%20Strategies%20Implementation%20Plan%20(2012%20-%202016).pdf. [Accessed 04 February 2016].

VanderMey, A. 2015. *The 12 disruptive tech trends you need to know*. [ONLINE] Available at: http://fortune.com/2015/07/22/mckinsey-disruptive/. [Accessed 19 February 2016].

Vimeo. 2016. *Deloitte Wearables on Vimeo*. [ONLINE] Available at: https://vimeo.com/122846215. [Accessed 29 April 2016].

Waverlylabs, 2016. *A World Without Language Barriers*. [ONLINE] Available at: https://vimeo.com/122846215. [Accessed 11 August 2016].

Your-flying-camera-drone.com. 2016. HOME. [Online] Available at: http://www.your-flying-camera-drone.com. [Accessed 22 August 2016].

CHAPTER 3

RESULTS & ANALYSIS OF RESULTS

RESULTS AND ANALYSIS OF RESULTS

3.1. Relating Technologies to Focus Areas

The technologies that were identified and investigated throughout the research study are displayed in Table 3.1. These technologies were slotted in to the table in relation to the corresponding focus areas within the mining cycle where they were identified to have potential to add value. The mining cycle's focus areas relating to these technologies include the applicable sub-phases, systems, processes, activities, challenges or specific focus areas (which may be commodity or mining method specific). These focus areas were further divided into the six main mining phases, in order to cover the full mining life cycle, which were labelled as follows:

1. Exploration & Target Generation Phase;
2. Mine Project Evaluation / Planning Phase;
3. Mine Design & Construction Phase;
4. Operations Phase (Mine-to-Mill);
5. Mine Decommissioning and Closure Phase;
6. Post-Closure.

It is advised that the reader should refer back to the literature study for details on each of the technologies to gain insight into why it was chosen as a potentially applicable technology.

Table 3.1: Technologies within the Mining Cycle

Technologies within the Mining Cycle	
Description of Sub-phases/Systems/Processes/Activities/ Challenges/Specific Focus Areas	**Technology Focus**
Exploration & Target Generation Phase	
Access to site	Unmanned Aerial Vehicles (UAVs) Hybrid Airships Modularisation
Aerial mapping, of surface topography, mineral prospect zones, outcrops, or general inspection of the surface	UAVs Visualisation Technologies, including but not limited to Virtual Reality & Augmented Reality
Environmental Impact Assessment	Internet of Things Internet of Everything Big Data Advanced analytics UAVs
Geological model creation	UAVs Augmented Reality Virtual Reality Advanced analytics 3D point-cloud technology Predictive modelling
Logistics planning	Visualisation and simulation technologies Augmented Reality Virtual Reality Advanced analytics
Obtaining exploration or mining rights (similar for community and stakeholder engagements)	Genomics - Plans for agricultural enhancement for communities - Plans for medical assistance for employees and communities

	- Environmental remediation and preservation plans. Precision agriculture Social technologies Blockchain
Resource calculations	Advanced analytics
Sample drilling and mineral resource evaluation	Augmented Reality Directional drilling Enhanced Drilling Systems Enhanced Asset Management Automation Artificial Intelligence Mobile Internet Cloud Services Robotics Amplified Intelligence 3D Seismics Airborne Gravimetry Advanced analytics Genomics for sampling & analysis
Stakeholder communication, engagement and assessment	Social Technologies & Social Media Advanced analytics Visualisation and simulation technologies Virtual Reality Augmented Reality
Mine Project Evaluation / Planning Phase	
Corporate social responsibility	Visualisation and simulation technologies Augmented and Virtual Reality Blockchain Precision agriculture Genomics Advanced analytics Social media and technologies
Data collection for feasibility (and other) studies	UAVs Advanced analytics Internet of Things
Drilling work	Directional drilling Augmented Reality 3D seismics UAVs Enhanced Drilling Systems Enhanced Asset Management Automation
Environmental impact assessment	Internet of Things Internet of Everything Big Data Advanced analytics UAVs
Environmental management plan	Big Data Internet of Things Advanced analytics Virtual and Augmented Reality

	Simulation and modelling
Evaluation & feasibility studies	Bid Data Advanced analytics Virtual Reality Augmented Reality
Geological and geotechnical model creation	UAVs Big Data Advanced analytics Augmented Reality Virtual Reality 3D point-cloud geo-spatial technology 3D seismics Airborne gravimetry Predictive modelling
Mine planning and layout	Virtual Reality & Augmented Reality Big Data Advanced analytics Simulation and modelling
Resource to reserve calculations	Advanced analytics
Shareholder and stakeholder buy-in	Advanced analytics Visualisation and simulation technologies Augmented Reality & Virtual Reality Blockchain technology Social technologies and media
Surveying and sampling	Advanced analytics Genomics Automation
Mine Design & Construction Phase	
CAPEX and OPEX planning	Advanced analytics Big Data Artificial intelligence Cloud technology
Construction of buildings	Green Cement UAVs for monitoring of progress compared to plan
Construction quality control	UAVs Artificial Intelligence
Data collection and collation	Big Data Internet of Things Internet of Everything Cloud technology Advanced analytics
Development to open up reserves	Automation Remote technologies Integrated Remote Operating Centres Tunnel Boring Machines Reef boring
Dewatering	Directional drilling
Equipment selection	Advanced analytics Big Data Augmented and Virtual Reality Predictive modelling

	Cloud technology Artificial Intelligence
Haul road, dump and pit design	UAVs
Mine design, modelling and simulations	Virtual Reality & Augmented Reality Advanced analytics
Mining method selection for mine design	Big Data Cloud technology Artificial Intelligence Advanced analytics Virtual and Augmented Reality Simulation and modelling Predictive modelling
Planning and scheduling	UAVs Internet of Things Big Data Automation Advanced analytics
Plant design and construction	Augmented and Virtual Reality Advanced analytics Cloud technology
Production management and productivity improvements	Wearable technologies Augmented Reality Social technologies Mobile Internet and smart devices Internet of Things Cloud technology Automation Automation of knowledge work UAVs Advanced analytics Artificial Intelligence Machine learning Enhanced asset management Language translation technology Tracking technologies Robotics
Progress monitoring & reporting	UAVs Advanced analytics Artificial Intelligence Mobile Internet
Transportation of equipment and other assets to remote sites	Hybrid airships Modularisation UAVs
Operations Phase (Mine-to-Mill)	
Abrasive rock leading to poor performance from equipment, unnecessary equipment downtime, low utilisation, and high-volume consumption on replacement parts (e.g. drill bits or other components used to break up the rock)	Advanced material and nanomaterial technology to enhance material properties, e.g. stronger and harder drill bits.
Aerial surveys and mapping	UAVs
Amplified Human Efficiency	Artificial Intelligence & Amplified intelligence Holographic displays, AR and VR, mobile internet, 5G, Big

	Data, Advanced Analytics and other IT's will enable other technology applications such as: - Tele-presence and tele-work - Improved efficiency from off-site personnel - Multi-presence at various locations
Asset management	Enhanced asset management Internet of Things Big Data Advanced Analytics Automation Tracking technologies, e.g. - Radio-frequency Identification (RFID) - GPS - WiFi - UAVs - Electromagnetic, magnetic and seismic wave detecting units - Thermal Imaging
Automation	Physical automation technologies for mining: - Autonomous trucks - Autonomous trains - Automated drills - Automatic longwall shearers - Other remote operating technologies Automated technologies in development: - Autonomous loaders Vehicle-to-vehicle communication technologies Advanced analytics Artificial Intelligence Machine learning Internet of Things Cloud services Remote operations
Carbon emission challenges and taxes	Consider an integrated approach to switching to electrical equipment with renewable energy generation installations. Internet of Things Advanced analytics Renewables (renewable energy generation technologies) Mining technologies that may reduce energy consumption (refer to Energy sections for details)
Commodity price and demand uncertainty/fluctuations	Big Data Advanced analytics Artificial Intelligence Scalable operations with remote operating centres feeding real-time commands to adapt to market needs
Communication and collaboration	Augmented Reality applications Mobile internet Wearable technologies Virtual Reality Internet of Things Social networking Cloud services
Communities and other stakeholders engagement and communication	Community relations/marketing, and impact reporting: - Social media technologies

	- UAVs - Virtual Reality - Augmented Reality Community engagement and involvement: - Augmented Reality & Virtual Reality - Language translation technologies
Connecting various devices and sensors	Internet of Things Artificial Intelligence Machine learning Mobile internet
Cooling of clean-air environments	Immersion-cooling technology Liquid-desiccant systems Pressurised-plenum-recirculation-air system
Cost management	Advanced analytics Big Data Artificial Intelligence Internet of Things
Cyber risks	Cyber technologies Blockchain technology
Damage assessment and control, e.g. to roads or highwalls	UAVs Internet of Things
Data capture	Big Data Artificial Intelligence Data-mining Sensors IT platforms and services - Cloud computing - Cloud services Internet of Things Automation
Data processing	Big Data Advanced analytics Artificial Intelligence Super-calculators & super computers Internet of Everything
Development	Tunnel Boring Machines Automation Non-explosive technologies (Refer to rock breaking section)
Diesel costs	Engine technologies that allow the substitution of diesel for LNG by running dual fuel systems and solar technology. Consider full LNG options. Electric vehicle replacements along with the incorporation of other energy technologies (e.g. renewables) and integrated systems. Bio-fuel options with genomics integrations
Difficult and/or dangerous human tasks	Advanced Robotics Machine learning Automation Exoskeleton Artificial intelligence
Drilling works	Enhanced drill systems with high-precision geolocation

	systems to provide equipment operators with continuous navigation and guidance. Augmented Reality Directional drilling technologies Internet of Things Advanced analytics
Drill & blast	Blast designs: - UAVs - Augmented Reality applications Pre- & post-blast data: UAVs Identification of misfires & wall damage: UAVs Management: Internet of Things, Advanced Analytics, Big Data, Augmented Reality
Electric equipment	Energy storage technologies Energy generation technologies Renewable energy generation
Electricity generation & supply	Renewable energy technologies Energy storage technologies Energy generation technologies - Fuel cell technology - Wind & solar generation
Emergency management	Internet of Things Advanced analytics Augmented Reality Virtual Reality Cloud services UAVs Robotics Tracking technologies
Employee communication	Social technologies Secure messaging Language translation technologies
Energy costs & efficiency	Internet of Things Renewable energy generation alternatives: - Wind - Solar - Biomass - Geothermal - Hydroelectricity - Hybrid systems Align work processes with energy availability and cost fluctuations over different time periods. IT's that could assist include advanced analytics, general automation algorithms, Big Data, Internet of Things. LNG options can also be re-evaluated with the reduction oil and gas developments in the U.S. Mining technologies that may reduce energy consumption: - Automated-mine-ventilation control and air reconditioning - High-pressure grinding rolls - In-pit crushing-conveyance and high-angle conveyance systems - Low-loss conveyor belts - Stirred-media mills

	- Energy management systems - Advanced analytics - Smart grids - Automated-mine-ventilation control and air reconditioning - High-pressure grinding rolls - In-pit crushing-conveyance and high-angle conveyance systems - Low-loss conveyor belts - Truck optimisation - Electro and hydro powered drilling - Continuous mining - Underground pre-concentration - Fuel cell-powered mine vehicles - Coarse flotation
Energy storage	Advanced materials Nanomaterials, e.g. graphene and carbon nanotubes Gold nanowire battery storage technology Lithium-ion battery storage technology
Environmental management	UAVs Genomics – AMD, bio-remediation, Agricultural enhancements Precision Agriculture Cloud Technologies & Services Internet of Things Internet of Everything Advanced analytics Big Data Automation Artificial Intelligence Engine technologies - Transition towards lower carbon fuel sources, e.g. LNG and technologies that reduce energy consumption or increase the efficiency of energy-based assets
Equipment downtime	Internet of Things Advanced analytics 3-D Printing of required, even customised, parts to reduce downtime on equipment and also other machinery.
Equipment operation	Augmented Reality Mobile internet Internet of Things Advanced analytics Big Data Artificial Intelligence Automation Autonomous Equipment
Exploration	Directional drilling 3D Seismics Airborne Gravimetry
Fleet management and dispatch	Advanced analytics Enhanced asset management Machine learning Artificial Intelligence Internet of Things

	Big Data Automation Tracking technologies Car-to-car communication
Food scarcity	Precision Agriculture Genomics
Geological mapping	Directional drilling UAVs Advanced analytics
Geotechnical planning	UAVs Big Data Augmented Reality Virtual Reality Advanced analytics Predictive modelling 3D point-cloud geo-spatial technology for real-time profiling of excavations
Hazards associated with people and equipment/machinery	Proximity detection technologies Tracking technologies Wearable technologies Augmented Reality Car-to-car communication Artificial Intelligence Advanced analytics
Haul road surface optimisation	UAVs Advanced analytics
Health and safety	Hazard identification: - UAVs - Augmented Reality - Advanced analytics - Artificial Intelligence Search and rescue operations: - UAVs - Augmented Reality - Wearable technologies Advanced analytics Internet of Things
Healthcare & medical treatment	Information Technology (IT) Internet of Things Nano-technology & nanoparticles Bio-technology Augmented Reality & Virtual Reality 3-D Printing of biomaterial Nanoparticles & nanomaterials Genomics application in: - Diagnostics - Monitoring - Alleviation, remedy or other treatment
High fuel costs (i.e. Diesel, LNG)	Assess the impact of advanced oil & gas exploration and recovery technologies on future fuel costs.
Human assistance	Advanced analytics Artificial Intelligence Internet of Things

	Advanced robotics Robotic exoskeletons Big Data Mobile Internet Automation Automation of knowledge work Wearable technologies: - Augmented Reality applications - Mobile computer devices
Human-machine interaction	Augmented Reality Artificial Intelligence Internet of Things Brain-machine interfaces Visualisation Ambient user experience
Hydrology	Drainage and water management: - Directional drilling - UAVs Mapping of water flow and surface water systems: UAVs Tailings dam management: UAVs Flooded area exploration/inspection: UAVs Internet of Things Big Data Advanced Analytics
Inspection of dangerous or inaccessible areas	UAVs
Inspection of various assemblies, machinery and equipment	UAVs Wearable technologies incorporating Augmented Reality Internet of Things
IT services, applications and development	Cloud services
Language challenges and barriers	Virtual Reality Augmented Reality Visual technologies Brain-machine interfaces Ambient user experience Mobile internet Language translation technologies and wearables Voice interfaces
Loading and Hauling challenges	Autonomous vehicle technologies AR assistance-based applications Internet of Things
Logistical challenges and remote mining operations	3-D & 4-D Printing of parts and consumables, even organs or bio-tissue for medical purposes. Modularisation: off- or on-site assemblies of components, depending on the best option. Cloud computing to reduce IT services intensities and getting designers or consultants on site. Hybrid Airships
Maintenance and repair	Augmented Reality Machine learning Artificial Intelligence Advanced analytics Enhanced asset management Internet of Things

	Big data 3-D printing / Additive manufacturing Advanced materials Nanomaterials
Management and Leadership	Big Data Internet of Things Advanced Analytics Language Translation Technologies Social Technologies Mobile Internet Augmented Reality Virtual Reality Artificial Intelligence
Market analysis (supply and demand dynamics)	Advanced analytics Big Data Artificial Intelligence
Materials, consumables and inventory management, purchase and inspection	Augmented Reality Virtual Reality Internet of Things Autonomous systems Advanced analytics
Mechanisation, mechanised machinery and autonomous mining	Advanced analytics Big Data Automation Remote operations Automation Automation of knowledge work Mechanised mining technologies - Stope development rigs - Stope drill rigs - Remotely placed backfill - Rock cutting machinery - Reef boring machines - Tunnel boring machines Enhanced asset management Machine learning Artificial Intelligence Internet of Things Internet of Everything Tracking technologies Wearable technologies Robotics Augmented Reality Virtual Reality
Mobile devices and Smartphones	Intelligent mobility Internet of Things IT platforms and services Everything as a Service (XaaS) / Cloud Services Cloud computing Mobile Internet
Mineral extraction, processing and recovery	Investigate genomic technology applications: - Improved extraction rates - Improved recovery of metals

	- Bio-friendly leaching - Improved metal leaching rates - Treating of contaminants - Reduced water consumption - Develop bioremediation bacteria for specific environments - Mitigating Acid Mine Drainage - Bioleaching for electroplate recovery - Bio-oxidation to concentrate valuable solids through the leaching of low value impurities - Cyanide replacement with certain microorganisms
Narrow reef, hard-rock mining	Hard-rock mechanisation technologies - LP mining fleet - XLP stoping fleet - ULP stoping fleet - Wide raise rig - Disc cutting - XLP drill and breaker - XLP multi-drill for stoping - Remote control mechanical sweeper and dozer - Reef boring - Remotely placed backfill
Natural elements monitoring	Internet of Things Internet of Everything Advanced analytics
Open pit dewatering	Directional drilling technology, using horizontal drilling to create high-performance mine dewatering well systems.
Operational costs	Cloud computing Internet of Things Advanced analytics Enhanced asset management Cloud services
Pit and dump management	UAVs Internet of Things Advanced analytics
Planning and Modelling	Virtual Reality Predictive modelling 3D point-cloud technology for real-time profiling and modelling
Plant management	Advanced analytics Big Data Internet of Things Automation Robotics
Processing of ore and minerals	Genomics - Bio-leaching Advanced analytics High pressure leaching In-pit crushing and conveyance Real-time, accelerated rock sorting technologies Transmission sorting of ore through X-ray, density assessment Flexible closed-belt conveyor – adaptable to bends and changes in elevation

	High pressure grinding rolls
Production/Operations planning	Advanced analytics and simulations Big Data Enhanced asset management Internet of Things Augmented Reality & Virtual Reality Visualisation technologies Automation
Productivity	Advanced analytics Internet of Things Enhanced asset management Advanced robotics 3-D Printing
Procurement of consumables and other materials	Advanced Analytics Internet of Things Transportation: - UAVs - Hybrid airships
Recycling of raw materials	Additive manufacturing (3-D Printing) Genomics Robotics Nano-materials
Remote mining	Robotics Mechanised technologies Automation Remote operating centres Mobile Internet Artificial Intelligence Machine learning Tracking technologies
Repetitive productions or tasks	Advanced analytics Internet of Things Advanced robotics Machine learning Anthropomorphic robots Automation of knowledge work Autonomous or semi-autonomous vehicles Nano-technology Artificial Intelligence - Autonomous and self-teaching algorithms Machine learning Big Data Drone technology
Reporting and sharing of information	Augmented Reality & Virtual Reality Advanced analytics Autonomous systems Internet of Things UAVs Mobile internet & smart devices Social media technologies
Risk or Hazard Management	Risk identification: - UAVs

	- Augmented Reality - Advanced analytics - Artificial Intelligence - Big Data - Internet of Things Risk alleviation or elimination: - Advanced analytics - Artificial Intelligence - Cloud services
Rock breaking with non-explosive technologies	Jet piercing Tunnel Boring Machines Erosion drilling Diamond cutting/drilling Percussion drilling Drag bit cutting Roller bit drilling Impact driven wedge Controlled Foam Injection Laser cutting
Sample collection	UAVs
Sample analysis	Advanced analytics
Search and Rescue operations	Advanced analytics Internet of Things AI in planning coordination AR eyewear applications Advanced Robotics Underwater drones and other UAVs
Security and safety	Surveillance and monitoring: - UAVs - Safety programs using Information and Communication Technologies and tracking technologies Advanced analytics Internet of Things Tracking technologies, e.g. - RFID - GPS - WiFi - UAVs - Electromagnetic, magnetic and seismic wave detecting units - Thermal Imaging
Slope stability and safety as a result of poor dewatering systems	Directional drilling technology, for dewatering management.
Specific problems that require specific parts, components or other systems (e.g. customised fittings on pipe systems during intense flooding)	3-D & 4-D Printing of parts to fit a specific need, from whichever material would best suit the situation.
Stakeholder information and engagement	Social technologies: - Social media/networking and analytics Language translation technologies Artificial Intelligence Advanced analytics Secure messaging
Stockpile	Mapping: UAVs

	Management: - UAVs - Advanced analytics - Internet of Things Monitoring: - Sensors and 3D vision and mapping (software)
Supply chain	Advanced analytics Artificial Intelligence Enhanced asset management Internet of Things and other sensors Hybrid Airships
Surface stability	Monitoring: UAVs
Surveying	UAVs Advanced analytics
Tracking of assets and employees	Tracking technologies, e.g. - RFID - GPS - WiFi - UAVs - Electromagnetic, magnetic and seismic wave detecting units - Thermal Imaging Internet of Things Mobile internet Wearables Advanced analytics Artificial Intelligence Enhanced asset management
Transactions	Blockchain technology Cyber security Augmented Reality Virtual Reality 3D modelling
Transportation and logistics	Advanced analytics Internet of Things Hybrid Airships Enhanced asset management Autonomous and semi-autonomous vehicles, rail systems and other equipment. Synthetic biology technologies that enable new applications through industrial production of biomaterials. Replacing chemicals from non-renewables with renewables (e.g. biofuels, hydrogen). Drone/UAV technology. Vehicle-to-vehicle communication technologies Electric, hybrid and hydrogen engines. Holographic displays, AR and VR, mobile internet, 5G along with autonomous vehicles will enable other technology applications such as: - Tele-presence and tele-work - Improved efficiency from off-site personnel - Multi-presence at various locations
Training and simulation	Advanced analytics

	Augmented Reality Virtual Reality Social Technologies Language translation technologies
Tunnel development	Controlled foam injection (non-explosive rock breaking) Tunnel Boring Machine (TBM)
Ultra-deep mining	Advanced materials Nanomaterial technology Robotics
Value chain capacity analysis	Advanced analytics and simulations
Water management	Water purification technologies: e.g. desalination plants or graphene biofilter purification Internet of Things Big Data Genomics Advanced Analytics
Wet ore haulage challenges	Improved dewatering in surface mining through directional drilling technologies.
Mine Decommissioning and Closure Phase	
Closure of mine workings and demolishing of infrastructure	Robotics Automation UAVs
Compliance to EMP	Virtual and Augmented Reality Advanced analytics UAVs
Corporate social responsibility & engagement with communities and other stakeholders	Green cement Precision agriculture Genomics Social technologies and media Language translation technologies UAVs
Environmental rehabilitation and/or remediation	Genomics - Bio-remediation - AMD treatment - Treatment of contaminants - Enhanced agriculture applications
Production planning	Big Data Advanced analytics Virtual and Augmented Reality Automation Artificial Intelligence
Rehabilitation	Big Data Internet of Things Internet of Everything Augmented and Virtual Reality Advanced analytics Automation Genomics Robotics
Post Mine Closure	
Environmental rehabilitation and/or remediation	Genomics - Bio-remediation

	- AMD treatment - Treatment of contaminants - Enhanced agriculture applications
Mine related medical problems	3-D Printing, e.g. bionic ear printing for NIHL solutions. Genomic medical applications for sickness/disease monitoring, diagnostics and treatment
Non-compliance to EMP and/or corporate social responsibilities	UAVs Advanced analytics Augmented and Virtual Reality Genomics Social technologies

3.2. Mapping the Mining Cycle

It was found that very little research and previous work existed on an all-inclusive description of "*what mining consists off*" for all of the mining phases and their constituent parts (or value drivers) across the entire life cycle. As a result, no complete layout was obtainable (at least in the public domain) for the entire *mining cycle* that would serve as a platform for the Technology Map (within the scope of this study). Therefore, in order to create a comprehensive Technology Map, that is representative of the full mining life cycle, a framework was firstly created that is representative of the life cycle of any mining venture.

The framework covered the six mining phases, from exploration to post mine closure, and consisted of seven main Value Driving Pillars. The pillars incorporate all aspects (termed value drivers for this study) that impact value creation in a mining venture and were classified as follows:

1. Mineral Resource Management;
2. Production;
3. Productivity & Asset Efficiency;
4. Profitability & Cost Control;
5. Supply Chain;
6. Socio-Economic Factors;
7. Health, Environment, Safety & Legal.

Figure 3.2a is an illustration of how these seven pillars form part of the general mining life cycle and why they were chosen to represent the framework for the *mining cycle*.

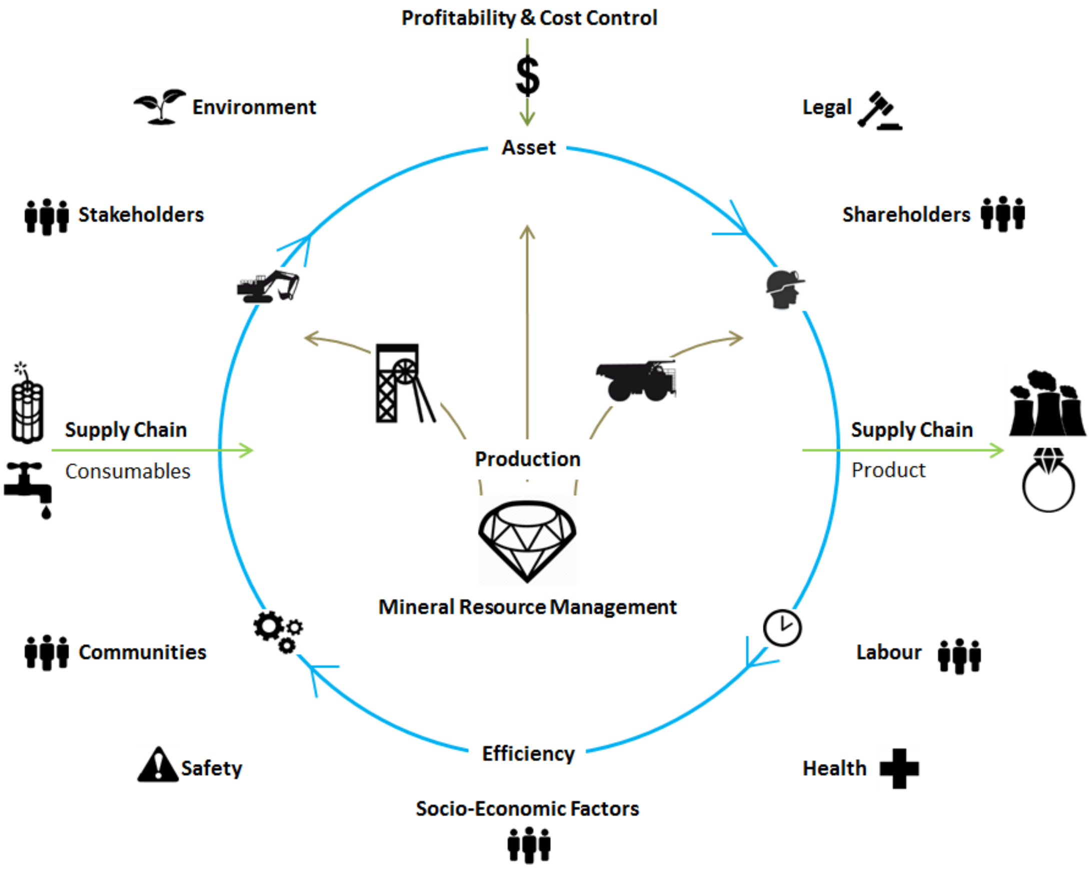


Figure 3.2a: Visual Representation for the Mining Cycle

In creating the framework for the *mining cycle*, numerous existing representations for the mining value chain were also investigated along with the associated illustrations, definitions and inclusive components. It was found that most companies have their own definitions, span/scope covered within the value chain and areas of importance as per company strategy. The goal was then to create a universal platform that would be able to represent the needs of any mining organisation, as accurately as possible, which will also be expandable to include specific company, commodity, mining method, location and other factors. As a result, the various factors (and flow) of different mining value chain illustrations were assessed and used as guidelines in creating the framework for the *mining cycle*. Two examples are shown in Figure 3.2b and 3.2c which showcase different illustrations of the value chain within the mining cycle. Figure 3.2b is an example from the Technology Innovation Agency of South Africa, while Figure 3.2c is an example of a company specific value chain as used by Namane Resources (Pty) Ltd.

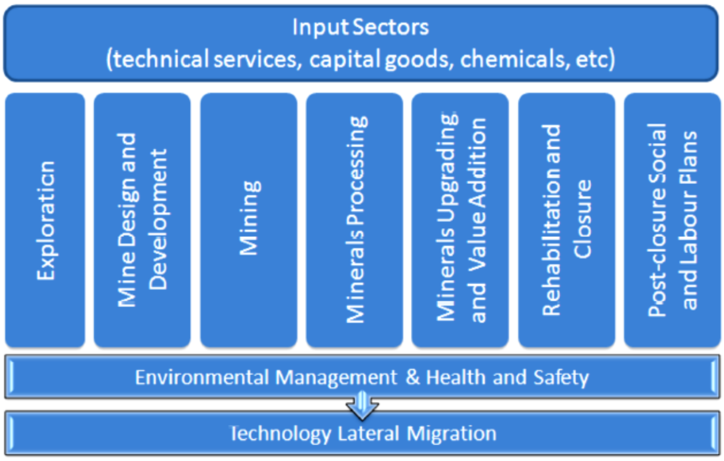


Figure 3.2b: Mining and minerals sub-sector view for recommended focus areas of technological development within the displayed critical areas within the value chain (TIA, 2012)

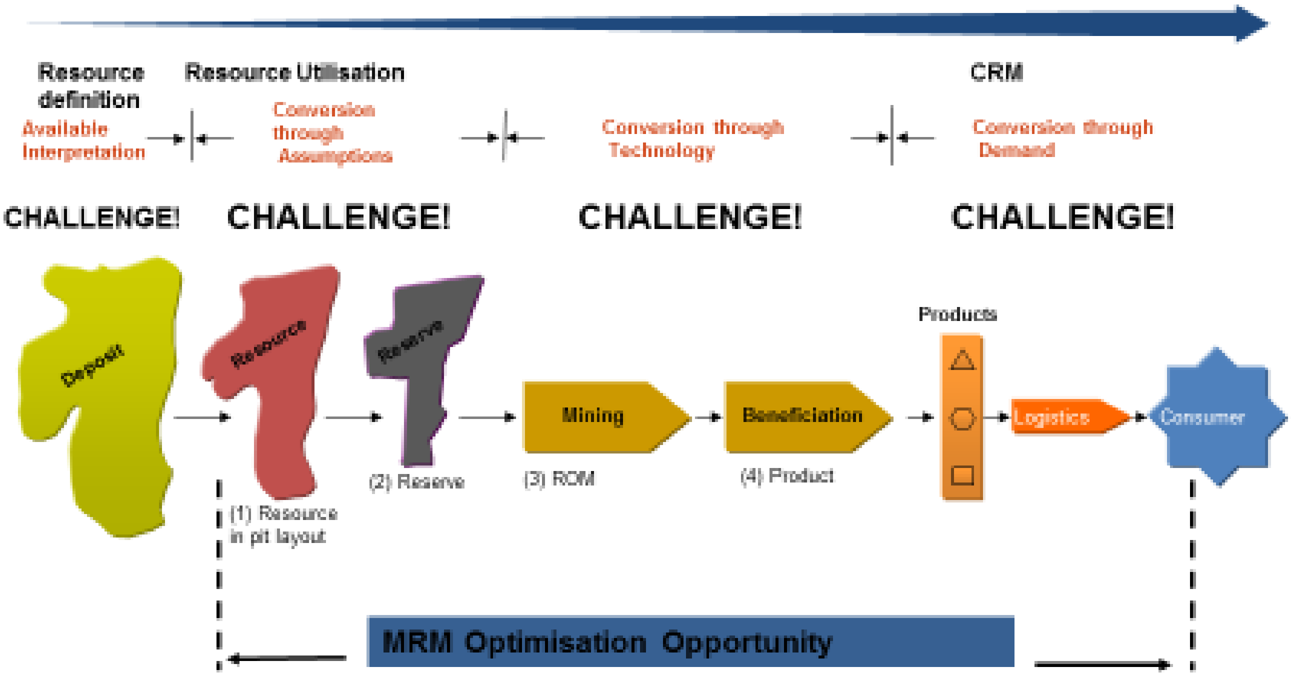


Figure 3.2c: Mining Value Chain as outlined by Namane Resources (Britz, 2016)

An iterative process was then followed in order to refine the created framework for the mining cycle. The result was 7x6 matrix, which housed the seven main value driving pillars (as previously discussed) along with the six mining phases (exploration-, mine evaluation-, mine design-, operations-, and mine closure to post-closure mining phases). This matrix was then populated with the value drivers for each main pillar within each of the appropriate mining phases. Through various workshops, face-to-face discussions and interviews with mining experts, the resulting framework was then assessed, modified and refined into the matrix shown in Table 3.2. Refer to Section 1.6 for more detail on the process that led to the creation of this framework.

After tabulating the value drivers for each corresponding area, the matrix contained a total of around 300 value drivers within the mining cycle (including sub-components). Nearly all of the aforementioned drivers represented potential opportunities, for the technologies that were investigated, to add value and as such facilitate mine modernisation. It should be noted that this framework is aimed at the mining cycle from a general overview perspective. As more focus areas are included into the original platform (Table 3.2), the resulting *mining cycle framework* can be expanded to include specific commodity types, mining methods, site-specific challenges, unique regulatory constraints and more.

Table 3.2: Main Value Drivers within the Mining Cycle

Value Drivers in the Mining Cycle						
	Exploration & Target Generation Phase	**Mine Project Evaluation / Planning Phase**	**Mine Design & Construction Phase**	**Operations Phase (Mine-to-Mill)**	**Mine Decommissioning and Closure Phase**	**Post-Closure**
Mineral Resource Management	Initial Target Generation	Data Collection	Data collation	Geology	Production Planning	In-Situ Reserves: Monitoring/Mapping/Sampling
	Target Identification	Evaluation Studies	Geotechnical Planning	Exploration		
	Target Definition and Discovery	Desktop Study and Literature Review	Mining Method Confirmation	Monitoring		
	Target Evaluation	Conceptual Study	Mine Design	Mapping & Modelling		
	Geological Model	Pre-Feasibility Study	Iteration & Optimisation	Geotechnical Planning		
	Geotechnical Model	Bankable Feasibility Study (& Investment)	Implementation	Hazard & Risk Management		
	Hydro Geology	Geological Model	Monitoring of Construction & Development	Hydrology Monitoring & Mapping		
	Interpretations	Geotechnical Model	Mine Closure Preparation	Operations Plan		
	Mineral Resource Evaluation	Mine Closure Planning	Operations Plan	Development Planning & Scheduling		
		Mine Planning	Planning & Scheduling	Production Planning & Scheduling		
		Resource to Reserve Calculations				
Production	Drilling Work & Blasting	Drilling Work & Blasting	Construction	Development	Closure of mine workings and associated infrastructure	In-Situ Reserves: Renewed Production
	Site Establishment	Mining Method Selection	Infrastructure & Physical Assets	Mineral/Ore and Waste Extraction	Ramp-down Management	
	Surveying & Sampling Efficiency	Support Method Selection	Development: Opening up Reserves	Infrastructure	Rehabilitation Management	
			Hazard & Risk Management	Hazard & Risk Management		
			Hydrology Management	Hydrology Management		
			Reservoirs/Dams/Infrastructure	Reservoirs/Dams/Infrastructure		
			Dewatering	Dewatering		
			Labour	Labour		
			Logistics	Logistics		
			Waste & Mineral/Ore Transport	Mineral/Ore Transport		
			-Load & Haul / tram / Hoist	Waste Transport		
			Operations Plan	-Load & Haul / Tram / Hoist		
			Plant Design & Construction	Operations Plan		
			Production Management	Plant Management		
			Production Rate Calculations for LoM	Processing & Refining		
			Tailing/Slime Dams/Waste Dumps: Plan/Construct	Comminution		
				Mineral Extraction & Recovery		
				Production Management		
				Rehabilitation		
				Stockpile Management		
				Tailing/Slime Dams, Waste Dumps: Management		
Productivity & Asset Efficiency	Drilling Equipment	Drilling Efficiency & Accuracy	Asset Management	Asset Management	Asset & Equipment Management	
	Drilling Efficiency & Accuracy	Equipment selection	Communication and collaboration	Communication and collaboration	Human Resources	
	Human Resources	Human Resources	Asset connectedness	Asset connectedness		
	Metallurgical Processing	Metallurgical Processing	Cyber Risks	Cyber Risks		
			Data Capture, Processing, Analysis & Output	Data Capture, Processing, Analysis & Output		
			Contractor Management	Availability		
			Communication and collaboration	Contractor Management		
			Equipment selection	Communication and collaboration		
			Fleet Management System Selection	Equipment Improvement/Upgrades		
			Hazard & Risk Management	Acquisition of new assets		
			Human Resources	Upgrading existing equipment		
			Sourcing	Hazard & Risk Management		
			Efficiency	Human Resources		
			Training & Inductions	Sourcing		
			Rock Breaking Efficiency	Communication and collaboration		
			Mechanical Breaking	Difficult, repetitive and/or dangerous human tasks		
			Drill & Blast	Efficiency		
				Human-Asset/Human-Machine interaction		
				Training & Inductions		
				Maintenance, Repair & Inspection		
				Equipment		
				Machinery		
				Infrastructure		
				Other Assets		
				Operation/Usage of Equipment & other Assets		
				Efficient Operation		
				Fleet Management		
				Rock Breaking Efficiency		
				Mechanical Breaking		
				Drill & Blast		
				Utilisation		

Profitability & Cost Control	CAPEX	CAPEX	CAPEX Planning	CAPEX Management	CAPEX Management	
	Investment Strategy	Investment Strategy	OPEX Planning	Hazard & Risk Management	OPEX Management	
	OPEX	Extraction Ratio	Pricing Forecasts	Market Analysis		
	Drilling work	Mining Method Selection	Unit Operating Cost	Commodity Price		
	Sampling/Coring	OPEX		Operations Plan		
		Pricing Forecasts		Marketing plan		
				Financial plan		
				Administration plan		
				OPEX Management		
				Consumable Resources		
				Remuneration		
Supply Chain	Access to site	Asset Acquisition Strategy	Acquisition of Assets	Electricity/Energy	Infrastructure Demolishing	
	Logistical planning	Infrastructure planning	Equipment	Supply		
	Consumables	Logistical planning	Machinery	Generation		
	Assets	Supplier Establishment	Other assets	Storage		
	Human Resources	HR Sourcing	Materials	Finance/Procurement/Transactions		
		Electricity Supply & Generation	Human Resources	Hazard & Risk Management		
			Electricity Supply & Generation	Infrastructure Maintenance		
			Infrastructure Design	Primary Access/Ore Transport Route		
			Infrastructure Development	Secondary Access/Consumables delivery		
				Ore Transportation		
				Procurement of Consumable, Parts & Assets		
				Product/Market Delivery		
				Warehousing & Inventory Management		
				Waste Transportation		
Socio-Economic Factors	Corporate Governance	Corporate Governance	Communities	Communities	Communities	Communities
	Labour and Communities	Labour and Communities	Coroporate Social Responsibility	Coroporate Social Responsibility	Coroporate Social Responsibility	Coroporate Social Responsibility
	Coroporate Social Responsibility	Coroporate Social Responsibility	Corporate Governance	Corporate Governance	Corporate Governance	Corporate Governance
	Shareholders and other Stakeholder	Shareholders and other Stakeholder	Hazard & Risk Management	Hazard & Risk Management	Hazard & Risk Management	Hazard & Risk Management
			Labour	Labour	Labour	Labour
			Other Stakeholders	Other Stakeholders	Other Stakeholders	Other Stakeholders
			Shareholders & Other Stakeholders	Shareholders & Other Stakeholders	Shareholders & Other Stakeholders	Shareholders & Other Stakeholders
Health, Environment, Safety & Legal	Environmental Impact Assessment	Environmental Impact Assessment	Civil Geotechnical Work on Foundations & Roads	Environmental Engineering	Emergency Management	Emerging HES Issues
	Mineral Rights	Environmental Management Plan	Environmental Engineering	Ventilation Engineering	EMP Compliance	EMP Non-Compliance
	Prospecting Rights	Operational EMP	Ventilation Engineering	Cooling	HES Monitoring	HES Monitoring
	Exploration Rights	Post-closure & rehab plan	Cooling	Environmental Management Program	Hazard & Risk Management	Malpractice
	Mining Rights	Mine Workings Layout	Environmental Management Program	Geotechnical Engineering	Long Term Stability of Workings	Mineral Rights
			Geotechnical Engineering	-Implementation and Design (Planning & CoPs)	Malpractice	Surface Stability / Infrastructure Stability
			-Implementation and Design (Planning & CoPs)	-Monitoring (Seismic/Non-Seismic)	Rehabilitation & Remediation	
			-Monitoring (Seismic/Non-Seismic)	Emergency Management	Surface Stability / Infrastructure Stability	
			Emergency Management	Healthcare & Medical Treatment		
			Healthcare	Hazard Identification		
			Hazard Identification	Hazard & Risk Management		
			Hazard Management	Difficult and/or dangerous human tasks		
			Legislation	Monitoring		
			Safety	Legislation		
				Safety		

3.3. Creating a Technology Map

The framework from Table 3.2 was further expanded to include additional constituent components beneath the value drivers that correspond to the technologies that were investigated. This expansion included the focus areas, activities, processes, systems, or challenges that are applicable to the mining life cycle and also to the potential of each of the investigated technologies from Table 3.1. This expanded matrix housed a total of around 360 value drivers and formed the basis of the Technology Map.

The technologies were then slotted in on this expanded framework as per their relevant areas of application, impact or value creation. The result was a Technology Map that spanned the entire mining life cycle. The contents of the Technology Map will follow, grouped by the applicable mining phase and main value driving pillar, with the all-inclusive matrix shown in Appendix 2 Table 7.2. Prior to this, note should be taken of the following list of abbreviations used (Table 3.3a) within the Technology Map.

Table 3.3a: Abbreviations used in the Technology Map

List of Abbreviations	**Description**
AA	Advanced Analytics
AI	Artificial Intelligence
AMD	Acid Mine Drainage
AR	Augmented Reality
Automation	The automation of systems and/or processes through various physical or ICT technologies to facilitate autonomous working that is independent of human interaction under normal operating circumstances
Autonomous Eq&Tech	Autonomous Equipment and Technologies: E.g. Autonomous drills, trucks, trains, (longwall) shearers, loaders, and other Remote Tech
BD	Big Data
Cloud	Cloud Technologies and Cloud Services, e.g. Everything as a Service (XaaS)
CoP	Code of Practice
C-T-C Coms	Car-to-car communication technology
EAM	Enhanced Asset Management
EDS	Enhanced drill systems with high-precision geolocation systems to provide equipment operators with continuous navigation and guidance
Energy Tech(nologies)	Energy technologies and technological applications and systems that increase the efficiency at which energy is used or reduces energy/electricity consumption, e.g. Energy-Management Systems, AA, Smart Grids, Mining Technologies that reduce energy consumption (MTREC)

EST	Energy storage technologies: Lithium-ion battery storage, Gold nanowire battery storage technology, advanced materials, nanomaterials (e.g. graphene and carbon nanotubes)
Hard-Rock Mech Tech	Hard-Rock Mechanisation Technologies: LP mining fleet, XLP stoping fleet, ULP stoping fleet, Wide raise rig, Disc cutting, XLP drill and breaker, XLP multi-drill for stoping, Remote control mechanical sweeper and dozer, Reef boring, Remotely placed backfill
HES	Health, Environment & Safety
ICTs	Information and Communication Technologies
IoE	Internet of Everything
IoT	Internet of Things
IROC	Integrated Remote Operating Centre
ITs	Information Technologies
GPS	Global Positioning System
Language Tech	Language translation and other technologies to assist with communication
LoM	Life of Mine
Mechanised Tech(nologies)	Stope development rigs, Stope drill rigs, Remotely placed backfill, Reef boring machines, TBMs, Remote Operations/Mining, Automation, Rock cutting machinery
MI	Mobile Internet
ML	Machine Learning
MTREC	Mining (and other) technologies that may reduce energy consumption: Automated-mine-ventilation control and air reconditioning, High-pressure grinding rolls, In-pit crushing-conveyance and high-angle conveyance systems, Low-loss conveyor belts, Stirred-media mills, Artificial Intelligence, Low-loss conveyor belts, Truck optimisation, Electro and hydro powered drilling, Continuous mining, Underground pre-concentration, Fuel cell-powered mine vehicles, Coarse flotation
Non-Explosives	Non-explosive technologies, e.g. Controlled Foam Injection (CFI)
Remote Tech(nologies)	Technologies that allow tele-presence or tele-work from employees, or the remote operation of on-site assets
RFID	Radio-Frequency Identification
Rock breaking Tech(nologies)	Jet piercing, TBMs, Erosion drilling, Diamond cutting/drilling, Percussion drilling, Drag bit cutting, Roller bit drilling, Impact driven wedge, Controlled Foam Injection, Laser cutting
Social Tech(nologies)	Social Networking, Digital Workforce Engagement, and social media and technologies that form part of people's social or private lives
TBM	Tunnel Boring Machine

Renewables	Renewable energy generation technologies, e.g. solar, wind, fuel cell technology, biomass, geothermal, hydroelectricity and hybrid systems
Tracking Tech(nologies)	RFID, GPS, WiFi, UAVs, Electromagnetic, magnetic and seismic wave detecting units, Thermal Imaging
UAV	Unmanned Aerial Vehicle
VR	Virtual Reality
V-T-V Coms	Vehicle-to-vehicle communication technologies
Wearables	Wearable technologies that may consist of various technologies and applications thereof, e.g. AR, VR, tracking technologies, monitoring technologies (a person's vitals etc.)

The abbreviations from Table 3.3a are displayed in square brackets beneath the applicable value drivers in the Technology Map matrix in Appendix 2 Table 7.2. The same abbreviations will be used in the following listings of the various components in the Technology Map. The tables that follow are grouped per mining phase, with one table per *main value driving pillar*. Within each table are the listed value drivers within the mining cycle, along with the corresponding technology that may potentially be applied to add value for that specific focus area.

Phase 1: Exploration & Target Generation

Table 3.3b: P1 - Mineral Resource Management

Value Drivers	Applicable Technology
Initial Target Generation	UAVs, Directional Drilling, Airborne Gravimetry
Target Identification	UAVs, Directional Drilling, Airborne Gravimetry, AA
Target Definition and Discovery	UAVs, Directional Drilling, Airborne Gravimetry, AA
Target Evaluation	UAVs, Directional Drilling, Airborne Gravimetry, AA
Geological Model	UAVs, AA, AR, VR, Predictive Modelling, 3D Seismic, Air-borne Gravimetry, 3D point-cloud technology, Visualisation
Geotechnical Model	UAVs, AA, 3D Point-Cloud Geo-Spatial Technology, AR, VR, BD, Predictive Modelling, Visualisation
Hydro Geology	Directional Drilling, AA, 3D Point-Cloud Geo-Spatial, Technology, AR, VR
Interpretations (of data and analysis)	AA, Visualisation, Simulation and Modelling, AR, VR
Mineral Resource Evaluation	AA

Table 3.3c: P1 - Production

Value Drivers	Applicable Technology
Drilling Work & Blasting	Directional drilling, AR, 3D seismics, UAVs, EDS, Airborne Gravimetry
Surveying & Sampling Efficiency	AA, Genomics

Table 3.3d: P1 - Productivity & Asset Efficiency

Value Drivers	Applicable Technology
Drilling Equipment	AR, EAM, EDS, Automation
Drilling Efficiency & Accuracy	Directional drilling, AR
Human Resources	Amplified Intelligence, AI, AR, VR, MI, BD, AA, Cloud, Automation, Automation of Knowledge Work, IoT, Robotics
Metallurgical Processing	AA, Genomics

Table 3.3e: P1 - Profitability & Cost Control

Value Drivers	**Applicable Technology**
CAPEX: Investment strategy	BD, AA
OPEX: Drilling Work	Directional drilling, AR
OPEX: Sampling/Coring	AA, Genomics

Table 3.3f: P1 - Supply Chain

Value Drivers	**Applicable Technology**
Access to site	UAVs, Hybrid Airships
Logistical planning - Consumables - Assets - Human Resources	[AA, Visualisation, AR/VR, UAVs]

Table 3.3g: P1 - Socio-Economic Factors

Value Drivers	**Applicable Technology**
Corporate Governance	Blockchain, social media/technologies, AA
Labour and Communities: Corporate Social Responsibility	Visualisation and simulation technologies, AR, VR, Precision Agriculture, Blockchain, Genomics, AA, Social media/technologies
Shareholders and other Stakeholder	Visualisation and simulation technologies, AR, VR Blockchain, Social media/technologies, AA

Table 3.3h: P1 - Health, Environment, Safety & Legal

Value Drivers	**Applicable Technology**
Environmental Impact Assessment	IoT, IoE, BD, AA, UAVs
Mineral Rights - Prospecting Rights - Exploration Rights - Mining Rights	Genomics, Precision Agriculture, Social Media and Social Technologies, Genomics, Blockchain

Phase 2: Mine Project Evaluation / Planning

Table 3.3i: P2 - Mineral Resource Management

Value Drivers	**Applicable Technology**
Data Collection	UAVs, AA, IoT
Evaluation Studies - Desktop Study and Literature Review - Conceptual Study - Pre-Feasibility Study - Bankable Feasibility Study (& Investment Decisions)	BD, AA, VR/AR, Visualisation
Geological Model	UAVs, AA, AR, VR, Predictive Modelling, 3D Seismics, Air-borne Gravimetry, 3D point-cloud technology, Visualisation
Geotechnical Model	UAVs, AA, 3D Point-Cloud Geo-Spatial Technology, AR, VR, BD, Predictive Modelling, Visualisation
Mine Closure Planning	AR, VR, AA, BD
Mine Planning	AR, VR, AA, BD
Resource to Reserve Calculations	AA

Table 3.3j: P2 - Production

Value Drivers	**Applicable Technology**
Drilling Work & Blasting	Directional drilling, AR, 3D seismics, UAVs, Airborne Gravimetry
Mining Method Selection	BD, AA, AI, VR, AR, Simulation and Modelling
Support Method Selection	BD, AA, AI, VR, AR, Simulation and Modelling

Table 3.3k: P2 - Productivity & Asset Efficiency

Value Drivers	**Applicable Technology**
Drilling Efficiency & Accuracy	Directional drilling, AR
Equipment selection	AR/VR, BD, AA, Simulation and Modelling
Human Resources: Communication and collaboration	Wearables, AR, VR, MI, Cloud, IoT, Social Tech, Voice Interfaces, Language Translation Tech
Human Resources: Efficiency	Amplified Intelligence, AI, AR, VR, MI, BD, AA, Cloud, Automation, Automation of Knowledge Work, IoT, Robotics
Human-Asset/Human-Machine interaction	AR, AI, ML, IoT, Brain-Machine Interfaces, Ambient User Experience, Visualisation & Visual Technologies
Metallurgical Processing	Genomics, AA, BD

Table 3.3l: P2 - Profitability & Cost Control

Value Drivers	Applicable Technology
CAPEX: Investment Strategy	BD, AA
Extraction Ratio	AA, Automation
Mining Method Selection	BD, AA
OPEX	BD, AA
Pricing Forecasts	BD, AA

Table 3.3m: P2 - Supply Chain

Value Drivers	Applicable Technology
Asset Acquisition Strategy - Infrastructure planning - Logistical planning - Supplier Establishment - HR Sourcing	AA, BD, VR/AR, Visualisation
Electricity Supply & Generation	EST, Renewables, Fusion, Hybrid systems

Table 3.3n: P2 - Socio-Economic Factors

Value Drivers	Applicable Technology
Corporate Governance	Blockchain, social media/technologies, AA
Labour and Communities: Corporate Social Responsibility	Visualisation and simulation technologies, AR, VR, Precision Agriculture, Blockchain, Genomics, AA, Social media/technologies
Shareholders and other Stakeholders	Visualisation and simulation technologies, AR, VR Blockchain, Social media/technologies, AA

Table 3.3o: P2 - Health, Environment, Safety & Legal

Value Drivers	Applicable Technology
Environmental Impact Assessment - Water - Energy - Fauna & Flora - Carbon Emission Management	IoT, IoE, BD, AA, UAVs
Environmental Management Plan - Operational EMP - Post-closure & rehab plan	BD, IoT, AA, VR/AR, Simulation and Modelling
Mine Workings Layout	BD, AA, VR/AR, Simulation and Modelling

Phase 3: Mine Design & Construction

Table 3.3p: P3 - Mineral Resource Management

Value Drivers	**Applicable Technology**
Data collation	BD, IoT, Cloud, IoE, AA
Geotechnical Planning	UAVs, AA, 3D Point-Cloud Geo-Spatial Technology, AR, VR, BD, Predictive Modelling
Mining Method Confirmation	VR, AR, Predictive Modelling, AA, BD, Cloud
Mine Design: Iteration & Optimisation	VR, AR, AA, BD, Cloud
Monitoring of Construction & Development	UAVs, AA, AI, AR, VR
Mine Closure Preparation	AA
Operations Plan: Planning & Scheduling	UAVs, Physical Monitoring: IoT, AA, Data Capture & Processing: IoT, AA, BD, Automation

Table 3.3q: P3 - Production

Value Drivers	**Applicable Technology**
Construction: Infrastructure & Physical Assets - Haul Roads & Mine Access - Dumps, Stockpiles, Dams - Surface preparation or Shaft sinking	Green cement
Development: Opening up Reserves	TBM, Automation, Remote Tech, IROC
Development: Opening up Reserves - Drill & Blast: Blast design & Drill pattern	AR, UAVs
Development: Opening up Reserves - Drill & Blast: Drilling Work & Blasting	Advanced Materials, Non-Explosives, EDS, AR, IoT, AA, Directional Drilling, Precision Drilling, Automation
Development: Opening up Reserves - Drill & Blast: Pre- & post-blast data	AR, UAVs, BD, IoT, AA
Development: Opening up Reserves - Drill & Blast: Identification of misfires & wall damage	AI, AA, UAVs
Development: Opening up Reserves - Drill & Blast: Management	AR, IoT, AA, BD, MI
Development: Opening up Reserves - Mechanised, Autonomous Mining	Mechanised Tech, BD, AA, ML, AI, IoT, IoE, AR, MI, EAM, IROC, Tracking Tech, Automation, Robotics
Development: Opening up Reserves - Mechanised, Autonomous Mining: Hard-Rock Narrow Reef Mining	Hard-Rock Mech Tech, Advanced Materials, Nanomaterials, Robotics, Automation

Hazard & Risk Management	BD, AA, IoT, Cloud, UAVs, Automation, AI
Hydrology Management	IoT, AA, BD, UAVs
Hydrology Management: Dewatering	Directional Drilling
Labour: Communication and collaboration	Wearables, AR, VR, MI and Smart Devices, IoT, Social Tech, AA, UAVs, Automation, Robotics, Automation (& Automation of knowledge work)
Labour: Management & Leadership	BD, IoT, AA, Language Tech, Social Tech, MI, AR, VR, AI
Logistics: Waste & Mineral/Ore Transport - Load & Haul / Tram / Hoist	Automation, Autonomous Eq&Tech, ML, AI, AR, C-T-C Coms, Remote Tech, IoT, Tracking Tech, EAM
Operations Plan	BD, AA, IoT, Cloud, Automation, AR, VR, EAM, Visualisation
Plant Design & Construction	VR, AR, AA, BD, Cloud
Production Management: Communication and collaboration	Wearables, AR, VR, MI and Smart Devices, IoT, Social Tech, AA, UAVs, Automation (of knowledge work), Cloud, Robotics
Production Rate Calculations for LoM	AA, BD, Cloud
Tailing/Slime Dams/Waste Dumps: Planning vs. Construction	UAVs, IoT, AA

Table 3.3r: P3 - Productivity & Asset Efficiency

Value Drivers	**Applicable Technology**
Asset Management: Communication and collaboration	Tracking Tech, IoT, Automation, BD, AA, EAM, AI, MI
Asset Management: Asset connectedness	IoT, Tracking Tech, AI, ML, MI, Wearables, AA, MI
Asset Management: Cyber Risks	Cyber Security, Blockchain
Asset Management: Data Capture, Processing, Analysis & Output	EAM, IoT, IoE, AA, BD, Automation, Cloud, AI, Super-Calculators & Computers
Contractor Management: Communication and collaboration	Wearables, AR, VR, MI and Smart Devices, IoT, Robotics, Social Tech, AA, UAVs, Automation (of knowledge work)
Equipment selection	AA, BD, AI, Cloud, VR, AR, Predictive Modelling
Fleet Management System Selection	AA, BD, AI, ML, Cloud, VR, AR, Predictive Modelling
Hazard & Risk Management	BD, AA, IoT, Cloud, UAVs, Automation, AI
Human Resources: Sourcing	BD, AA, AI, Cloud
Human Resources: Communication and collaboration	Wearables, AR, VR, MI, Cloud, IoT, Social Tech, Voice Interfaces, Language Translation Tech
Human Resources: Difficult, repetitive and/or dangerous	Robotics, Exoskeletons, AI, ML, MI, Automation, MI, IoT, AA,

human tasks	BD, Anthropomorphic Robots, Automation of Knowledge Work, Nano-Technology, UAVs
Human Resources: Efficiency	Amplified Intelligence, AI, AR, VR, MI, BD, AA, Cloud, Automation, Automation of Knowledge Work, IoT, Robotics
Human Resources: Human-Asset/Human-Machine interaction	AR, AI, ML, IoT, Brain-Machine Interfaces, Ambient User Experience, Visualisation & Visual Technologies
Human Resources: Training & Inductions	Social Tech, VR, AR, Language Tech
Rock Breaking Efficiency: Mechanical Breaking - Efficiency & Fragmentation	Advanced Materials, Nanomaterials, Mechanised Tech, Rock breaking Tech
Rock Breaking Efficiency: Drill & Blast - Rock Abrasiveness, Drilling Efficiency and Drilling Accuracy	Advanced Materials, Non-Explosives, EDS, AR, IoT, AA, Directional Drilling, Precision Drilling, Automation

Table 3.3s: P3 - Profitability & Cost Control

Value Drivers	**Applicable Technology**
CAPEX Planning	BD, AA, AI, Cloud, VR/AR, Predictive Modelling, EAM
OPEX Planning	BD, AA, AI, Cloud, VR/AR, Predictive Modelling, EAM
Pricing Forecasts	BD, AA, AI, Cloud
Unit Operating Cost	BD, AA, AI, Cloud, VR/AR, Predictive Modelling

Table 3.3t: P3 - Supply Chan

Value Drivers	**Applicable Technology**
Acquisition of Assets - Equipment - Machinery - Other assets - Materials - Human Resources	Hybrid Airships, Modularisation, UAVs
Electricity Supply & Generation	EST, Renewables, Fusion, Hybrid systems
Infrastructure Design	AA, AR, VR, Visualisation
Infrastructure Development	Green Cement, UAVs, AA, AR

Table 3.3u: P3 - Socio-Economic Factors

Value Drivers	**Applicable Technology**
Communities: Corporate Social Responsibility	Green cement, Precision Agriculture, Genomics
Communities: Engagement & Communication	Social Tech, UAVs, VR, AR, Language Tech, Secure Messaging
Corporate Governance	Blockchain, Social Tech, UAVs
Hazard & Risk Management	Social Tech, UAVs, VR, AR, Language Tech, BD, AA, IoT, Cloud, AA
Labour: Engagement & Communication	Social Tech, UAVs, VR, AR, Language Tech, Secure Messaging
Other Stakeholders: Engagement & Communication	Social Tech, UAVs, VR, AR, Language Tech, Secure Messaging
Shareholders: Engagement & Communication	Social Tech, VR, AR, Language Tech

Table 3.3v: P3 - Health, Environment, Safety & Legal

Value Drivers	**Applicable Technology**
Environmental Engineering: Ventilation Engineering	Automation, Energy Tech, IoT, BD, AA
Environmental Engineering: Cooling	Clean air environments: Immersion-cooling technology Liquid-desiccant systems, Pressurised-plenum-recirculation-air system
Environmental Engineering: Geotechnical Engineering - Implementation and Design (Planning & CoPs)	BD, AA, IoT, Predictive Modelling
Environmental Engineering: Geotechnical Engineering - Monitoring (Seismic/Non-Seismic)	UAVs, IoT, AA
Environmental Management Program: Carbon Emission Management	Electrical Technologies and Equipment, IoT, AA, renewables
Environmental Management Program: Water	Desalination plant technology, Graphene biofilter purification
Environmental Management Program: Energy	Automation, Energy Tech
Environmental Management Program: Fauna & Flora	Genomics, Precision Agriculture
Environmental Management Program: Recycling	Genomics
Emergency Management	Tracking Tech, IoT, AA, AR, VR, Cloud, UAVs, Robotics Wearables, AI
Healthcare & Medical Treatment	Genomics, 3D Printing, AA, AI, Nanomaterials, Robotics, Automation, Exoskeletons, UAVs, IoT, Wearables, ICTs, Nano-technology, Nano-particles, biotechnology, AR, VR

Hazard Identification	AR, AA, AI, UAVs, IoT, IoE
Hazard & Risk Management: Difficult and/or dangerous human tasks	Automation, Robotics, Exoskeletons, AA
Hazard & Risk Management: Monitoring	IoT, BD, AA. Tracking Tech
Safety: Surveillance and monitoring	Tracking Tech, IoT, AA, AR, VR, Cloud, UAVs, Robotics, Wearables
Safety: Tracking of people and assets	Tracking Tech, AR, VR, IoT, AA, BD, Wearables
Safety: Continuous Improvement	AA, BD, IoT, AI, ML

Phase 4: Operations Phase (Mine-to-Mill)

Table 3.3w: P4 - Mineral Resource Management

Value Drivers	Applicable Technology
Geology: Exploration	Directional Drilling Technologies, 3D Seismics, Air-borne Gravimetry
Geology: Monitoring	IoT, BD, AA
Geology: Mapping & Modelling	UAVs, AA, AR, VR, Predictive Modelling, 3D point-cloud technology
Geotechnical Planning	UAVs, AA, 3D Point-Cloud Geo-Spatial Technology, AR, VR, BD, Predictive Modelling
Hazard & Risk Management	BD, AA, IoT, Cloud, UAVs, Automation, AI
Hydrology Monitoring & Mapping	UAVs, IoT, AA
Operations Plan: Development Planning & Scheduling	UAVs, IoT, BD, Automation, AA, AI
Operations Plan: Production Planning & Scheduling	UAVs, IoT, BD, Automation, AA, AI

Table 3.3x: P4 - Production

Value Drivers	Applicable Technology
Development	TBM, Automation, Remote Tech, IROC
Development: Mineral/Ore & Waste Extraction - Drill & Blast: Blast design & Drill pattern	AR, UAVs
Development: Mineral/Ore & Waste Extraction - Drill & Blast: Drilling Work & Blasting	Advanced Materials, Non-Explosives, EDS, AR, IoT, AA, Directional Drilling, Precision Drilling, Automation
Development: Mineral/Ore & Waste Extraction - Drill & Blast: Pre- & post-blast data	AR, UAVs, BD, IoT, AA
Development: Mineral/Ore & Waste Extraction - Drill & Blast: Identification of misfires & wall damage	AI, AA, UAVs
Development: Mineral/Ore & Waste Extraction - Drill & Blast: Management	AR, IoT, AA, BD, MI
Development: Mineral/Ore & Waste Extraction - Mechanised, Autonomous Mining	Mechanised Tech, BD, AA, ML, AI, IoT, IoE, AR, MI, EAM, IROC, Tracking Tech, Automation, Robotics
Development: Mineral/Ore & Waste Extraction - Mechanised, Autonomous Mining: Hard-Rock Narrow Reef Mining	Hard-Rock Mech Tech, Advanced Materials, Nanomaterials, Robotics, Automation
Development: Infrastructure	Green Cement, Robotics, Automation, IROCs

Hazard & Risk Management	BD, AA, IoT, Cloud, UAVs, Automation, AI
Hydrology Management	IoT, AA, BD, UAVs
Hydrology Management: Dewatering	Directional Drilling
Labour: Communication and collaboration	Wearables, AR, VR, MI and Smart Devices, IoT, Social Tech, AA, UAVs, Automation, Robotics, Automation (& Automation of knowledge work)
Labour: Management & Leadership	BD, IoT, AA, Language Tech, Social Tech, MI, AR, VR, AI
Logistics: Waste & Mineral/Ore Transport - Load & Haul / Tram / Hoist	Automation, Autonomous Eq&Tech, ML, AI, AR, C-T-C Coms, Remote Tech, IoT, Tracking Tech, EAM
Operations Plan	BD, AA, IoT, Cloud, Automation, AR, VR, EAM, Visualisation
Plant Management	IoT, BD, AA, Automation, Robotics, Flexible closed-belt conveyor
Processing & Refining: Comminution	High Pressure Grinding Rolls, Transmission sorting of ore through X-ray, density assessment
Processing & Refining: Mineral Extraction & Recovery	Genomic applications, BD, AA, High Pressure Leaching, Real-Time, Accelerated Rock Sorting Technologies, Transmission sorting of ore through X-ray, density assessment
Production Management: Communication and collaboration	Wearables, AR, VR, MI and Smart Devices, IoT, Social Tech, AA, UAVs, Automation (of knowledge work), Cloud, Robotics
Rehabilitation	Automation
Stockpile Management	IoT, UAVs, AA
Tailing/Slime Dams, Waste Dumps: Management	IoT, UAVs, AA

Table 3.3y: P4 - Productivity & Asset Efficiency

Value Drivers	**Applicable Technology**
Asset Management: Communication and collaboration	Tracking Tech, IoT, Automation, BD, AA, EAM, AI, MI
Asset Management: Asset connectedness	IoT, Tracking Tech, AI, ML, MI, Wearables, AA, MI
Asset Management: Cyber Risks	Cyber Security, Blockchain
Asset Management: Data Capture, Processing, Analysis & Output	EAM, IoT, IoE, AA, BD, Automation, Cloud, AI, Super-Calculators & Computers
Availability	IoT, AA, AR, Automation
Contractor Management: Communication and collaboration	Wearables, AR, VR, MI and Smart Devices, IoT, Robotics, Social Tech, AA, UAVs, Automation (of knowledge work)

Hazard & Risk Management	BD, AA, IoT, Cloud, UAVs, Automation, AI
Human Resources: Sourcing	BD, AA, AI, Cloud
Human Resources: Communication and collaboration	Wearables, AR, VR, MI, Cloud, IoT, Social Tech, Voice Interfaces, Language Translation Tech
Human Resources: Difficult, repetitive and/or dangerous human tasks	Robotics, Exoskeletons, AI, ML, MI, Automation, MI, IoT, AA, BD, Anthropomorphic Robots, Automation of Knowledge Work, Nano-Technology, UAVs
Human Resources: Efficiency	Amplified Intelligence, AI, AR, VR, MI, BD, AA, Cloud, Automation, Automation of Knowledge Work, IoT, Robotics
Human Resources: Human-Asset/Human-Machine interaction	AR, AI, ML, IoT, Brain-Machine Interfaces, Ambient User Experience, Visualisation & Visual Technologies
Human Resources: Training & Inductions	Social Tech, VR, AR, Language Tech
Maintenance, Repair & Inspection - Equipment - Machinery - Infrastructure - Other Assets	IoT, BD, AA, AR, 3D &4D Printing, ML, AI, MI, EAM, Advanced Materials, Nanomaterials
Operation/Usage of Equipment & other Assets: Efficient Operation	AR, MI, IoT, AI, BD, AA, Automation, Autonomous Eq & Tech, Brain-Machine Interfaces, Ambient User Experience, Visualisation & Visual Technologies
Fleet Management	AR, MI, IoT, AI, BD, AA, Cloud, Automation, Tracking Tech, C-T-C Coms, EAM, ML
Rock Breaking Efficiency: Mechanical Breaking - Efficiency & Fragmentation	Advanced Materials, Nanomaterials, Mechanised Tech, Rock breaking Tech
Rock Breaking Efficiency: Drill & Blast - Rock Abrasiveness, Drilling Efficiency and Drilling Accuracy	Advanced Materials, Non-Explosives, EDS, AR, IoT, AA, Directional Drilling, Precision Drilling, Automation
Utilisation	Automation, EAM, AA, AI, IoT, BD

Table 3.3z: P4 - Profitability & Cost Control

Value Drivers	**Applicable Technology**
CAPEX Management	BD, AA, AI, Cloud, VR/AR, Predictive Modelling, EAM
Hazard & Risk Management	BD, AA, IoT, Cloud, AI
Market Analysis: Commodity Price (Forecasts)	BD, AA, AI
OPEX Management	BD, AA, AI, Cloud, VR/AR, Predictive Modelling, EAM
Cost Control - Consumable Resources: Energy - Costs	Renewables, Energy-Management, Systems, AA, Smart Grids, MTRECs, LNG alternatives
Cost Control - Consumable Resources: Energy - Efficiency	Energy Tech & Equipment, EST, AA, BD, IoT, MTRECs
Cost Control - Consumable Resources: Water	IoT, AA
Cost Control - Consumable Resources: Diesel/Fuel	LNG Engine Technologies, Energy Tech & Equipment, EST
Cost Control - Remuneration	Automation

Table 3.3aa: P4 - Supply Chain

Value Drivers	**Applicable Technology**
Electricity/Energy: Supply	EST, Renewables, Fusion, Hybrid systems
Electricity/Energy: Generation	EST, Renewables, Hybrid Systems
Electricity/Energy: Storage	EST
Finance/Procurement/Transactions	Blockchain, Cyber Security, AR, VR, AA
Hazard & Risk Management	BD, AA, IoT, Cloud, UAVs, AI, EAM
Infrastructure Maintenance	UAVs, AA, Automation
Ore & Waste Transportation	Hybrid Airships, EAM, (Semi) Autonomous Equipment, Electric/Hybrid/Hydrogen Engines, Synthetic Biology Technologies, AA, IoT
Procurement of Consumable, Parts & Assets	UAVs, Hybrid Airships, AA, 3D & 4D Printing, Modularisation, AI
Product/Market Delivery	Hybrid Airships, EAM, AA, AI
Warehousing & Inventory Management	AR, AA, IoT, BD, Automation, VR, UAVs, Robotics
Waste Transportation	Hybrid Airships, EAM, (Semi) Autonomous Equipment, Electric/Hybrid/Hydrogen Engines, Synthetic Biology

	Technologies, AA, IoT

Table 3.3ab: P4 - Socio-Economic Factors

Value Drivers	Applicable Technology
Communities: Corporate Social Responsibility	Green cement, Precision Agriculture, Genomics
Communities: Engagement & Communication	Social Tech, UAVs, VR, AR, Language Tech, Secure Messaging
Corporate Governance	Blockchain, Social Tech, UAVs
Hazard & Risk Management	Social Tech, UAVs, VR, AR, Language Tech, BD, AA, IoT, Cloud, AA
Labour: Engagement & Communication	Social Tech, UAVs, VR, AR, Language Tech, Secure Messaging
Other Stakeholders: Engagement & Communication	Social Tech, UAVs, VR, AR, Language Tech, Secure Messaging
Shareholders: Engagement & Communication	Social Tech, VR, AR, Language Tech

Table ac: P4 - Health, Environment, Safety & Legal

Value Drivers	Applicable Technology
Environmental Engineering: Ventilation Engineering	Automation, Energy Tech, IoT, BD, AA
Environmental Engineering: Cooling	Clean air environments: Immersion-cooling technology Liquid-desiccant systems, Pressurised-plenum-recirculation-air system
Environmental Engineering: Geotechnical Engineering - Implementation and Design (Planning & CoPs)	BD, AA, IoT, Predictive Modelling
Environmental Engineering: Geotechnical Engineering - Monitoring (Seismic/Non-Seismic)	UAVs, IoT, AA
Environmental Management Program	AA, IoT, UAVs, BD, AI, Cloud, IoE, Automation
Environmental Management Program: Carbon Emission Management	Electrical Technologies and Equipment, IoT, AA, Renewables, Energy Tech, MTRECs
Environmental Management Program: Water	Desalination plant technology, Graphene biofilter purification, IoT, BD, AA, Genomics
Environmental Management Program: Energy	Automation, Energy Tech, MTRECs
Environmental Management Program: Fauna & Flora	Genomics, Precision Agriculture
Environmental Management Program: Recycling	Genomics
Emergency Management	Tracking Tech, IoT, AA, AR, VR, Cloud, UAVs, Robotics

	Wearables, AI
Healthcare & Medical Treatment	Genomics, 3D Printing, AA, AI, Nanomaterials, Robotics, Automation, Exoskeletons, UAVs, IoT, Wearables, ICTs, Nano-technology, Nano-particles, biotechnology, AR, VR
Hazard Identification	AR, AA, AI, UAVs, IoT, IoE
Hazard & Risk Management: Difficult and/or dangerous human tasks	Automation, Robotics, Exoskeletons, AA
Hazard & Risk Management: Monitoring	IoT, BD, AA. Tracking Tech
Safety: Surveillance and monitoring	Tracking Tech, IoT, AA, AR, VR, Cloud, UAVs, Robotics, Wearables
Safety: Tracking of people and assets	Tracking Tech, AR, VR, IoT, AA, BD, Wearables
Safety: Continuous Improvement	AA, BD, IoT, AI, ML

Phase 5: Mine Decommissioning and Closure

Table ad: P5 - Mineral Resource Management

Value Drivers	**Applicable Technology**
Production Planning	BD, IoT, AA, VR/AR, AI, Automation

Table 3.3ad: P5 - Production

Value Drivers	**Applicable Technology**
Closure of mine workings and associated infrastructure	Robotics, Automation, AA, UAVs
Ramp-down Management	BD, IoT, AA, VR/AR, Automation
Rehabilitation Management	BD, IoT, AA, VR/AR, Automation, Genomics, Robotics

Table 3.3ae: P5 - Productivity & Asset Efficiency

Value Drivers	**Applicable Technology**
Asset & Equipment Management	Tracking Tech, EAM, IoT, BD, AA, Automation
Human Resources: Communication and collaboration	Wearables, AR, VR, MI, Cloud, IoT, Social Tech, Voice Interfaces, Language Translation Tech
Human Resources: Difficult, repetitive and/or dangerous human tasks	Robotics, Exoskeletons, AI, ML, MI, Automation, MI, IoT, AA, BD, Anthropomorphic Robots, Automation of Knowledge Work, Nano-Technology, UAVs
Human Resources: Efficiency	Amplified Intelligence, AI, AR, VR, MI, BD, AA, Cloud, Automation, Automation of Knowledge Work, IoT, Robotics
Human Resources: Human-Asset/Human-Machine interaction	AR, AI, ML, IoT, Brain-Machine Interfaces, Ambient User Experience, Visualisation & Visual Technologies

Table 3.3af: P5 - Profitability & Cost Control

Value Drivers	**Applicable Technology**
CAPEX Management	BD, AA, Cloud, AI, Blockchain
OPEX Management	BD, AA, Cloud, AI, Blockchain

Table 3.3ag: P5 - Supply Chain

Value Drivers	**Applicable Technology**
Demolishing infrastructure	Robotics, Automation

Table 3.3ah: P5 - Socio-Economic Factors

Value Drivers	**Applicable Technology**

Communities: Corporate Social Responsibility	Green cement, Precision Agriculture, Genomics
Communities: Engagement & Communication	Social Tech, UAVs, VR, AR, Language Tech, Secure Messaging
Corporate Governance	Blockchain, Social Tech, UAVs
Hazard & Risk Management	Social Tech, UAVs, VR, AR, Language Tech, BD, AA, IoT, Cloud, AA
Labour: Engagement & Communication	Social Tech, UAVs, VR, AR, Language Tech, Secure Messaging
Other Stakeholders: Engagement & Communication	Social Tech, UAVs, VR, AR, Language Tech, Secure Messaging
Shareholders: Engagement & Communication	Social Tech, VR, AR, Language Tech

Table 3.3ai: P5 - Health, Environment, Safety & Legal

Value Drivers	**Applicable Technology**
Emergency Management	Tracking Tech, IoT, AA, AR, VR, Cloud, UAVs, Robotics Wearables, AI
Environmental Management Plan: Compliance	VR or AR comparisons to original agreement
Rehabilitation & Remediation	Genomics: bio-remediation, AMD & contaminant treatment, enhanced agriculture applications

Phase 6: Post-Closure

Table 3.3aj: P6 - Mineral Resource Management

Value Drivers	**Applicable Technology**
In-Situ Reserves: Monitoring/Mapping/Sampling	Directional Drilling Technologies, 3D Seismics, Air-borne Gravimetry, IoT, BD, AA, UAVs, Predictive Modelling, 3D point-cloud technology

Table 3.3ak: P6 - Production

Value Drivers	**Applicable Technology**
In-Situ Reserves: Renewed production	Mechanised Tech, Remote Tech, Advanced Materials, Nanomaterials, Robotics, Hard-Rock Mech Tech, Genomics

Table 3.3al: P6 - Socio-Economic Factors

Value Drivers	**Applicable Technology**
Communities: Corporate Social Responsibility	Green cement, Precision Agriculture, Genomics
Communities: Engagement & Communication	Social Tech, UAVs, VR, AR, Language Tech, Secure Messaging
Corporate Governance	Blockchain, Social Tech, UAVs
Hazard & Risk Management	Social Tech, UAVs, VR, AR, Language Tech, BD, AA, IoT, Cloud, AA
Labour: Engagement & Communication	Social Tech, UAVs, VR, AR, Language Tech, Secure Messaging
Other Stakeholders: Engagement & Communication	Social Tech, UAVs, VR, AR, Language Tech, Secure Messaging
Shareholders: Engagement & Communication	Social Tech, VR, AR, Language Tech

Table 3.3am: P6 - Health, Environment, Safety & Legal

Value Drivers	**Applicable Technology**
Emerging HES Issues	3D Printing, Social Tech, Genomics: bio-remediation, AMD & contaminant treatment, enhanced agriculture applications, medical applications for monitoring diagnostics and treatment
Environmental Management Plan: Non-Compliance	VR or AR comparisons
Mineral Rights	Blockchain, Cyber Security

To showcase how the Technology Map may be illustrated, consider the following examples of sections from different aspects within it. Figure 3.3a displays an example from the Operations Phase under the Mineral Resource Management Pillar for the chosen main value drivers Geology and Geotechnical Mapping. Figure 3.3b, on the other hand, is an example from the Operations Phase under the Production Pillar with a specific focus on Development. The chosen constituent value driver is Mineral/Ore and Waste Extraction, which in turn branches out to Drill & Blast and Mechanised, Autonomous Mining. For each of the value drivers (and/or constituent value drivers) in these examples, the investigated technologies with potential to add value (through any given combination of the five qualifying factors listed in Section 1.2) value are shown in square brackets under

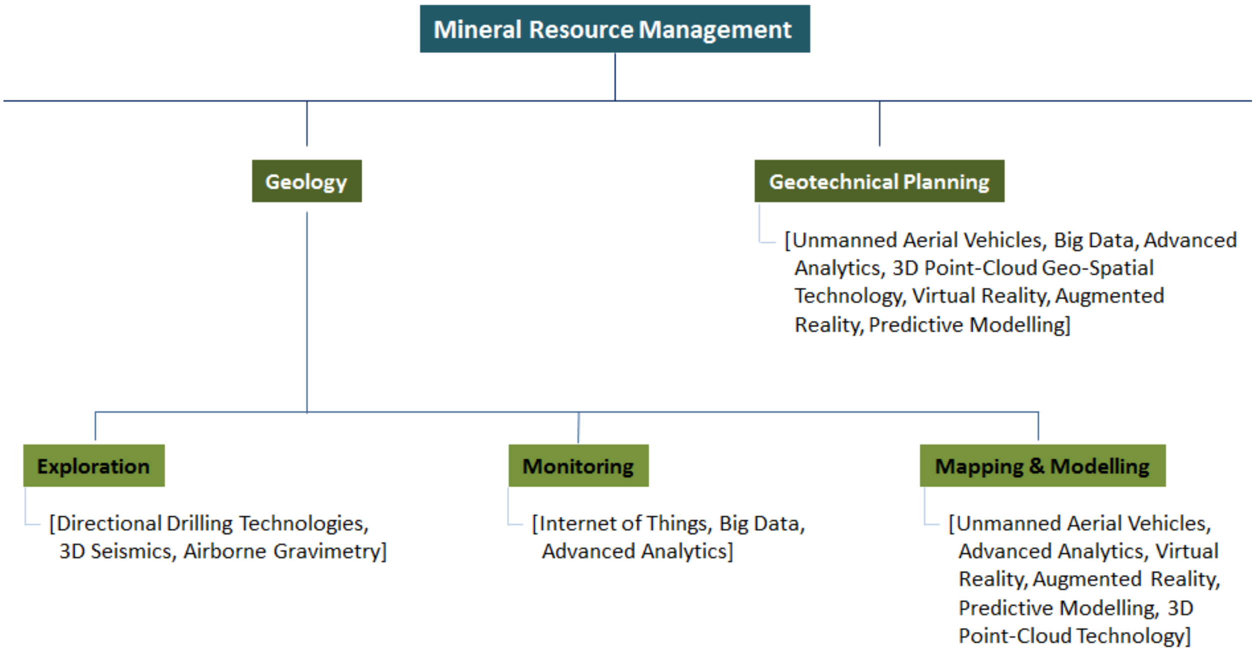


Figure 3.3a: Technology Map Example 1

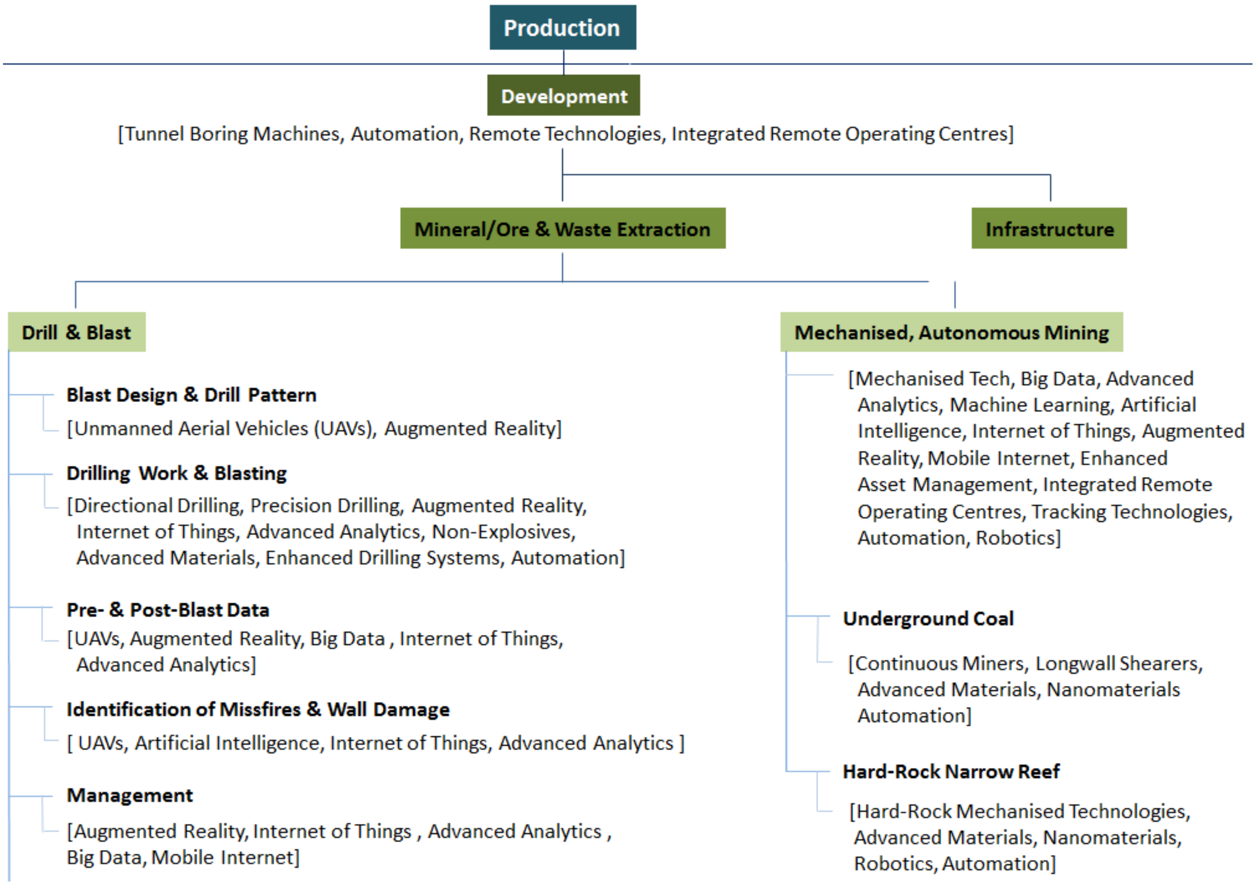


Figure 3.3b: Technology Map Example 2

REFERENCES

Britz, J. 2016. Personal correspondence – CEO of Namane Resources.

TIA. 2012. *The Mining Sector Innovation Strategies Implementation Plan*. [ONLINE] Available at: http://www.tia.org.za/CMS/uploaded_docs/TIA%20Mining%20and%20Minerals%20Innovation%20Strategies%20Implementation%20Plan%20(2012%20-%202016).pdf. [Accessed 04 February 2016].

CHAPTER 4

CONCLUSIONS

CONCLUSIONS

Objective No.	**Conclusions**
1.	The need for innovation in mining was clearly identified. This was done in relation to the current state of the global mining industry where it was found that numerous experts (both within mining and service providing companies) call for innovation as the tool to be used to get the industry out of its current slump.
2.	After this the scope for the study was refined to technological innovation, specifically looking at the adoption of external technologies in order to create value and foster innovation within the mining industry. Focus was particularly placed on emerging, exponential and disruptive technologies. However, recent technological innovations in the mining industry were also investigated (although to a limited extent), in order to create awareness of existing possibilities.
3. to 5.	Each of the investigated technologies, within the different groups (emerging, exponential and potentially disruptive) and classifications (physical and digital), was subjected to assessment in order to gauge their potential to add value to a mining organisation or individual operation. This potential to add value was also assessed in terms of the technology's potential to be applied, or to be modified to be applied, to a given focus area within the mining life cycle. The assessment was further based on five qualifying factors, which included the potential of the technology to: increase production; increase productivity; increase efficiency; improve safety; and/or, reduce the risk of human error. When a technology had potential to increase one or more of these factors it was deemed to have potential to facilitate the mine modernisation process.
6.	In order to effectively display the potential areas of application, impact or value creation of each of these technologies within the mining life cycle, a framework was created that is representative of the value drivers within each of the mining phases (within the *mining cycle*). This framework then served as the platform upon which the Technology Map was subsequently created.
7.	This Technology Map then serves to highlight potentially value adding technologies that may be applied to add value to a mining venture in the context of mine modernisation. Each technology, in whichever form and under whichever category, may be subjected to further research and development in order to create a tailor-made solution that is specific to the problem, operation, organisation, operational risk management strategies or other business strategies. This table is by no means a 'plug-and-play' for any technology to its corresponding focus area, but serves to provide information on starting-points into solutions that will enhance modernisation efforts and add value within the mining cycle.

CHAPTER 5

RECOMMENDATIONS

RECOMMENDATIONS

It is recommended that the platform for the *mining cycle* should be expanded to include all subsequent functions, activities, systems, and other constituents for each of the main value drivers. As such, a flow diagram may be created that is representative of all aspects related to mining, for all mining methods, geological characteristics, geographical factors, commodity types and other variables. Such a framework should be created on a digital platform and be made publicly available to assist further research and development, academia and other. The *mining cycle framework* will provide a rigid structure that is fully representative of the mining industry and its subsequent phases. It can then be used for various purposes in a digital format, one example being the overlaying of potentially applicable technologies for the various components within the mining cycle. In the same way as a Technology Map has been created from such an overlay, so too can other applications be found that could build on the foundation of the created framework. Another example may be the benchmarking of various figures. When overlaying such information on a well-structured foundation it will also assist non-mining experts in building the understanding required for a specific task or project. Often non-mining professionals lack a general understanding of the mining environment. By combining a digital mining life cycle platform with visual technologies, this understanding could be enhanced in order to increase the efficiency and accuracy with which such professionals perform their work relating to the mining industry.

It is then also recommended that the created Technology Map should be expanded upon to incorporate existing technologies that are currently in use in industry, as well as all new and emerging technologies with potential to add value or have impact. Such a continually growing Technology Map should be digitised in order to effectively create a *search engine* for technologies that are applicable to mining. It is recommended that such a "digital blueprint" for a Mining Technology Map should be made publicly available in order to reduce the resources that various organisations, institutions and individuals spend on doing similar research. By collectively pooling R&D on general (non-secretive) technologies, instead of working in silos, the industry stands to gain value and reduce waste on R&D.

CHAPTER 6

SUGGESTIONS FOR FURTHER WORK

SUGGESTIONS FOR FURTHER WORK

In most instances have academia and industry remained separated in South Africa. Integration and cooperation between the two have only happened in small percentage, with research and development (R&D) typically being conducted in-house or at governing bodies. The R&D at academia, although progressive in nature, has also not primarily focussed on addressing industry needs first and foremost (at least not in recent years). The result is that industry, in general, is not aware of what kinds of research transpires in the academic realm, nor are they interested to find out.

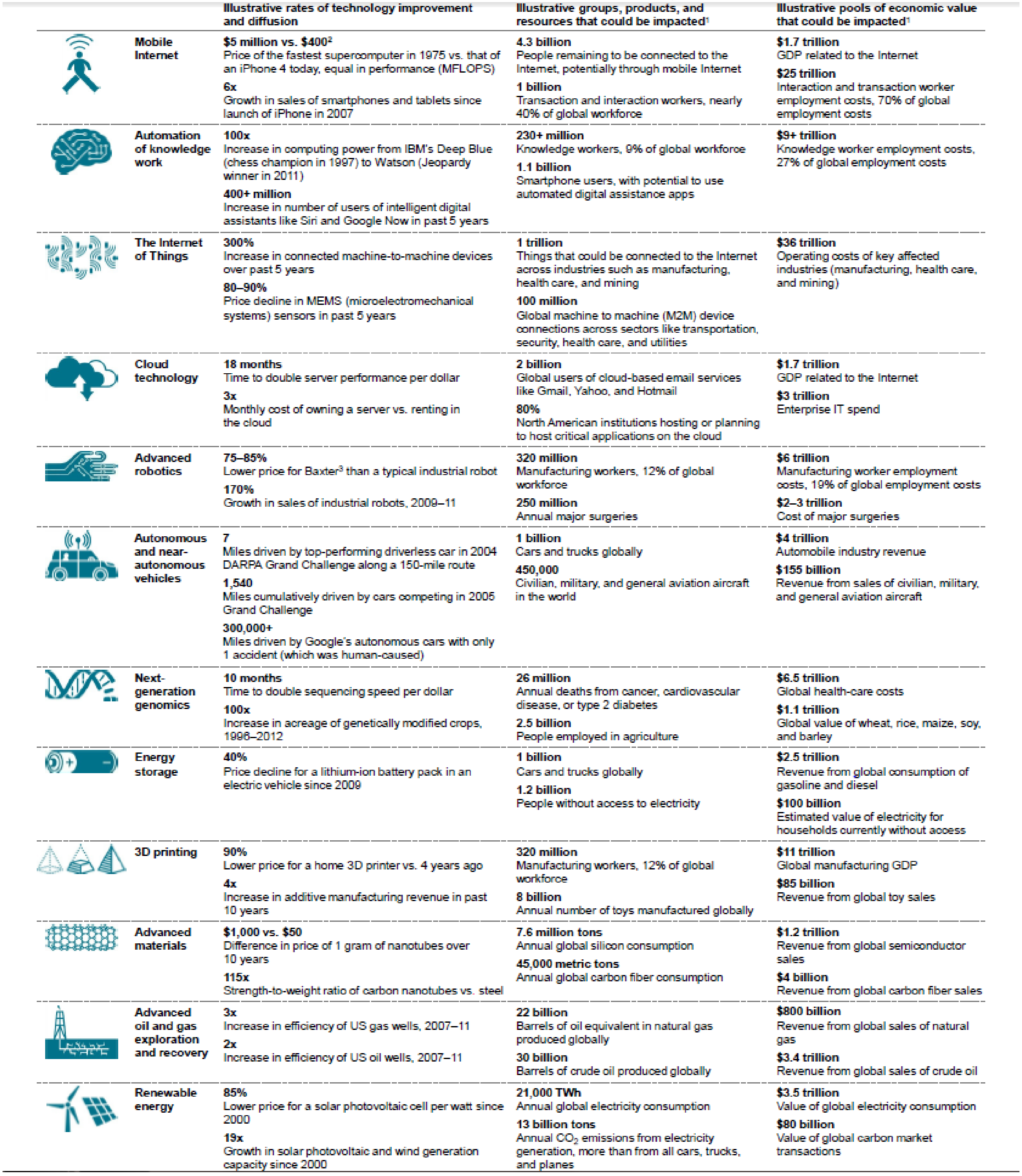
This has led to (intellectual) resources being 'wasted' or not applied to its full potential in the academic environment. Adding on to this, the silos in which organisations, governing bodies and academic institutions function, have caused further misalignment and a loss of potential synergy. To address this, it is recommended that the platform created in this study be expanded to include not only more in-depth investigations of technologies, but to also be made available to anyone who could draw benefit from it. It is envisioned that an online website in the form of a flow diagram, identifying all relevant and potentially applicable technologies to each of the components in the mining cycle, will enable ease of use and access to a Technology Map. Such an online tool can also be expanded to accommodate timeline trends and it can be designed in such a way to enable improved collaboration between the various parties (e.g. through an open communication and sharing platform), leading to improved synergy. This will greatly add value to research projects that aim to identify technological applications that may add value to a mining operation or organisation as whole and as such facilitate mine modernisation. In this manner, many of the initial research phases to identify technologies can be eliminated or reduced. The researcher or research team will be able to select technologies applicable to their specific needs and conduct further R&D and prototype development in their own context.

In terms of further academic work, it is suggested that a proper analysis tool be created to accompany the Technology Map that would serve as guidance to identifying applicable technologies based on inputs of variables, factors or other criteria as provided by the user of the Technology Map. This would be a refinement process specific to the Technology Map that would serve to reduce the number of technologies (and potentially their designs and method of application to a sufficient level that would transition the *idea* or *concept* to the refinement process applicable to the user). This analysis tool may then be developed to include the ability to align business strategies and operational risk management strategies with the technology map. As such, the user would have a complete tool that is able to take inputs based on organisational and operational parameters and identify technological solutions that have the potential to add value to a component of the mining cycle. This should then be followed by a well-structured and proven refinement (research and development) process.

APPENDIX 1

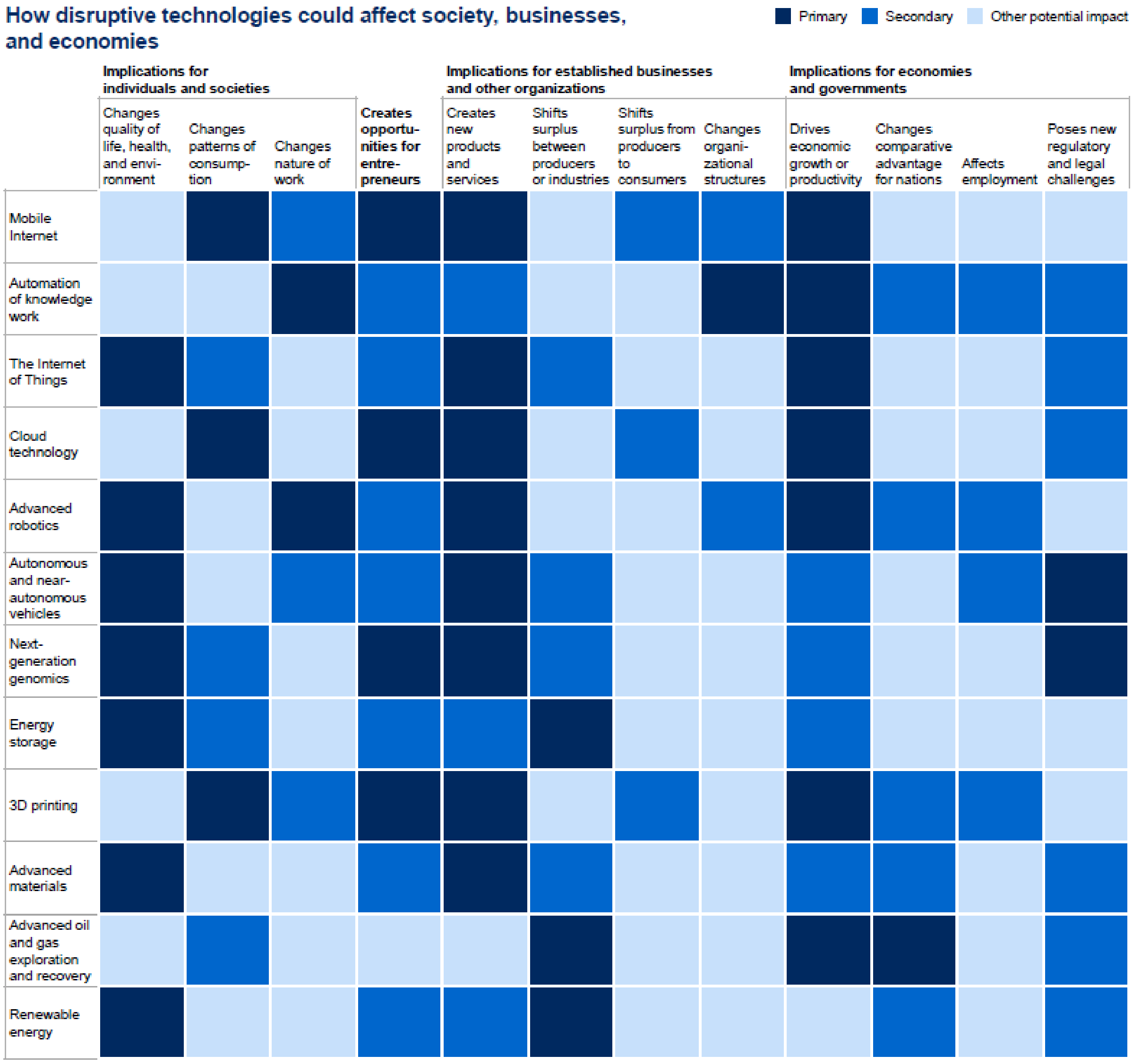
7.1 Appendix 1

Table 7.1a: Speed, scope, and economic value at stake of 12 potentially economically disruptive technologies (McKinsey Global Institute, 2013)



	Illustrative rates of technology improvement and diffusion	Illustrative groups, products, and resources that could be impacted[1]	Illustrative pools of economic value that could be impacted[1]
Mobile Internet	**$5 million vs. $400[2]** Price of the fastest supercomputer in 1975 vs. that of an iPhone 4 today, equal in performance (MFLOPS) **6x** Growth in sales of smartphones and tablets since launch of iPhone in 2007	**4.3 billion** People remaining to be connected to the Internet, potentially through mobile Internet **1 billion** Transaction and interaction workers, nearly 40% of global workforce	**$1.7 trillion** GDP related to the Internet **$25 trillion** Interaction and transaction worker employment costs, 70% of global employment costs
Automation of knowledge work	**100x** Increase in computing power from IBM's Deep Blue (chess champion in 1997) to Watson (Jeopardy winner in 2011) **400+ million** Increase in number of users of intelligent digital assistants like Siri and Google Now in past 5 years	**230+ million** Knowledge workers, 9% of global workforce **1.1 billion** Smartphone users, with potential to use automated digital assistance apps	**$9+ trillion** Knowledge worker employment costs, 27% of global employment costs
The Internet of Things	**300%** Increase in connected machine-to-machine devices over past 5 years **80–90%** Price decline in MEMS (microelectromechanical systems) sensors in past 5 years	**1 trillion** Things that could be connected to the Internet across industries such as manufacturing, health care, and mining **100 million** Global machine to machine (M2M) device connections across sectors like transportation, security, health care, and utilities	**$36 trillion** Operating costs of key affected industries (manufacturing, health care, and mining)
Cloud technology	**18 months** Time to double server performance per dollar **3x** Monthly cost of owning a server vs. renting in the cloud	**2 billion** Global users of cloud-based email services like Gmail, Yahoo, and Hotmail **80%** North American institutions hosting or planning to host critical applications on the cloud	**$1.7 trillion** GDP related to the Internet **$3 trillion** Enterprise IT spend
Advanced robotics	**75–85%** Lower price for Baxter[3] than a typical industrial robot **170%** Growth in sales of industrial robots, 2009–11	**320 million** Manufacturing workers, 12% of global workforce **250 million** Annual major surgeries	**$6 trillion** Manufacturing worker employment costs, 19% of global employment costs **$2–3 trillion** Cost of major surgeries
Autonomous and near-autonomous vehicles	**7** Miles driven by top-performing driverless car in 2004 DARPA Grand Challenge along a 150-mile route **1,540** Miles cumulatively driven by cars competing in 2005 Grand Challenge **300,000+** Miles driven by Google's autonomous cars with only 1 accident (which was human-caused)	**1 billion** Cars and trucks globally **450,000** Civilian, military, and general aviation aircraft in the world	**$4 trillion** Automobile industry revenue **$155 billion** Revenue from sales of civilian, military, and general aviation aircraft
Next-generation genomics	**10 months** Time to double sequencing speed per dollar **100x** Increase in acreage of genetically modified crops, 1996–2012	**26 million** Annual deaths from cancer, cardiovascular disease, or type 2 diabetes **2.5 billion** People employed in agriculture	**$6.5 trillion** Global health-care costs **$1.1 trillion** Global value of wheat, rice, maize, soy, and barley
Energy storage	**40%** Price decline for a lithium-ion battery pack in an electric vehicle since 2009	**1 billion** Cars and trucks globally **1.2 billion** People without access to electricity	**$2.5 trillion** Revenue from global consumption of gasoline and diesel **$100 billion** Estimated value of electricity for households currently without access
3D printing	**90%** Lower price for a home 3D printer vs. 4 years ago **4x** Increase in additive manufacturing revenue in past 10 years	**320 million** Manufacturing workers, 12% of global workforce **8 billion** Annual number of toys manufactured globally	**$11 trillion** Global manufacturing GDP **$85 billion** Revenue from global toy sales
Advanced materials	**$1,000 vs. $50** Difference in price of 1 gram of nanotubes over 10 years **115x** Strength-to-weight ratio of carbon nanotubes vs. steel	**7.6 million tons** Annual global silicon consumption **45,000 metric tons** Annual global carbon fiber consumption	**$1.2 trillion** Revenue from global semiconductor sales **$4 billion** Revenue from global carbon fiber sales
Advanced oil and gas exploration and recovery	**3x** Increase in efficiency of US gas wells, 2007–11 **2x** Increase in efficiency of US oil wells, 2007–11	**22 billion** Barrels of oil equivalent in natural gas produced globally **30 billion** Barrels of crude oil produced globally	**$800 billion** Revenue from global sales of natural gas **$3.4 trillion** Revenue from global sales of crude oil
Renewable energy	**85%** Lower price for a solar photovoltaic cell per watt since 2000 **19x** Growth in solar photovoltaic and wind generation capacity since 2000	**21,000 TWh** Annual global electricity consumption **13 billion tons** Annual CO_2 emissions from electricity generation, more than from all cars, trucks, and planes	**$3.5 trillion** Value of global electricity consumption **$80 billion** Value of global carbon market transactions

Table 7.1b: How disruptive technologies could affect society, businesses, and economies (McKinsey Global Institute, 2013)

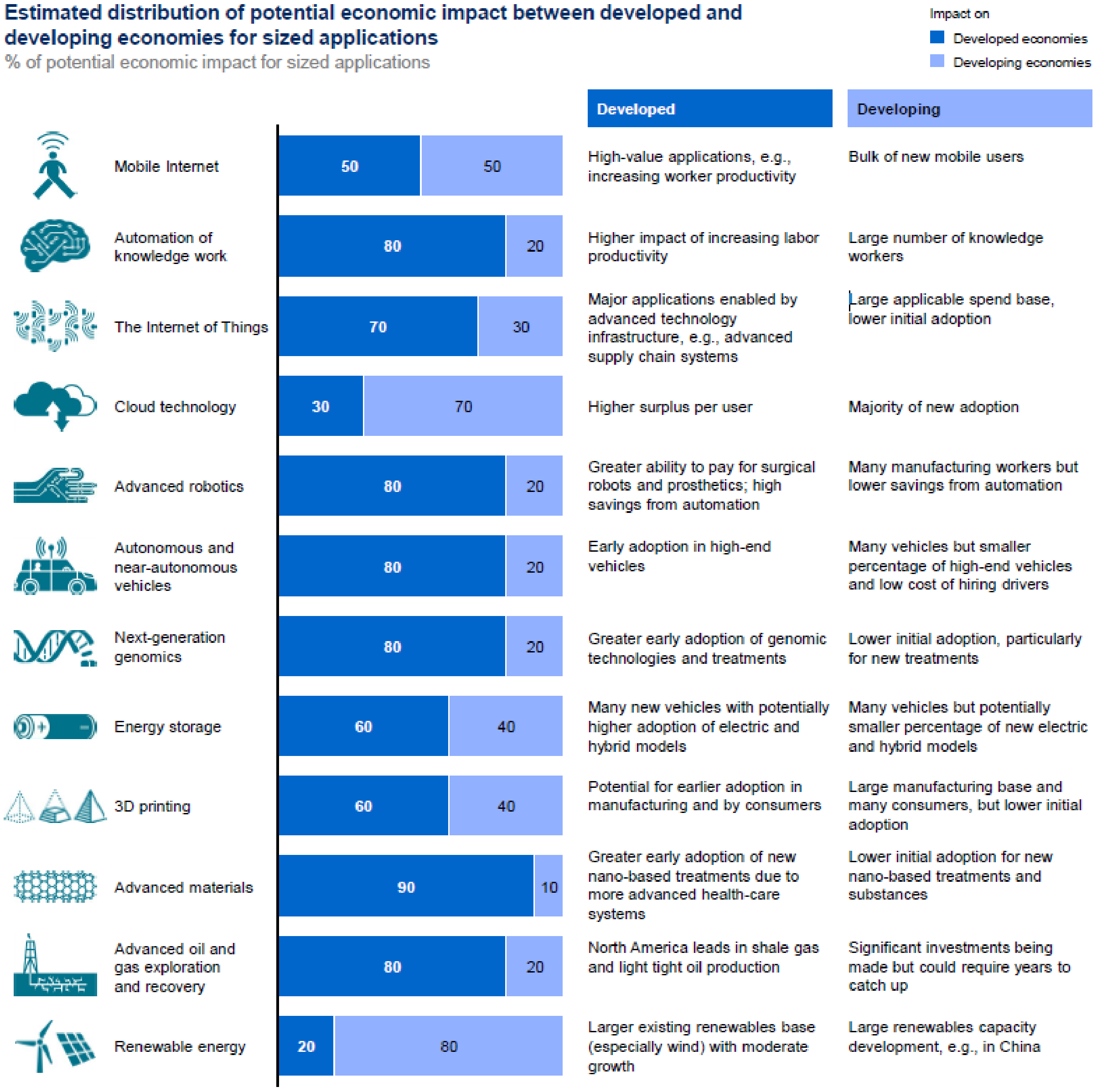


How disruptive technologies could affect society, businesses, and economies

■ Primary ▣ Secondary □ Other potential impact

	Implications for individuals and societies				Implications for established businesses and other organizations				Implications for economies and governments			
	Changes quality of life, health, and environment	Changes patterns of consumption	Changes nature of work	**Creates opportunities for entrepreneurs**	Creates new products and services	Shifts surplus between producers or industries	Shifts surplus from producers to consumers	Changes organizational structures	Drives economic growth or productivity	Changes comparative advantage for nations	Affects employment	Poses new regulatory and legal challenges
Mobile Internet	□	■	▣	■	■	□	▣	▣	■	□	□	□
Automation of knowledge work	□	□	■	▣	▣	□	□	■	■	▣	▣	▣
The Internet of Things	■	▣	□	▣	■	▣	□	□	■	□	□	▣
Cloud technology	□	■	□	■	■	□	▣	□	■	□	□	▣
Advanced robotics	■	□	■	▣	■	□	□	▣	■	▣	▣	□
Autonomous and near-autonomous vehicles	■	□	▣	▣	■	▣	□	□	▣	□	▣	■
Next-generation genomics	■	▣	□	■	■	▣	□	□	▣	□	□	■
Energy storage	■	▣	□	▣	▣	■	□	□	▣	□	□	□
3D printing	□	■	▣	■	■	□	▣	□	■	▣	▣	□
Advanced materials	■	□	□	▣	■	▣	□	□	▣	▣	□	▣
Advanced oil and gas exploration and recovery	□	▣	□	□	□	■	□	□	■	■	□	▣
Renewable energy	■	□	□	▣	▣	■	□	□	□	▣	□	▣

Table 7.1c: Estimated distribution of potential economic impact between developed and developing economies for sized applications (McKinsey Global Institute, 2013)



Estimated distribution of potential economic impact between developed and developing economies for sized applications

% of potential economic impact for sized applications

Impact on
🟦 Developed economies
▨ Developing economies

	🟦	▨	**Developed**	**Developing**
Mobile Internet	50	50	High-value applications, e.g., increasing worker productivity	Bulk of new mobile users
Automation of knowledge work	80	20	Higher impact of increasing labor productivity	Large number of knowledge workers
The Internet of Things	70	30	Major applications enabled by advanced technology infrastructure, e.g., advanced supply chain systems	Large applicable spend base, lower initial adoption
Cloud technology	30	70	Higher surplus per user	Majority of new adoption
Advanced robotics	80	20	Greater ability to pay for surgical robots and prosthetics; high savings from automation	Many manufacturing workers but lower savings from automation
Autonomous and near-autonomous vehicles	80	20	Early adoption in high-end vehicles	Many vehicles but smaller percentage of high-end vehicles and low cost of hiring drivers
Next-generation genomics	80	20	Greater early adoption of genomic technologies and treatments	Lower initial adoption, particularly for new treatments
Energy storage	60	40	Many new vehicles with potentially higher adoption of electric and hybrid models	Many vehicles but potentially smaller percentage of new electric and hybrid models
3D printing	60	40	Potential for earlier adoption in manufacturing and by consumers	Large manufacturing base and many consumers, but lower initial adoption
Advanced materials	90	10	Greater early adoption of new nano-based treatments due to more advanced health-care systems	Lower initial adoption for new nano-based treatments and substances
Advanced oil and gas exploration and recovery	80	20	North America leads in shale gas and light tight oil production	Significant investments being made but could require years to catch up
Renewable energy	20	80	Larger existing renewables base (especially wind) with moderate growth	Large renewables capacity development, e.g., in China

APPENDIX 2

7.2 Appendix 2

Table 7.2: Technology Map for the Value at may facilitate Mine Modernisation

Technology Map for the Value Drivers in the Mining Cycle to enable Improvements in Operational Risk Management Strategies

	Exploration & Target Generation Phase	Mine Project Evaluation / Planning Phase	Mine Design & Construction Phase	Operations Phase (Mine-to-Mill)	Mine Decommissioning and Closure Phase	Post-Closure
Mineral Resource Management	Initial Target Generation *[Aerial Surveys & Mapping: UAVs]* *[Directional Drilling, Airborne Gravimetry]* Target Identification *[Aerial Surveys & Mapping: UAVs]* *[Directional Drilling, Airborne Gravimetry, AA]* Target Definition and Discovery *[Aerial Surveys & Mapping: UAVs]* *[Directional Drilling, Airborne Gravimetry, AA]* Target Evaluation *[Aerial Surveys & Mapping: UAVs]* *[Directional Drilling, Airborne Gravimetry, AA]* Geological Model *[UAVs, AA, AR, VR, Predictive Modelling, 3D Seismics, Air-borne Gravimetry, 3D point-cloud technology, Visualisation]* Geotechnical Model *[UAVs, AA, 3D Point-Cloud Geo-Spatial Technology, AR, VR, BD, Predictive Modelling, Visualisation]* Hydro Geology *[Directional Drilling, AA, 3D Point-Cloud Geo-Spatial, Technology, AR, VR]* Interpretations *[AA, Visualisation, Simulation and Modelling, AR, VR]* Mineral Resource Evaluation *[AA]*	Data Collection *[UAVs, AA, IoT]* Evaluation Studies *[BD, AA, VR/AR, Visualisation]* Desktop Study and Literature Review Conceptual Study Pre-Feasibility Study Bankable Feasibility Study (& Investment Decisions) Geological Model *[UAVs, AA, AR, VR, Predictive Modelling, 3D Seismics, Air-borne Gravimetry, 3D point-cloud technology, Visualisation]* Geotechnical Model *[UAVs, AA, 3D Point-Cloud Geo-Spatial Technology, AR, VR, BD, Predictive Modelling, Visualisation]* Mine Closure Planning *[AR, VR, AA, BD]* Mine Planning *[AR, VR, AA, BD]* Resource to Reserve Calculations *[AA]*	Data collation *[BD, IoT, Cloud, IoE, AA]* Geotechnical Planning *[UAVs, AA, 3D Point-Cloud Geo-Spatial Technology, AR, VR, BD, Predictive Modelling]* Mining Method Confirmation *[VR, AR, Predictive Modelling, AA, BD, Cloud]* Mine Design Iteration & Optimisation *[VR, AR, AA, BD, Cloud]* Implementation Monitoring of Construction & Development *[UAVs, AA, AI, AR, VR]* Mine Closure Preparation *[AA]* Operations Plan Planning & Scheduling *[Aerial Surveys, Mapping & Monitoring: UAVs]* *[Physical Monitoring: IoT, AA]* *[Data Capture & Processing: IoT, AA, BD, Automation]*	Geology Exploration *[Directional Drilling Technologies, 3D Seismics, Air-borne Gravimetry]* Monitoring *[IoT, BD, AA]* Mapping & Modelling *[UAVs, AA, AR, VR, Predictive Modelling, 3D point-cloud technology]* Geotechnical Planning *[UAVs, AA, 3D Point-Cloud Geo-Spatial Technology, AR, VR, BD, Predictive Modelling]* Hazard & Risk Management *[BD, AA, IoT, Cloud, UAVs, Automation, AI]* Hydrology Monitoring & Mapping *[Aerial Surveys, Mapping & Monitoring: UAVs]* *[Physical Monitoring: IoT, AA]* Operations Plan Development Planning & Scheduling *[Aerial Surveys, Mapping & Monitoring: UAVs]* *[Physical Monitoring: IoT, AA]* *[Data Capture & Processing: IoT, AA, BD, AI, Automation]* Production Planning & Scheduling *[Aerial Surveys, Mapping & Monitoring: UAVs]* *[Physical Monitoring: IoT, AA]* *[Data Capture & Processing: IoT, AA, AI, BD, Automation]*	Production Planning *[BD, IoT, AA, VR/AR, AI, Automation]*	In-Situ Reserves: Monitoring/Mapping/Sampling *[Directional Drilling Technologies, 3D Seismics, Air-borne Gravimetry, IoT, BD, AA, UAVs, Predictive Modelling 3D point-cloud technology]*
Production	Drilling Work & Blasting *[Directional drilling, AR, 3D seismics, UAVs, EDS, Airborne Gravimetry]* Site Establishment Surveying & Sampling Efficiency *[AA, Genomics]*	Drilling Work & Blasting *[Directional drilling, AR, 3D seismics, UAV, Airborne Gravimetry]* Mining Method Selection *[BD, AA, AI, VR, AR, Simulation and Modelling]* Support Method Selection *[BD, AA, AI, VR, AR, Simulation and Modelling]*	Construction *[Green cement]* Infrastructure & Physical Assets -Haul Roads & Mine Access -Dumps, Stockpiles, Dams -Surface preparation or Shaft sinking Development: Opening up Reserves *[TBM, Automation, Remote Tech, IROC]* Drill & Blast -Blast design & Drill pattern *[AR, UAVs]* -Drilling Work & Blasting *[Advanced Materials, Non-Explosives, EDS, AR, IoT, AA, Directional Drilling, Precision Drilling, Automation]* -Pre- & post-blast data *[AR, UAVs, BD, IoT, AA]* -Identification of misfires & wall damage *[AI, AA, UAVs]* -Fragmentation -Management *[AR, IoT, AA, BD, MI]* Mechanised, Autonomous Mining *[Mechanised Tech, BD, AA, ML, AI, IoT, IoE, AR, MI EAM, IROC, Tracking Tech, Automation, Robotics]* -Hard-Rock Narrow Reef Mining *[Hard-Rock Mech Tech, Advanced Materials, Nanomaterials, Robotics, Automation]* Hazard & Risk Management *[BD, AA, IoT, Cloud, UAVs, Automation, AI]* Hydrology Management *[IoT, AA, BD, UAVs]* Reservoirs/Dams/Infrastructure Dewatering *[Directional Drilling]* Labour Communication and collaboration *[Wearables, AR, VR, MI and Smart Devices, IoT, Social Tech, AA, UAVs, Automation (of knowledge work) Robotics]* Management & Leadership *[BD, IoT, AA, Language Tech, Social Tech, MI AR, VR, AI]* Logistics Waste & Mineral/Ore Transport *[Automation, Autonomous Eq&Tech, ML, AI, Conveyor Systems, AA, IoT, Tracking Tech]* -Load & Haul / Tram / Hoist *[Automation, Autonomous Eq&Tech, ML, AI, AR C-T-C Coms, Remote Tech, IoT, Tracking Tech, EAM]* Operations Plan *[BD, AA, IoT, Cloud, Automation, AR, VR, EAM, Visualisation]* Plant Design & Construction *[VR, AR, AA, BD, Cloud]* Production Management Communication and collaboration *[Wearables, AR, VR, MI and Smart Devices, IoT, Social Tech AA, UAVs, Automation (of knowledgework), Cloud, Robotics]* Production Rate Calculations for LoM *[AA, BD, Cloud]* Tailing/Slime Dams/Waste Dumps: Plan vs. Construct *[Aerial Surveys, Mapping & Monitoring: UAVs]* *[Physical Monitoring: IoT, AA]*	Development *[TBM, Automation, Remote Tech, IROC]* Mineral/Ore and Waste Extraction -Drill & Blast *Blast design & Drill pattern *[AR, UAVs]* *Drilling Work & Blasting *[Advanced Materials, Non-Explosives, EDS, AR, IoT, AA, Directional Drilling, Precision Drilling, Automation]* *Pre- & post-blast data *[AR, UAVs, BD, IoT, AA]* *Identification of misfires & wall damage *[AI, AA, UAVs]* *Fragmentation *Management *[AR, IoT, AA, BD, MI]* -Mechanised, Autonomous Mining *[Mechanised Tech, BD, AA, ML, AI, IoT, IoE, AR, MI EAM, IROC, Tracking Tech, Automation, Robotics]* *Hard-Rock Narrow Reef Mining *[Hard-Rock Mech Tech, Advanced Materials, Nanomaterials, Robotics, Automation]* Infrastructure *[Green Cement, Robotics, Automation, IROCs]* Hazard & Risk Management *[BD, AA, IoT, Cloud, UAVs, Automation, AI]* Hydrology Management *[IoT, AA, BD, UAVs]* Reservoirs/Dams/Infrastructure Dewatering *[Directional Drilling]* Labour Communication and collaboration *[Wearables, AR, VR, MI and Smart Devices, IoT, Social Tech, AA, UAVs, Automation (of knowledge work) Robotics]* Management & Leadership *[BD, IoT, AA, Language Tech, Social Tech, MI AR, VR, AI]* Logistics Mineral/Ore Transport *[Automation, Autonomous Eq&Tech, ML, AI Conveyor Systems, AA, IoT, Tracking Tech]* Waste Transport *[Automation, Autonomous Eq&Tech, ML, AI* *[Conveyor Systems, AA, IoT, Tracking Tech]* -Load & Haul / Tram / Hoist *[Automation, Autonomous Eq&Tech, ML, AI, AR C-T-C Coms, Remote Tech, IoT, Tracking Tech, EAM]* Operations Plan *[BD, AA, IoT, Cloud, Automation, AR, VR, EAM, Visualisation]* Plant Management *[IoT, BD, AA, Automation, Robotics, Flexible closed-belt conveyor]* Processing & Refining Comminution *[High Pressure Grinding Rolls, Transmission sorting of ore through X-ray, density assessment]* Mineral Extraction & Recovery *[Genomic applications, BD, AA, High Pressure Leaching, Real-Time, Accelerated Rock Sorting Technologies Transmission sorting of ore through X-ray, density assessment]* Production Management Communication and collaboration *[Wearables, AR, VR, MI and Smart Devices, IoT, Social Tech AA, UAVs, Automation (of knowledgework), Cloud, Robotics]* Rehabilitation *[Automation]* Stockpile Management *[Aerial Surveys, Mapping & Monitoring: UAVs]* *[Physical Management and Monitoring: IoT, AA* Tailing/Slime Dams, Waste Dumps: Management *[Aerial Surveys, Mapping & Monitoring: UAVs]* *[Physical Monitoring: IoT, AA]*	Closure of mine workings and associated infrastructure *[Robotics, Automation, AA, UAVs]* Ramp-down Management *[BD, IoT, AA, VR/AR, Automation]* Rehabilitation Management *[BD, IoT, AA, VR/AR, Automation, Genomics, Robotics]*	In-Situ Reserves: Renewed Production *[Mechanised Tech, Remote Tech, Advanced Materials, Nanomaterials, Robotics, Hard-Rock Mech Tech, Genomics]*

Productivity & Asset Efficiency	Drilling Equipment *[AR, EAM, EDS, Automation]* Drilling Efficiency & Accuracy *[Directional drilling, AR]* Human Resources *[Amplified Intelligence, AI, AR, VR, MI, BD, AA, Cloud, Automation, Automation of Knowledge Work, IoT, Robotics]* Metallurgical Processing *[AA, Genomics]*	Drilling Efficiency & Accuracy *[Directional drilling, AR]* Equipment selection *[AR/VR, BD, AA, Simulation and Modelling]* Human Resources Communication and collaboration *[Wearables, AR, VR, MI, Cloud, IoT, Social Tech, Voice Interfaces, Language Translation Tech]* Efficiency *[Amplified Intelligence, AI, AR, VR, MI, BD, AA, Cloud, Automation, Automation of Knowledge Work, IoT, Robotics]* Human-Asset/Human-Machine interaction *[AR, AI, ML, IoT, Brain-Machine Interfaces, Ambient User Experience, Visualisation & Visual Technologies]* Metallurgical Processing *[Genomics, AA, BD]*	Asset Management Communication and collaboration *[Tracking Tech, IoT, Automation, BD, AA, EAM, AI, MI]* Asset connectedness *[IoT, Tracking Tech, AI, ML, MI, Wearables, AA, MI]* Cyber Risks *[Cyber Security, Blockchain]* Data Capture, Processing, Analysis & Output *[EAM, IoT, IoE, AA, BD, Automation, Cloud, AI, Super-Calculators & Computers]* Contractor Management Communication and collaboration *[Wearables, AR, VR, MI and Smart Devices, IoT, Robotics Social Tech, AA, UAVs, Automation (of knowledgework)]* Equipment selection *[AA, BD, AI, Cloud, VR, AR, Predictive Modelling]* Fleet Management System Selection *[AA, BD, AI, ML, Cloud, VR, AR, Predictive Modelling]* Hazard & Risk Management *[BD, AA, IoT, Cloud, UAVs, Automation, AI]* Human Resources Sourcing *[BD, AA, AI, Cloud]* Communication and collaboration *[Wearables, AR, VR, MI, Cloud, IoT, Social Tech, Voice Interfaces, Language Translation Tech]* Difficult, repetitive and/or dangerous human tasks *[Robotics, Exoskeletons, AI, ML, MI, Automation, MI, IoT, AA, BD, Anthropomorphic Robots, Automation of Knowledge Work, Nano-Technology, UAVs]* Efficiency *[Amplified Intelligence, AI, AR, VR, MI, BD, AA, Cloud, Automation, Automation of Knowledge Work, IoT, Robotics]* Human-Asset/Human-Machine interaction *[AR, AI, ML, IoT, Brain-Machine Interfaces, Ambient User Experience, Visualisation & Visual Technologies]* Training & Inductions *[Social Tech, VR, AR, Language Tech]* Rock Breaking Efficiency Mechanical Breaking -Efficiency & Fragmentation *[Advanced Materials, Nanomaterials, Mechanised Tech Rockbreaking Tech]* Drill & Blast -Rock Abrasiveness & Drilling Efficiency and Accuracy *[Advanced Materials, Non-Explosives, EDS, AR, IoT, AA, Directional Drilling, Precision Drilling, Automation]*	Asset Management Communication and collaboration *[Tracking Tech, IoT, Automation, BD, AA, EAM, AI, MI]* Asset connectedness *[IoT, Tracking Tech, AI, ML, MI, Wearables, AA, MI]* Cyber Risks *[Cyber Security, Blockchain]* Data Capture, Processing, Analysis & Output *[EAM, IoT, IoE, AA, BD, Automation, Cloud, AI, Super-Calculators & Computers]* Availability *[IoT, AA, AR, Automation]* Contractor Management Communication and collaboration *[Wearables, AR, VR, MI and Smart Devices, IoT, Robotics Social Tech, AA, UAVs, Automation (of knowledgework)]* Equipment Improvement/Upgrades Acquisition of new assets Upgrading existing equipment Hazard & Risk Management *[BD, AA, IoT, Cloud, UAVs, Automation, AI]* Human Resources Sourcing *[BD, AA, AI, Cloud]* Communication and collaboration *[Wearables, AR, VR, MI, Cloud, IoT, Social Tech, Voice Interfaces, Language Translation Tech]* Difficult, repetitive and/or dangerous human tasks *[Robotics, Exoskeletons, AI, ML, MI, Automation, MI, IoT, AA, BD, Anthropomorphic Robots, Automation of Knowledge Work, Nano-Technology, UAVs]* Efficiency *[Amplified Intelligence, AI, AR, VR, MI, BD, AA, Cloud, Automation, Automation of Knowledge Work, IoT, Robotics]* Human-Asset/Human-Machine interaction *[AR, AI, ML, IoT, Brain-Machine Interfaces, Ambient User Experience, Visualisation & Visual Technologies]* Training & Inductions *[Social Tech, VR, AR, Language Tech]* Maintenance, Repair & Inspection *[IoT, BD, AA, AR, 3D &4D Printing, ML, AI, MI, EAM, Advanced Materials, Nanomaterials]* Equipment Machinery Infrastructure Other Assets Operation/Usage of Equipment & other Assets Efficient Operation *[AR, MI, IoT, AI, BD, AA, Automation, Autonomous Eq & Tech, Brain-Machine Interfaces, Ambient User Experience, Visualisation & Visual Technologies]* Fleet Management *[AR, MI, IoT, AI, BD, AA, Cloud, Automation, Tracking Tech, C-T-C Coms, EAM, ML]* Rock Breaking Efficiency Mechanical Breaking -Efficiency & Fragmentation *[Advanced Materials, Nanomaterials, Mechanised Tech Rockbreaking Tech]* Drill & Blast -Rock Abrasiveness & Drilling Efficiency and Accuracy *[Advanced Materials, Non-Explosives, EDS, AR, IoT, AA, Directional Drilling, Precision Drilling, Automation]* Utilisation *[Automation, EAM, AA, AI, IoT, BD]*	Asset & Equipment Management *[Tracking Tech, EAM, IoT, BD, AA, Automation]* Human Resources Communication and collaboration *[Wearables, AR, VR, MI, Cloud, IoT, Social Tech, Voice Interfaces, Language Translation Tech]* Difficult, repetitive and/or dangerous human tasks *[Robotics, Exoskeletons, AI, ML, MI, Automation, MI, IoT, AA, BD, Anthropomorphic Robots, Automation of Knowledge Work, Nano-Technology, UAVs]* Efficiency *[Amplified Intelligence, AI, AR, VR, MI, BD, AA, Cloud, Automation, Automation of Knowledge Work, IoT, Robotics]* Human-Asset/Human-Machine interaction *[AR, AI, ML, IoT, Brain-Machine Interfaces, Ambient User Experience, Visualisation & Visual Technologies]*	
Profitability & Cost Control	CAPEX Investment Strategy *[AA, BD]* OPEX Drilling work *[Directional drilling, AR]* Sampling/Coring *[AA, Genomics]*	CAPEX Investment Strategy *[BD, AA]* Extraction Ratio *[AA, Automation]* Mining Method Selection *[BD, AA]* OPEX *[BD, AA]* Pricing Forecasts *[BD, AA]*	CAPEX Planning *[BD, AA, AI, Cloud, VR/AR, Predictive Modelling]* OPEX Planning *[BD, AA, AI, Cloud, VR/AR, Predictive Modelling]* Pricing Forecasts *[BD, AA, AI, Cloud]* Unit Operating Cost *[BD, AA, AI, Cloud, VR/AR, Predictive Modelling]*	CAPEX Management *[BD, AA, AI, Cloud, VR/AR, Predictive Modelling, EAM]* Hazard & Risk Management *[BD, AA, IoT, Cloud, AI]* Market Analysis *[BD, AA, AI]* Commodity Price Operations Plan Marketing plan Financial plan Administration plan OPEX Management *[BD, AA, AI, Cloud, VR/AR, Predictive Modelling, EAM]* Consumable Resources -Energy *Costs *[Renewables, Energy-Management Systems, AA, Smart Grids, MTRECs, LNG alternatives]* *Efficiency *[Energy Tech & Equipment, EST, AA, BD, IoT, MTRECs]* -Water *[IoT, AA]* -Compressed Air -Diesel/Fuel *[LNG Engine Technologies, Energy Tech & Equipment, EST]* Remuneration *[Automation]*	CAPEX Management *[BD, AA, Cloud, AI, Blockchain]* OPEX Management *[BD, AA, Cloud, AI, Blockchain]*	

Supply Chain	Access to site *[UAVs, Hybrid Airships]* Logistical planning *[AA, Visualisation, AR/VR, UAVs]* Consumables Assets Human Resources	Asset Acquisition Strategy *[AA, BD, VR/AR, Visualisation]* Infrastructure planning Logistical planning Supplier Establishment HR Sourcing Electricity Supply & Generation *[EST, Renewables, Fusion, Hybrid systems]*	Acquisition of Assets *[Hybrid Airships, Modularisation, U* Equipment Machinery Other assets Materials Human Resources Electricity Supply & Generation *[EST, Renewables, Fusion, Hybrid systems]* Infrastructure Design *[AA, AR, VR, Visualisation]* Infrastructure Development *[Green Cement, UAVs, AA, AR]*	rgy *[EST, Renewables, Fusion, Hybrid systems]* Generation *[EST, Renewables, Hybrid systems]* Storage *[EST]* Finance/Procurement/Transactions *[Blockchain, Cyber Security, AR, VR, AA]* Hazard & Risk Management *[BD, AA, IoT, Cloud, UAVs, AI, EAM]* Infrastructure Maintenance *[UAVs, AA, Automation]* Primary Access/Ore Transport Route -Haul Roads -Conveyor System Secondary Access/Delivery of consumables Ore & Waste Transportation *[Hybrid Airships, EAM, (Semi) Autonomous Equipment, Electric/Hybrid/Hydrogen Engines, Synthetic Biology Technologies, AA, IoT]* Procurement of Consumable, Parts & Assets *[UAVs, Hybrid Airships, AA, 3D & 4D Printing, Modularisation, AI]* Product/Market Delivery *[Hybrid Airships, EAM, AA, AI]* Warehousing & Inventory Management *[AR, AA, IoT, BD, Automation, VR, UAVs, Robotics]* Waste Transportation *[Hybrid Airships, EAM, (Semi) Autonomous Equipment, Electric/Hybrid/Hydrogen Engines, Synthetic Biology Technologies, AA, IoT]*	Infrastructure Demolishing *[Robotics, Automation]*	
Socio-Economic Factors	Corporate Governance *[Blockchain, social media/technologies, AA]* Labour and Communities Corporate Social Responsibility *[Visualisation and simulation technologies, AR, VR, Precision Agriculture, Blockchain, Genomics, AA, Social media/technologies]* Shareholders and other Stakeholders *[Visualisation and simulation technologies, AR, VR Blockchain, Social media/technologies, AA]*	Corporate Governance *[Blockchain, social media/technologies, AA]* Labour and Communities Corporate Social Responsibility *[Visualisation and simulation technologies, AR, VR, Precision Agriculture, Blockchain, Genomics, AA, Social media/technologies]* Shareholders and other Stakeholders *[Visualisation and simulation technologies, AR, VR Blockchain, Social media/technologies, AA]*	Communities Corporate Social Responsibility *[Green cement, Precision Agriculture, Genomics]* Engagement & Communication *[Social Tech, UAVs, VR, AR, Language Tech]* Corporate Governance *[Blockchain, Social Tech, UAVs]* Hazard & Risk Management *[Social Tech, UAVs, VR, AR, Language Tech, BD, AA, IoT, Cloud, AI]* Labour Engagement & Communication *[Social Tech, UAVs, VR, AR, Language Tech]* Other Stakeholders Engagement & Communication *[Social Tech, UAVs, VR, AR, Language Tech]* Shareholders Engagement & Communication *[Social Tech, VR, AR, Language Tech]*	Communities Corporate Social Responsibility *[Green cement, Precision Agriculture, Genomics]* Engagement & Communication *[Social Tech, UAVs, VR, AR, Language Tech, Secure Messaging]* Corporate Governance *[Blockchain, Social Tech, UAVs]* Hazard & Risk Management *[Social Tech, UAVs, VR, AR, Language Tech, BD, AA, IoT, Cloud, AI]* Labour Engagement & Communication *[Social Tech, UAVs, VR, AR, Language Tech, Secure Messaging]* Other Stakeholders Engagement & Communication *[Social Tech, UAVs, VR, AR, Language Tech, Secure Messaging]* Shareholders Engagement & Communication *[Social Tech, UAVs, VR, AR, Language Tech, Secure Messaging]*	Communities Corporate Social Responsibility *[Green cement, Precision Agriculture, Genomics]* Engagement & Communication *[Social Tech, UAVs, VR, AR, Language Tech]* Corporate Governance *[Blockchain, Social Tech, UAVs]* Hazard & Risk Management *[Social Tech, UAVs, VR, AR, Language Tech]* Labour Engagement & Communication *[Social Tech, UAVs, VR, AR, Language Tech]* Other Stakeholders Engagement & Communication *[Social Tech, UAVs, VR, AR, Language Tech]* Shareholders Engagement & Communication *[Social Tech, VR, AR, Language Tech]*	Communities Corporate Social Responsibility *[Green cement, Precision Agriculture, Genomics]* Engagement & Communication *[Social Tech, UAVs, VR, AR, Language Tech]* Corporate Governance *[Blockchain, Social Tech, UAVs]* Hazard Management *[Social Tech, UAVs, VR, AR, Language Tech]* Labour Engagement & Communication *[Social Tech, UAVs, VR, AR, Language Tech]* Other Stakeholders Engagement & Communication *[Social Tech, UAVs, VR, AR, Language Tech]* Shareholders Engagement & Communication *[Social Tech, VR, AR, Language Tech]*
Health, Environment, Safety & Legal	Environmental Impact Assessment *[IoT, IoE, BD, AA, UAVs]* Mineral Rights *[Genomics, Precision Agriculture, Social Media and Social Technologies, Genomics, Blockchain]* Prospecting Rights Exploration Rights Mining Rights	Environmental Impact Assessment *[IoT, IoE, BD, AA, UAVs]* Water Energy Fauna & Flora Carbon Emission Management Environmental Management Plan *[BD, IoT, AA, VR/AR, Simulation and Modelling]* Operational EMP Post-closure & rehab plan Mine Workings Layout *[BD, AA, VR/AR, Simulation and Modelling]*	Civil Geotechnical Work on Foundations & Roads Environmental Engineering Ventilation Engineering *[Automation, Energy Tech, IoT, BD, AA]* Cooling *[Clean air environments: Immersion-cooling technology, Liquid-desiccant systems, Pressurised-plenum-recirculation-air system]* Environmental Management Program -Carbon Emission Management *[Electrical Technologies and Equipment, IoT, AA, Renewables]* -Water *[Desalination plant technology, Graphene biofilter purification]* -Energy *[Automation, Energy Tech]* -Fauna & Flora *[Genomics, Precision Agriculture]* -Recycling *[Genomics]* Geotechnical Engineering -Implementation and Design (Planning & CoPs) *[BD, AA, IoT, Predictive Modelling]* -Monitoring (Seismic/Non-Seismic) *[UAVs, IoT, AA]* Emergency Management *[Tracking Tech, IoT, AA, AR, VR, Cloud, UAVs, Robotics Wearables, AI]* Healthcare & Medical Treatment *[Genomics, 3D Printing, AA, AI, Nanomaterials, Robotics, Automation, Exoskeletons, UAVs, IoT, Wearables, ICTs, nano-technology, nano-particles, biotechnology, AR, VR]* Hazard Identification *[AR, AA, AI, UAVs, IoT, IoE]* Hazard & Risk Management Difficult and/or dangerous human tasks *[Automation, Robotics, Exoskeletons, AA]* Monitoring *[IoT, BD, AA. Tracking Tech]* Legislation Safety Surveilance and monitoring *[Tracking Tech, IoT, AA, AR, VR, Cloud, UAVs, Robotics, Wearables]* Tracking of people and assets *[Tracking Tech, AR, VR, IoT, AA, BD, Wearables]* Continuous Improvement *[AA, BD, IoT, AI, ML]*	Environmental Engineering Ventilation Engineering *[Automation, Energy Tech, IoT, BD, AA]* Cooling *[Clean air environments: Immersion-cooling technology, Liquid-desiccant systems, Pressurised-plenum-recirculation-air system]* Environmental Management Program *[AA, IoT, UAVs, BD, AI, Cloud, IoE, Automation]* -Carbon Emission Management *[Electrical Technologies and Equipment, IoT, AA, Renewables, Energy Tech, MTRECs]* -Water *[Desalination plant technology, Graphene biofilter purification, IoT, BD, AA, Genomics]* -Energy *[Automation, Energy Tech, MTRECs]* -Fauna & Flora *[Genomics, Precision Agriculture]* -Recycling *[Genomics]* Geotechnical Engineering -Implementation and Design (Planning & CoPs) *[BD, AA, IoT, Predictive Modelling]* -Monitoring (Seismic/Non-Seismic) *[UAVs, IoT, AA]* Emergency Management *[Tracking Tech, IoT, AA, AR, VR, Cloud, UAVs, Robotics Wearables, AI]* Healthcare & Medical Treatment *[Genomics, 3D Printing, AA, AI, Nanomaterials, Robotics, Automation, Exoskeletons, UAVs, IoT, Wearables, ICTs, nano-technology, nano-particles, biotechnology, AR, VR]* Hazard Identification *[AR, AA, AI, UAVs, IoT, IoE]* Hazard & Risk Management Difficult and/or dangerous human tasks *[Automation, Robotics, Exoskeletons, AA]* Monitoring *[IoT, BD, AA. Tracking Tech]* Legislation Safety Surveilance and monitoring *[Tracking Tech, IoT, AA, AR, VR, Cloud, UAVs, Robotics Wearables]* Tracking of people and assets *[Tracking Tech, AR, VR, IoT, AA, BD, Wearables]* Continuous Improvement *[AA, BD, IoT, AI, ML]*	Emergency Management *[Tracking Tech, IoT, AA, AR, VR, Cloud, UAVs, Robotics]* EMP Compliance *[VR or AR comparisons to original agreement]* HES Monitoring Hazard & Risk Management Long Term Stability of Workings Malpractice Rehabilitation & Remediation *[Genomics: bio-remediation, AMD & contaminant treatment, enhanced agriculture applications]* Surface Stability / Infrastructure Stability	Emerging HES Issues *[3D Printing, Social Tech, Genomics: bio-remediation, AMD & contaminant treatment, enhanced agriculture applications, medical applications for monitoring diagnostics and treatment]* EMP Non-Compliance *[VR or AR comparisons]* HES Monitoring Malpractice Mineral Rights *[Blockchain, Cyber Security]* Surface Stability / Infrastructure Stability