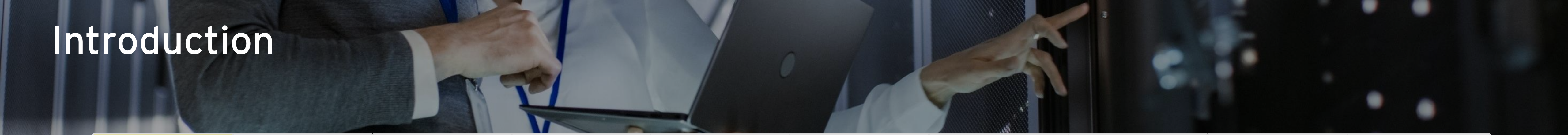
Future of work: The economic implications of technology and digital mining

A Report for the Minerals Council of Australia

February 2019

Building a better working world

Contents



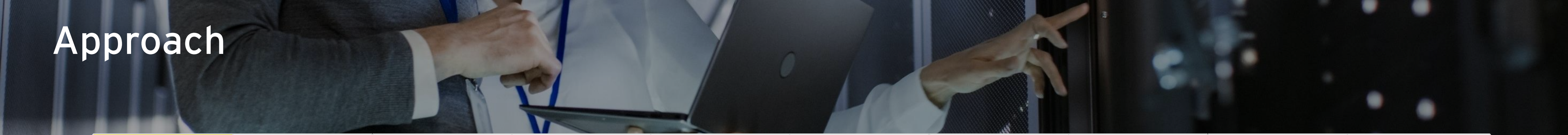
Introduction

Context

The mining industry is increasing its adoption of digital and technology solutions. This is having a variety of impacts on conventional operating models. There is a need to understand the impacts of these changes on mining operations.

Future of Work to 2030

- This report forms part of a wider integrated study to review the ‘Future of Work’ trends in the mining industry over the horizon to 2030 and to assist in the development of the industry response to the changing landscape
- This report presents the findings of the initial phase of the study which was focussed on the identification of potential digital and technological innovation and the impact of these innovations on the mining workforce
- Case studies have been developed to explore the opportunities digital innovation could provide across the mining value chain and the potential associated productivity improvements and impact on the workforce
- High level industry investment requirements have also been considered, both in terms of investment in technology and people
- Subsequent phases will examine the economic and workforce impactions of the adoption of digital technologies across the mining value chain in further detail



Approach

Objective: To prepare case studies to explore productivity improvement across the key elements of the mining value chain, providing an overall view to quantify the productivity impact and investment required to implement digital mining operations.

1 Value Hypotheses
Establish key value hypotheses for each element of the mining value chain

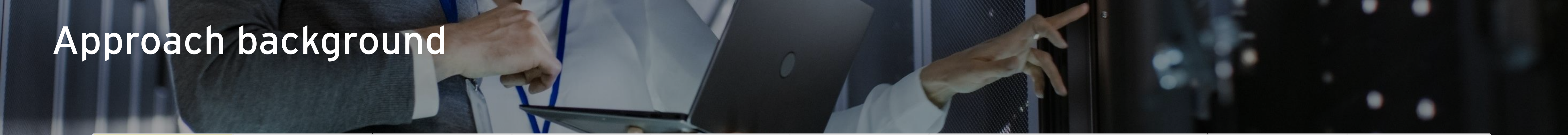
2 Productivity Improvement Identification
For each hypothesis, identify productivity improvements that will deliver value

3 Enabler Identification
Identify digital / technological enablers that will deliver productivity improvements

4 Case Development
Develop industry leading practice of how digital solutions are being implemented to deliver value

5 Impact Analysis
Identify the productivity, quality, safety, environmental benefits and workforce implications associated with key digital enablers

6 Investment Required
Analyse the investment required from industry to implement the digital enablers



Approach background

Our approach

Value based

- Successful long term adoption of technology will only occur where true value is delivered
- Therefore, a value based approach has been used to identify the technological innovations that are likely to be adopted by 2030

Technology scope

- Value opportunities identified are those that are supported by current or emerging technology
- Whilst there will be rapid technological change over the target timeframe, the time and investment required to convert existing operations to future technologies may constrain overall industry progress by 2030
- Select industry examples have been included to illustrate adoption and application of elements of current technology – this is not an exhaustive list of all current technology applications

Potential value

- The potential value improvements have been estimated using current examples, wider industry knowledge and our global mining experience
- Productivity improvements were considered on both an aspirational and sensitised basis based on historical application of technology and systems within the industry

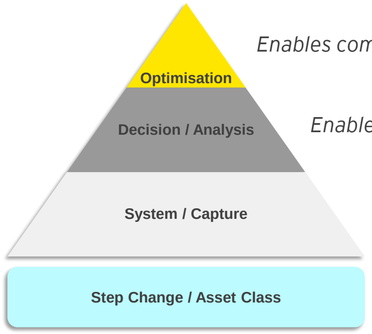
Potential investment

- Potential investment values have been estimated using current and previous investment examples of similar implementations and high level projections based on our industry experience
- Technology investment considered both mining and non mining technology applications, while people investment considered level of change required in workforce capability and supporting organisational structures
- Investments were considered on both an aspirational and sensitised basis based on historical application of technology and systems within the industry

Technology enabling value

Different levels of contribution

- Enabling technology can be characterised into one of four categories based on how they contribute to the generation of value:



Enables complex process / asset optimisation

Enables higher level decision support / analysis

Establishes / integrates systems or enables data capture

Introduces a new or significantly advanced process or asset class

Executive Summary

A view of the future
10 case studies have been selected from across the mining value chain to explore productivity improvements within the industry

Opportunities

1 Exploration

1.1 Data enabled exploration
Increased resource identification per metre drilled

Enablers
- Artificial Intelligence
- 3D visualisation software
- Downhole assay
- Hyper-spectral core imaging
- Autonomous drilling

2 Mining Operations

2.1 Integrated drill and blast
Creating a data rich environment to optimise drill and blast and downstream comminution

2.2 Autonomous and continuous mining
Using fewer total equipment hours per tonne of product produced

2.3 Underground mine of the future
Optimise underground resource extraction

Enablers
- Artificial Intelligence
- Machine learning
- 3D simulation and modelling
- Autonomous assets
- Digital twin
- Truck-less system
- Electrification

3 Processing

3.1 Fully integrated mine / plant
Improved throughput and recovery per operating hour

Enablers
- Artificial Intelligence
- Digital twin
- Mobile decision support
- Mineral sensing / sorting
- Integrated Operating Centre
- Renewable energy

4 Transport

4.1 Integrate and optimised transport
Fewer total equipment hours per tonne

Enablers
- Artificial Intelligence
- Autonomous assets
- Digital twin
- Machine learning
- Integrated Operating Centre
- Centre of Excellence

5 Trading

5.1 Customer integration
Accurate forecasting and response to product demand (upstream integration of supply to market)

Enablers
- Artificial Intelligence
- Machine learning
- Integrated Operating Centre
- Blockchain
- Smart contracts

6 End-to-End

6.1 End-to-end productivity optimisation
Integrated decision making across the value chain to improve product to customer

6.2 Integrated quality management
Monitoring of product quality across the value chain to increase DIFOT and reduce waste/re-work

6.3 Asset management
Optimised asset management to increase productivity and reduce over maintenance

Enablers
- Digital twin
- Remote Operating Centre
- Integrated Operating Centre
- Centre of Excellence
- Integrated automation

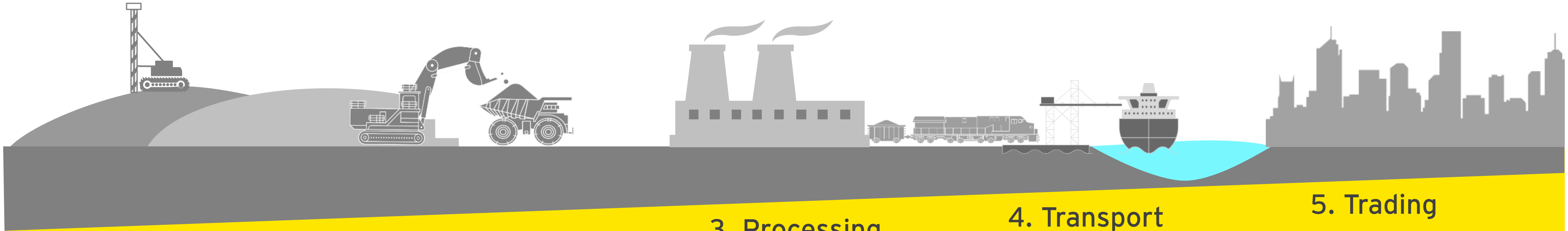
Change across the value chain

These case studies have shown that the impact of digital enablers will create significant change across every aspect of the value chain

6. End-to-End

Siloed approach to productivity within the value chain creating reactive practices

Integration across all elements of the value chain, supporting complex decision making to improve productivity, increase product quality and improve management of assets



1. Exploration

Limited adjustment to exploration program based on ongoing or wider historic drill results

Utilising historical data to create dynamic exploration designs that allow companies to optimise exploration

2. Mining Operations

Unplanned asset downtime and sub-optimal operational discipline results in deviation from plans

Improved information flow and autonomous and continuous mining solutions provide a more consistent, productive and safer working environment. Progressively, operational and maintenance scheduling and planning roles will be performed by automation, robotics and AI

3. Processing

Minimal information flow across the value chain and frequent unplanned asset downtime result in reactive operations

Upstream material information is used to optimise processing efficiency, reduce unplanned downtime and improve asset productivity

4. Transport

Limited integration of transport and upstream planning see significant shipment losses due to tide cycles, weather conditions and schedule clashes

Integrated planning and scheduling of shared systems and autonomous assets provides improved system efficiency and throughput

5. Trading

Significant manual / paper based documentation creates difficulty tracking status of shipments as they move along the supply chain

Auto-execution and contract transparency allow customer requirements to drive production decisions and improve access to niche spot sales markets

What does this mean for the mining industry?

To successfully support the industry through this disruption, guidance, collaboration and investment will be required

Digital and technological innovation has the potential to provide major improvements in productivity, safety and environmental management within the mining industry. However, to achieve this significant investment and an adaptive workforce will be required.

Benefits

- **Productivity:** Adoption of digital and technological innovation has the potential to deliver productivity improvements to the industry of between 9% and 23%
- **Safety:** Advancements in automation and remote operations will dramatically shift the type and severity of risks workers are exposed to thus improving overall workforce health and wellbeing as well as reducing the financial impact of safety related events
- **Environment:** More efficient and precise operations will see a reduction in the overall environmental footprint and reduced reliance on fossil fuels will see lower emissions of greenhouse gases

Challenges

- There will be a number of barriers to the adoption and effective management of digital and technological innovation – however, people and culture will likely be the limiting factor not technology
- The changing political and social landscape and business structures and processes will also influence the industry's ability to implement technology

Investment

- **Technology:** The current investment trend towards point solutions will move to a more coordinated and systemic approach. An investment of between $9.4b - $35.2b across the industry will be required to unlock the potential productivity gains identified
- **People:** Significant investment in the capability and structure of the workforce will be required to support successful implementation of new technologies. An investment of between $5b - $12.8b across the industry will be required to unlock the potential productivity gains identified

Workforce impact

- **Capability:** Digital mining will see the need for traditional operators reduce, with a more technologically savvy workforce required. Mining professionals will combine technical mining skills with digital technological competency while newer capabilities such as data scientists, modellers etc. will provide core functional support
- **Location:** An increase in remote operations will see a shift of site based workforces to remote operating centres located in the regions or in larger cities
- **Number:** Whilst there will be a reduction in certain types of roles other new roles will be created to support the changing work environment, where possible affected roles will be transitioned to re-defined roles

1 Exploration

1.1 Data enabled exploration
Increased resource identification per metre drilled

Current
- Minimal / disaggregated use of previously collected data on potential mineral deposits
- Limited adjustment to exploration programme based on ongoing drill results

Future
- Utilising all historical data and a broader range of indicators to optimise targeting, identification and delineation
- Dynamic rescheduling of exploration design based on ongoing results

Potential Value
- 10% to 15% reduction in drilling costs
- 5% to 10% asset productivity improvement
- Increased discovery success rate
- Improved safety for employees
- Overall 6% to 10% productivity improvement

Industry Implications
- Fewer drill operators
- Increased demand on data analytics and design
- Reduction in traditional surveyors and field geologists

	Opportunity	Benefits	Enablers	Value
1	Utilisation of historical databases to improve exploration accuracy	▸ Improved target identification ▸ Improved field program planning ▸ Geological / metallurgical prediction ▸ Increased ore discovery per $	▸ 3D visualisation software ▸ Ubiquitous database ▸ Cloud access and interrogations tools	▸ Increased resource identification ▸ Reduction in number of holes drilled
2	Real-time drill results and assessment with dynamic target / exploration design to improve the quantity and efficiency of exploration	▸ Improved process and quality management ▸ Improved resource understanding ▸ Dynamic rescheduling of exploration program based on live data feedback ▸ Use of mineral characterisation for downstream planning	▸ Downhole assay and analysis ▸ Hyper-spectral core imaging ▸ Geological modelling ▸ 3D and virtual reality technology to generate and interpret predictive data models ▸ Autonomous drilling / sampling / assay systems	▸ Improved geological information ▸ Reduction in number of holes drilled required ▸ Increased amount of material assayed ▸ Improved success rate

1.1 Data enabled exploration
Increased resource identification per metre drilled

Utilisation of historical databases to improve exploration accuracy

Across the mining industry there is minimal and disaggregated use of the historical data sets that has been collected on potential orebodies, resulting in significant re-work. Utilising historic data will minimise this re-work and improve resource identification through effectively, helping to improve field program target identification and planning.

3D mapping technology and geo-spatial data capturing tools provide the ability to view, compare and evaluate data to gain a deeper understand of what is beneath the earth surface. This can result in increased geological / metallurgical prediction, providing an advantage in recovery of mineral deposits.

Used in conjunction and across the whole industry, a historical database integrated with 3D mapping technology has the potential to increase resource identification and delineation ore bodies, improve waste classification and drilling efficiency and effectiveness.

Real-time results assessment and design realignment to improve efficiency of exploration

Exploration design is currently retrospective and static, based off typical grid patterns with minimal adjustment due to continuous feedback from the drill. Continual assessment of the material characteristics and grade during the drilling process can allow the exploration design to be adapt dynamically.

Down hole assay and hyper-spectral core imaging enable real-time data capture and analysis capability in exploration, providing an increased granularity of data mineralisation, assisting in boundary identification and improving field program planning. Autonomous drills collect live data and respond consistently to the material characteristics identified. Together, these technologies provide the opportunity to dynamically reschedule the exploration drilling design leading to a reduction in drilling costs per unit discovery and improved geological information, providing benefits to downstream mining operations.

Industry examples

Rio Tinto 3D Mapping Technology - Australia

Rio Tinto has developed a 3D visualisation technology, RTVis, that is being used in their Australian operations. It is linked to their Mine Automation System (MAS) and provides the ability to easily evaluate data collected to gain a deeper understanding of deposits located below the surface resulting in improved boundary identification and field task planning. It allows workers to make faster and more informed decisions contributing to a boost in productivity and cost savings[1].

Global Mining Guidelines Group (GMG) Data Exchange - Canada

GMG is working to produce an open-source standard for data file format and data access and usage to enable unfettered access to data and facilitate agreement between operators and OEMs to enable open access to on-board data for mobile equipment across the mine cycle[2].

BHP Downhole Assay – Australia

BHP is using downhole assay in their Pilbara operations. FastGrade enables real-time data capture capability through downhole assay and analysis in exploration. This technology minimises drilling in waste and is expected to save BHP more than US$10 million on drilling and assay costs at sites in Western Australia[3].

GoldCorp AI Exploration Technology - Canada

GoldCorp and IBM have co-created a new technology product which aims to improve predictability for gold mineralisation. It has been developed from data at GoldCorp's mine in northern Ontario and applies AI to predict the potential for gold mineralisation and uses search and query capability across exploration datasets[4].

[1] *Rio Tinto wins 'gold medal' at awards for innovative mine technologies,* Rio Tinto, 29th May 2017, URL: https://www.riotinto.com/media/media-releases-237_22401.aspx ; Accessed: 20th November, 2018
[2] *Data Access and Usage (DAU) Working Group,* GMG, URL: https://gmggroup.org/groups/data-access-and-usage-dau/ ; Accessed: 20th November, 2018
[3] *Downhole data without delay,* CSIRO, URL: https://www.csiro.au/en/Research/MRF/Areas/Resourceful-magazine/Issue-10/Downhole-data-without-delay ; Accessed: 20th November, 2018
[4] *Golgcorp and IBM Develop New AI Technology Solution to Improve Predictability for Gold Mineralization,* Goldcorp, URL: https://www.goldcorp.com/English/investors/news-releases/news-release-details/2018/Goldcorp-and-IBM-Develop-New-AI-Technology-Solution-to-Improve-Predictability-for-Gold-Mineralization/default.aspx ; Accessed: 20th November, 2018

1.1 Data enabled exploration
Increased resource identification per metre drilled

Potential Value

Fewer holes drilled – utilising a historical database to improve resource boundary identification and real-time material assessment could result in 10% - 15% reduction in drilling costs

Improved asset productivity – improvements from automation could deliver improvement in productivity from 5% - 10%

Improved discovery success rate – utilising all historical information and improvements in exploration techniques will result in an increased discovery success rate

Improved safety – increasing levels of automation and remote operations will further reduce exposure of employees to hazardous environments

Workforce Implications

Workforce number

- Adoption of autonomous drilling will lead to a reduction in traditional drill operators

Workforce capability

- There will be a shift towards decision support based on live data collected to optimise the drill design. This will result in an increased demand on analytics and modelling skills and better communication with central decision making management

Location of workforce

- The increased focus on data analytics and model design means much of this work may be conducted remotely through an IROC facility
- Relocating employees to an IROC facility enables teams to work in a cleaner and safer environment

2 Mining Operations

2.1 Integrated drill and blast
Using all information to optimise drill and blast and downstream comminution

Current
- Standard drill and blast design, minimal utilisation of geology data
- Limited use of information from drills into design
- Poor tracking of material displacement in the final muckpile

Future
- Drill and blast tailored to accurate geological model
- Information collected and used downstream
- Autonomous drills, data analysis and integration with drill and blast design (pattern, loading and initiation)
- Accurate location of geological units post blast

Potential Value
- 10% - 15% reduction in drilling costs
- 10% - 20% reduction in explosive costs
- 10% - 15% reduced dilution
- 5% - 10% due to asset productivity
- Improved safety due to reduced exposure to hazards
- Overall productivity improvement of 5% to 10%

Industry Implications
- Fewer drill operators
- Increased demand on data analytics and design
- Fewer traditional mine geologists
- Focus on decision support as opposed to execution focus

	Opportunity	Benefits	Enablers	Value
1	Improved drill and blast design through the use of all geological information	▸ Improved understanding of the ore body ▸ Design aligned to material characteristics ▸ Tailored drilling design	▸ Historical database / GIS ▸ Analytics on the exploration drills ▸ Autonomous drills	▸ Reduction in number of holes drilled ▸ Less explosives consumed
2	Adaptive drill and blast to better manage ore variability	▸ Improved blast design matching material characteristics ▸ More efficient recovery of the orebody ▸ Improved "blasting for excavator performance" ▸ Improved downstream processing through material characterisation	▸ Autonomous drills ▸ Artificial Intelligence ▸ Robot Process Automation	▸ Reduced use of explosives ▸ Lower drilling costs ▸ Reduced dilution (less contaminants) ▸ Improved loader productivity (fragmentation and muckpile profile optimisation)
3	Predictive blast displacement to increase the quality of ore supplied downstream	▸ Reduced dilution from blasting ▸ Improved downstream processing ▸ Improved muckpile profile for productivity	▸ Database of upstream data ▸ 3D simulation and modelling ▸ Artificial Intelligence	▸ Increased delineation of the ore body ▸ Increased ROM grade through lower dilution ▸ Improved loader productivity

2.1 Integrated drill and blast

Increased resource identification per metre drilled

Improved drill and blast design through the use of all geological information

The accuracy of the geological model is key to efficiency in mining operations through to material processing. Utilisation of historical geological data from exploration and previous benches, provides an opportunity to optimise the drill pattern design. Access to real-time and video data provides the ability to customise the drill pattern. This can result in an improved understanding of the ore body, allowing tailored drilling to material characteristics.

- A ubiquitous database of the information collected in the exploration phase will allow for an optimised drill design through an increased understanding of the ore body
- Autonomous drills provide the ability to capture real-time information on the material characteristics of the rock mass which has not been fully possible with manual drilling
- Advanced analytics can be applied to the drills to allow them to differentiate between rock types and waste, allowing the drill design to be adjusted in real-time

These enablers can lead to a reduction in the total number of holes drilled, explosive consumed and an increase in the quality of ore extracted.

Adaptive drill and blast to better manage ore variability

Fragmentation control through effective drill and blast design can be challenging and influences a range of downstream processes including load, haul and processing. Optimising the drill and blast design provides an opportunity to improve the productivity of downstream operations and improve mineral recovery.

Autonomous drills collecting live data, in conjunction with advanced analytics, provide the ability to adjust the drill pattern and tailor the blasting to the specific material characteristics identified. This will result in a reduction in the use of explosives and reduced dilution of the ore. Adaptive blasting also provides significant value downstream, though increased quality of ore extracted and reduced waste management. Optimised fragmentation will improve muckpile profile, loader productivity and downstream processing efficiency.

Predictive blast displacement to increase the quality of ore supplied downstream

Poor tracking of blast displacement can lead to product dilution. Predictive blast displacement provides an opportunity to increase the delineation of the ore body and increase the run of mine (ROM) grade. Reduced dilution can realise benefits downstream including an improvement in loader productivity due to a reduction in waste rehandling.

A complete dataset of the information collected upstream captures the material characteristics of the area being blasted. The application of advanced analytics to this data provides the opportunity to predict the displacement of material caused by blasting. 3D simulation and visualisation technology can enable the tracking of blast displacement to be optimised through testing outcomes.

Industry examples

Rio Tinto Autonomous Drilling - Australia

In 2014 Rio Tinto deployed their Autonomous Drilling System (ADS) in their Pilbara operations. From their remote operating centre, a single operator is capable of operating up to four autonomous drill rigs simultaneously. This technology brings considerable benefits in utilisation, precision and provides a safer working environment for the operator. Rio Tinto's automated drills have resulted in a 15% increase in availability compared to manned drills[5].

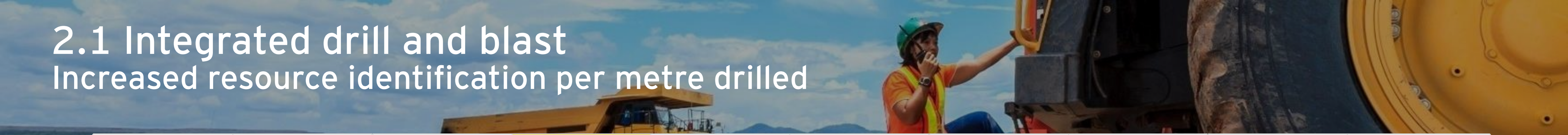
Anglo American Automated Drilling – South Africa

Anglo American started to implement automated drilling at their Kolomela and Sishen mines. Benefits from this project include 25% reduction in total drills required, 18% gain in drill rate and 23% gain in direct operating hours[6].

Orica BlastIQ - Australia

In 2018, Orica released a digital platform designed to integrated data and insights across the drill and blast process to optimise blasting outcomes. The complete blast control system integrates explosive delivery control system, blast design and quality management[7].

[5] *Mine of the Future*, Rio Tinto, URL: https://www.riotinto.com/australia/pilbara/mine-of-the-future-9603.aspx ; Accessed:19th November, 2018
[6] *A smarter and safer Kolomela mine through automated drilling*, AngloAmerican, URL: https://southafrica.angloamerican.com/our-stories/a-smarter-safer-kolomela-mine.aspx ; Accessed: 19th November, 2018
[7] *Optimising drill and blast operations with next generation BlastIQ™ digital platform*, Orica, URL:http://www.orica.com/news---media/optimising-drill-and-blast-operations-with-the-next-generation-blastiq-digital-platform#.XAdOG2gzY2y ; Accessed: 19th November, 2018



2.1 Integrated drill and blast
Increased resource identification per metre drilled

Potential Value

Fewer holes drilled – aligning the quality and number of drill holes for blast optimisation could result in a 10% - 15% decrease in drilling costs

Less explosives – tailoring and optimising blast design to material type could reduce explosive costs by 10% - 20%

Reduced dilution – improved blast efficiency has the potential to reduce dilution by 10% - 15%

Improved asset productivity – improvements from automation could deliver improvement in productivity from 5% - 10% and improved downstream processing productivity / recovery

Improved safety – increasing levels of automation and remote operations will further reduce exposure of employees to hazardous environments

Workforce Implications

Workforce number

- The continued adoption of autonomous drilling will reduce the need for traditional drill operators

Workforce capability

- The key skills focus of drill and blast will shift from technical execution to decision support focus
- The workforce will be upskilled and more productive, operating multiple drills remotely
- New roles will be created in systems engineering, communications and data analysis

Location of workforce

- The increased focus on data analytics and model design means much of this work can be conducted remotely either internally through an IROC arrangement, a global hub or though a third party partner

2.2 Autonomous and continuous mining solutions
Improved asset and system OEE

Current
- Departure from plan and schedule due to unplanned asset downtime and sub-optimal operation discipline
- Underutilised assets, discrete operations processes
- Reactive maintenance strategies and tactics

Future
- Autonomous assets
- Continuous mining solutions
- Safer working environment for employees
- Predictive/proactive asset management strategies and capability
- Ability to dynamically adapt to conditions or unplanned events to minimise productivity losses

Potential Value
- 10% - 20% reduction in fleet size
- 15% - 20% increase in asset productivity
- 7% - 15% increase in operating hours
- Improved safety for employees due to reduced exposure to hazardous environment
- Overall productivity improvement of 8% to 25%

Industry Implications
- Fewer on-site employees
- Fewer truck operators
- Re-defined relationship between people and assets
- Increased demand on data analytics
- Fundamental change in operations (truck-less system)
- Fundamentally sophisticated approach to plan execution

	Opportunity	Benefits	Enablers	Value
1	Asset utilisation optimisation	▸ Increased asset productivity/throughput ▸ Optimised plan and schedule (reduction in queuing, buffering and bottlenecks)	▸ Autonomous trucks ▸ Autonomous decision making ▸ Integrated Operations Centres ▸ IoT ▸ Centre of Excellence	▸ Increased throughput ▸ Fleet reduction
2	Continuous pit to load out mining operations	▸ Stockpile elimination ▸ Reduced bottlenecks ▸ Continuous operations	▸ Truck-less system ▸ IoT	▸ Smaller fleet / no trucks ▸ Increased utilisation ▸ Increased rate ▸ Reduced headcount
3	Predictive, risk based Asset Management strategies and tactics	▸ Improved asset reliability ▸ Reduced departure from plan and schedule	▸ Advanced analytics and simulation modelling ▸ Digital twin ▸ Machine learning ▸ Centre of Excellence	▸ Reduced unplanned downtime (target 80% PM Benchmarks) ▸ Improved asset reliability

2.2 Autonomous and continuous mining solutions
Improved asset and system OEE

Asset utilisation optimisation

The vast majority of mining equipment is manually operated by 4 drivers over 24 hours, due to shift coverage requirements. The adoption of autonomous trucks has been seen across the mining industry, providing multifaceted benefits. Companies that have implemented autonomous trucks have realised increased equipment utilisation by eliminating breaks and shift changes, elimination of unplanned stops allowing more optimised fleet deployment, increased productivity, reduced costs and beneficial safety implications for employees.

Autonomous trucks provide an opportunity to collect an increased amount of data on the assets performance on different paths, corners, ramps and loading zones. This information can be utilised to understand when the trucks are operating most efficiently. The consistent and repeatable nature of automation makes trucks more responsive to changes in tactics resulting in more control over outcomes and decreased process variability. These benefits all result in increasing the trucks operating hours which provides an opportunity to reduce the size of the fleet leading to a reduction in operating costs.

Continuous pit to load out mining operations

Auto haulage has seen improvement in availability, utilisation and safety, however, bottlenecks still exist requiring the use of stockpiles. Stockpiles are inefficient due to rehandling and impacts on quality / grade control management. To further improve productivity and reduced costs, companies are developing truck-less operations. Instead of using trucks, a structure comprising of shovels and moveable conveyors extract the ore and feed conveyor belts that move the product directly to the processing plant. The most significant advantage of truck-less operations is the ability to operate in all weather conditions, such as heavy rainfall, which would compromise regular operations. Truck-less operations have seen benefits including an uplift in OEE, increased throughput and reduction in diesel consumption.

Predictive, risk based Asset Management strategies and tactics

Asset management strategies are key to ensuring optimised mining operations. Unplanned breakdowns can have a significant impact on productivity and quality. Mining companies widely use time base maintenance strategies where repair or replacement is based on fixed time intervals irrespective of the condition of the equipment leading to parts being replaced before end of life and higher amounts of asset downtime. Technologies including predictive analytics and condition based monitoring provide the ability to shift towards a predictive maintenance strategy based on asset health.

Assets can be fitted with sensors to monitor asset condition such as vibration monitoring. This allows component problems to be identified prior to failure, resulting in a reduction in asset downtime.

Autonomous drills and trucks produce significant amounts of data about the asset including condition. They are connected though a fully integrated network providing improved scheduling of maintenance to reduce the impact on operations.

Industry examples

Anglo American Digital Twin – Chile and Brazil

Digital twin technology is being used in Los Bronces mine site in Chile and at a pipeline in Brazil. Benefits include optimization of its mining fleet. Applications to track the performance of haulage is carried out by using digital twins which are virtual models of the technical process that allow companies to analyse data and improve equipment efficiency[8].

Truck-less Operations - Americas

A major mining company has established a truck-less operating system for a large open cut mining operation. Long distance conveyors and movable crushers have replaced trucks and fixed crushers, extracting ore and transporting product directly to the processing plant. This operation has delivered marked increases in production and has significantly reduced diesel and water consumption.

Rio Tinto Autonomous Haulage System (AHS) - Australia

Rio Tinto has introduced fully automated, driverless haulage trucks across iron ore mines in Western Australia. The AHS are specially built to perform normal tasks associated with driving a vehicle, and respond to GPS directions. AHS has realised benefits including improved employee safety with reduced exposure to hazards and risks associated with operations, 14% improvement in productivity and 13% reduction in load and haul operating costs from the automated fleet [5].

[8] *Anglo using 'Digital Twins'', robotics to boost mining: Q&A*, Bloomberg, 20th February 2017, URL:https://about.bnef.com/blog/anglo-using-digital-twins-robotics-boost-mining-qa/ ; Accessed: 21st November, 2018

2.2 Autonomous and continuous mining solutions

Improved asset and system OEE

Potential Value

Reduction in fleet size – automating truck fleets can lead to a 10% - 20% decrease in fleet size

Increased operating hours – autonomous and continuous solutions can lead to an increase in asset operating time of 7% - 15%

Improved asset productivity – improvements from autonomous and continuous solutions could deliver improvement in productivity from 15% to 20%

Improved safety – increasing levels of automation and remote operations will further reduce exposure of employees to hazardous environments

Workforce Implications

Workforce number

- The adoption of autonomous haulage will result in a reduction in need for traditional operators

Workforce capability

- Reduction of routine work with a higher level of thinking to anticipate and plan activity
- Ancillary fleet operators will be learning to manage the human-to-machine interface
- Skilled mining professionals required for day-to-day management, advanced system development and system integration

Workforce location

- Relocating operators to a remote operating centre would lead to a reduction in exposure to hazardous work environments where industrial accidents can happen, elimination of operators fatigue and elimination of repetitive tasks that may cause long term injuries
- Locating workers in a safer environment closer to their community can attract new employees, allowing for greater diversity

2.3 Underground mine of the future
Optimise underground resource extraction

Current

- Mine design significantly influenced by workforce and asset requirements
- Predominately diesel powered asset fleet
- Ventilation and access constraints dictate design

Future

- Electrification of fleet
- Continuous mining solutions
- Autonomous operations
- Tailored mining solutions

Potential Value

- Up to 50% reduction in ventilation and refrigeration costs
- 40% - 60% reduction in underground headcount
- 10% - 15% reduced dilution
- Improved life of mine
- Overall productivity improvement of 4% to 15%

Industry Implications

- Reduction in underground workforce
- Increased demand for geotechnical engineers and modellers
- Increase in remote operations
- Reduced environmental impact
- Increased underground operations

	Opportunity	Benefits	Enablers	Value
1	Safer work environment	▸ Improved safety / fewer people underground ▸ Reduced exposure to diesel particulate matter ▸ Reduced footprint underground	▸ Autonomous operations ▸ Electrification (battery or trolley assist) of fleet	▸ Reduced headcount underground ▸ Reduced cost of ventilation and refrigeration ▸ Lower unit energy cost ▸ Improved safety
2	More aggressive mining strategy (increased reserve to resource conversion)	▸ Increased reserve to resource ratio ▸ Increased ore recovery	▸ Autonomous operations ▸ Continuous mining ▸ 3D simulation and modelling	▸ Increased throughput ▸ Lower unit cost per ton of ore
3	Predictive grade and blast design	▸ Less waste ▸ More accurate drill and blast ▸ Use of mineral characterisation for downstream planning ▸ Improved process and quality management	▸ Database of upstream / historical data ▸ 3D simulation and modelling ▸ Advanced analytics	▸ Increased quality (reduced dilution) reduced waste haulage ▸ Reduced explosive consumption
4	Predictive rock mechanics	▸ Fewer catastrophic events ▸ Improved geotechnical engineering solutions	▸ Database of upstream data ▸ 3D simulation and modelling ▸ Advanced analytics	▸ Reduced unplanned event based downtime ▸ Increased safety ▸ Reduced ore loss due to rock mass failures

2.3 Underground mine of the future
Optimise underground resource extraction

Safer work environment

Underground mining operations present a technically challenging and hazardous environment for workers, through inadequate ventilation, exposure to dust, heat and gas as well as threat of rock falls or mine collapse. Significant progress has been made to improve safety standards. Technological advances now make it possible to make further progress. Electrification of vehicles from diesel based fleet either using overhead connections or battery power, will provide significant benefits. Zero emissions from electric vehicles will mean the exposure to Diesel Particulate Matter, a known carcinogen after prolonged exposure will be eliminated. There will be a significant reduction in noise and vibrations and worker comfort will increase.

Autonomous remote operations will offer an opportunity to redefine what is possible in underground mining and completely remove workers from the hazards of underground mining by eliminating the need for manual manned operations.

More aggressive mining strategy (increased reserve to resource conversion)

The current design of underground mines is heavily influenced by workforce and asset requirements. Ventilation, emergency escape and workforce infrastructure make up significant elements of a mine's design and therefore cost. The introduction of autonomous remote operations will provide an opportunity to fundamentally redesign requirements for underground mines. This will reduce costs associated with the establishment and operation of workforce based infrastructure such as ventilation and refrigeration. It will enable greater resource conversion by allowing for more aggressive mine designs and mining strategies that were previously unavailable due to technical or safety limitations. Other advances in mining techniques such as continuous mining will further improve resource conversion whilst increasing operational productivity.

Predictive grade and blast design

The efficiency and accuracy of drill and blast operations has a major impact on the efficiency of downstream operations. The development of predicative grade and blast designs will provide a significant improvement in drill and blast efficiency as well as subsequent comminution and beneficiation processes. Advanced analytics and 3D simulation based on real-time, upstream and historical information will enable operators to predict material characteristics and optimise drill and blast designs accordingly. This will result in less dilution of ore, less overall waste to manage as well as improved process and quality management for downstream operations.

Predictive rock mechanics

Underground mining presents significant technical challenges, understanding and managing the geological forces and the interaction with mining activities is increasingly difficult as mines get deeper. Catastrophic events such as rockbursts, outbursts of gas and mine collapse etc. occur when there is a lack of understanding or appropriate management of these conditions.

The development of precise predicative rock mechanics will allow for greater fundamental understanding of rock mechanics and failure and an ability to predict and model changes induced by mining operations. This can be incorporated into design and will create a significantly safer and more productive mining operations by minimising exposure of workers and equipment to unstable conditions. It will also allow for the development of improved engineering solutions to better manage those conditions.

Industry examples

Goldcorp Electrification - Canada

Goldcorp is currently constructing the first all electric underground mine in Canada. The new mining technology includes battery operated drilling and blasting, electric bottlers and electric haul trucks. Goldcorp estimate this operation will eliminate approximately 2 million litres of diesel per year and reduce greenhouse gas emissions by 70%. This will result in a 50% reduction in ventilation requirements for the mine[9].

Resolute Mining Autonomous Mine - Mali

In December 2018, Resolute Mining will commence the construction of a completely autonomous end-to-end underground mine in West Africa. This operation is expected to realise multifaceted benefits including increased asset productivity, optimised scheduling, estimated reduction in operating costs of 30%, reduction in personnel underground and improved safety outcomes including reduced emission, noise and vibration[10].

[9] *Borden*, Goldcorp, URL: https://www.goldcorp.com/English/portfolio/development-projects/borden/default.aspx ; Accessed on 22nd November, 2018
[10] *Syma - Mali, West Africa*, Resolute, URL: https://www.rml.com.au/africa.html ; Accessed: 22nd November, 2018

2.3 Underground mine of the future
Optimise underground resource extraction

Potential Value

- ***Reduction in ventilation and refrigeration*** – the removal of workforce related infrastructure will reduce UG capital and operating costs by up to 50%
- ***Reduction in underground workforce*** – the shift to autonomous remote operations could result in a reduction of employees by 40% - 60%
- ***Reduced dilution*** – improved drill and blast efficiency has the potential to reduce dilution by 10% - 15%
- ***Fewer catastrophic events*** – improved understanding and management of rock mechanics will reduce the instances and impact of catastrophic events
- ***Improved safety*** – increasing levels of automation and remote operations will further reduce exposure of employees to hazardous environments
- ***Reduction of CO_2 and diesel particulate matter*** – electrification of mine fleet can effectively mitigate diesel emissions

Workforce Implications

Workforce number

- The shift to autonomous remote operations will see a significant reduction in the number of underground operators
- There will be an increase in numbers of technology and system support staff

Workforce capability

- There will be increased demand for geotechnical engineers, data scientists and modellers
- There will be increased demand for workforce that can cross over practical, technical and technological boundaries

Location of workforce

- Operations will increasingly become remote with only technical maintenance functions required on-site
- Removing employees from a confined environment where heavy machinery is operated and serious risks exist from rock fall and explosions
- Advanced analytics and modelling will likely be conducted through a mix of in-house global hub operations and third party partner

3 Processing

3.1 Fully integrated mine to plant
Improved throughput and recovery per operating hour

Current
- Significant departure from plan and schedule due to unplanned asset breakdown
- Minimal integration with upstream processes/information
- Reactive asset management and time based strategies

Future
- Utilise upstream process or material characterisation for optimised processing
- Integrated upstream and downstream operations
- Predictive asset management

Potential Value
- 10% - 15% increase in throughput
- 20% - 35% unplanned downtime
- reduction
- 7% - 15% asset productivity improvement
- 10% - 15% processing cost reduction
- Reduced CO_2 emissions
- 8% - 20% overall productivity improvement

Industry Implications
- Increased demand on data and analytics
- Increased decision support focus for plant set point management

	Opportunity	Benefits	Enablers	Value
1	Optimisation of asset utilisation	▸ Increased asset productivity/throughput	▸ Autonomous and continuous solutions ▸ Autonomous decision making ▸ Machine learning ▸ Centre of Excellence	▸ Increased throughput
2	Plant set point optimisation	▸ Plant set point prediction for incoming material characteristics	▸ Drones to scan materials entering plant ▸ Geological characterisation from exploration and drill and blast ▸ Digital twin – correct parameters for incoming material ▸ Advanced analytics to optimise plant configuration for predicted feed ▸ Integrated Operating Centre	▸ Improved processing efficiency ▸ Reduced bottleneck ▸ Increased throughput ▸ Improved product quality / consistency
3	Automated ore sorting	▸ Reduced rehandling ▸ Increased product recovery ▸ Improved material beneficiation	▸ Mineral sensing and sorting technology e.g. scan and microjets	▸ Increased quality (reduced dilution) ▸ Lower costs
4	Predictive asset management strategies	▸ Improved asset reliability ▸ Reduced departure from plan and schedule ▸ Reduced bottlenecks	▸ Advanced analytics (on-board and central) ▸ Digital twin ▸ Machine learning ▸ Centre of Excellence for asset management	▸ Reduced unplanned downtime ▸ Increased throughput ▸ Lower maintenance costs per operating hour
5	Alternative sources of energy	▸ Sustainability differentiator ▸ Reduced reliance on diesel ▸ Reduced green house gas emission ▸ Reduced energy costs	▸ Use of renewable energy including solar and wind	▸ Reduced spend on diesel

3.1 Fully integrated mine to plant
Improved throughput and recovery per operating hour

Optimisation of asset utilisation

The processing plant often becomes a point of constraint in mining operations. Poor planning and scheduling of upstream processes can lead to the plant being under utilised due to lack of feed or compromised due to inappropriate feed. There is a need to deliver the right amount of product, in the correct mix at the right time to ensure operating hours and throughput are optimised. This can be achieved through the use of integrated scheduling and execution. Improved management of ROM quality and schedule and plant feed has significant impact on stockpile requitements and reduced rehandling to ensure the plant continues to run efficiently.

Plant set point management

Typically, there is minimal integration between the processing plant and upstream mining and operational processes. Processing throughput can be improved through the use of drones, advanced analytics, digital twins and an Integrated Operating Centre to better manage feed presentation for plant optimisation.

Drones can be used to scan the minerals being transported to the plant to collect information on particle size distribution and characteristics. An IOC enables integration of the plant with upstream processes such as drill and blast, providing an increased understanding of the mineral composition entering the plant and the ability to manage controllable elements. Advanced analytics provide the opportunity to utilise the increased information on the minerals entering the plant to optimise the plant operational parameters. Digital twins offers an immersive virtual replica of the plant that takes real-time data from the physical environment, allowing teams to test scenarios to optimise the plant control systems parameters, resulting in plant optimisation and increased throughput. Development of mobile applications can provide live data to improve decision making in metal extraction.

Automated ore sorting

High-grade mineral ore deposits are depleting and new deposits are increasingly lower in quality, making it more difficult to operate economically. Ore sorting technologies offer a solution to this problem by separating the valuable minerals from waste in a ROM stream, resulting in a reduction in the amount of material that needs to be processed to produce a given amount of product. Sorting technologies provide the ability to significantly boost productivity, realise energy savings, provide capital and cost advantages and improve product quality.

Industry examples

Global Miner SAG Mill Optimisation - Chile

To further optimise SAG Mill performance the company used a digital twin where data is used to train a 'twin' of the SAG Mill so that it can provide an indication of the behaviour of a real SAG Mill in multiple scenarios. Predicted optimal set points could increase throughput translating to a $40M USD per annum revenue uplift.

NextOre Copper and Iron sorting – South America and Canada

NextOre have developed a sensor system for large-scale ore sorting. It can quickly send material for processing or to waste due to its low quality. While productivity benefits vary depending on the characteristics of the ore body, the analyser has the potential to more than double average ore grades once sorted. It could represent as much as a 20% reduction in processing costs in some copper mines. They are focused on marketing the technology in South American and Canada[11].

Global Materials and Chemicals Company

The company is developing a mobile application that provides data to improve decision making and optimise the metal extraction process.

[11] *MRI for mining to sort out copper waste,* CRISO, 5th December, 2018, URL: https://www.csiro.au/en/News/News-releases/2018/MRI-for-mining-to-sort-out-copper-waste ; Accessed: 19th November, 2018

3.1 Fully integrated mine to plant
Improved throughput and recovery per operating hour

Predictive Asset Management strategies

Processing plant maintenance effectiveness plays a vital role in determining the overall productivity of a mine. Breakdowns can lead directly to overall production losses, rescheduling of production and material loss. Mining companies focus on reducing or eliminating major breakdowns and keeping the plant operational whilst minimising cost. A shift towards predictive maintenance strategies helps to reduce the likelihood of breakdowns and minimises impact on production.

Alternative sources of energy

The mining industry consumes approximately 11% of global energy. This energy is mainly supplied from diesel, natural gas and grid electricity. Mine sites are often in remote areas and typically depend on diesel-generated power plants which can be extremely costly and pose challenges for transport and logistics. Loss of power can be catastrophic for mining companies as seen in 2016 when a 24-hour state-wide blackout in South Australia halted production At BHP's Olympic Dam mine for nearly two weeks. There is an opportunity for companies to use renewable sources of energy, differentiating them on the basis of sustainability. Companies have begun to utilise renewable energy, in particular solar and wind, resulting in a reduction in the amount of diesel used and CO2 emissions and consequent cost savings.

Industry examples

Shanta Gold Hybrid Solar Power Plant – Tanzania

At the new Luika mine in Tanzania, a 63kW solar photovoltaic pilot power plant has been operating successfully for over two years. The plant is connected to the mine's island grid and operates automatically in a hybrid mode in conjunction with a rented 4.8MW Aggreko power plant. Average solar energy generation has amounted to ~80,000kWh per annum with a consequent savings of ~50 tonnes per annum of CO_2 emissions[12].

[12] *Environment*, Shanta Gold, URL: https://www.shantagold.com/sustainability/environment/ ; Accessed: 19th November, 2018

3.1 Fully integrated mine to plant
Improved throughput and recovery per operating hour

Potential Value

- ↓ ***Reduction in unplanned downtime*** – predictive maintenance strategies can lead to a 20% - 35% decrease in asset downtime
- ↑ ***Increased throughput*** – asset utilisation optimisation and plant set point management can lead to an increase in throughput of 10% - 15%
- ↓ ***Reduction in processing costs***– ore sorting technologies could deliver a reduction in processing costs of 10% to 15%
- ↑ ***Improved asset productivity*** – predictive maintenance strategies, plant set point management and utilisation optimisation can lead to improved asset productivity of 7% to 15%
- ↑ ***Improved sustainability*** – utilisation of renewable energy can reduce CO_2 emissions and expenditure on diesel

Workforce Implications

Workforce number

- Minimal change in workforce numbers will be seen

Workforce capability

- There will be an increase in reliance on advanced analytics resulting in an increased in data scientists and modellers
- There will be an upskilling of workforce to manage increased information collected through the processing stage

Workforce location

- Minimal impact on workforce location will be seen, maintainers and operators will stay on-site

4 Transport

4.1 Integrated and optimised transport
Fewer total equipment hours per tonne produced

Current

- Departure from plan and schedule due to unplanned asset downtime
- Shipment losses due to tide cycles, weather conditions and schedule clashes
- Limited integration of planning and scheduling for shared rail systems

Future

- Autonomous assets (rail, conveyors systems etc.)
- Optimised planning and scheduling of shared rail systems and logistics
- Integrated shipping planning and scheduling to upstream processes and tide cycles

Potential Value

- Up to 20% increase in asset operating time
- 20% - 35% reduction in unplanned downtime
- Up to 20% reduction in rail operations workforce
- Overall productivity improvement 3% - 15%

Industry Implications

- Increased demand on data and analytics
- Reduced on-site workforce

	Opportunity	Benefits	Enablers	Value
1	Predictive asset management strategies	▸ Improved asset reliability ▸ Reduced departure from plan and schedule ▸ Real-time detection of rail condition	▸ Advanced analytics ▸ Digital twin ▸ Machine learning ▸ Rail detection	▸ Reduced unplanned downtime ▸ Increased throughput
2	Optimisation of asset utilisation	▸ Increased asset productivity/throughput	▸ Autonomous trains and ships ▸ Autonomous decision making ▸ Machine learning ▸ Centre of Excellence for asset management	▸ Increased throughput ▸ Lower stock levels (Working capital reduction)
3	Optimised ship loading	▸ Increased ability to deliver in full, on time ▸ Optimise ship loadout for each tide cycle	▸ Data optimisation between multiple sources both internally (Enterprise Resource Planning/productivity) and external (Bureau of Meteorology/maritime) ▸ Integrated Operating Centre ▸ Blockchain and smart contracts	▸ Reduction in missed shipments

4.1 Integrated and optimised transport
Fewer total equipment hours per tonne produced

Predictive Asset management strategies

Reliability of trains is an integral part of mining operations as failure of one aspect can halter operations causing significant downstream implications, such as missed shipment. To minimise the costs associated with rail breakdown and ensure reliability of the network, strong maintenance practices are required. Technology such as broken rail detection and digital twins provides the ability to shift towards predictive maintenances as opposed to reactive, accurately identify breaks to minimise interruption or derailment and enabling the convergence of engineering operational and information technology forecast problems and provide actionable information for decision support.

Optimisation of asset utilisation

Trains are the most common form of long distance transport in the mining industry to move product from the processing plant to the port for shipping. The trains transport material over significant distances, making optimising operating time is key to efficiency. Manually operated trains add approximately one hour to the journey due to operator shift changes and breaks. Preventing stoppages and keeping the network operating can allow more ore to be transported. 2017 saw the commissioning of the first long distance autonomous rail operation. Autonomous trains allow operators to be relocated to a remote operating centre, removing the need for operator induced stoppages. The consistent nature of automation can drive improvements through reduced operational variability and increased speed across the network leading to a reduction in average cycle times and consequently an increase in productivity.

Autonomous trains utilise advanced analytics and autonomous decision making in their operation with benefits both for safety and efficiency. Once the train controller has set the route on-board computer networks allow the train to make decisions including ensuring it is travelling at optimal speed and ensuring it doesn't run into another train or obstacle. This provides an opportunity for improved safety outcomes and operational efficiencies.

Optimised ship loading

Demurrage is a significant cost that can result from shipment losses due to tide cycles, weather conditions and schedule clashes (stock out). Every missed shipment typically results in sales revenue that can't be recovered. An opportunity exists to optimise ship loadout for each tide cycle which will result in a reduction in missed shipments and increased ability to deliver in full and on time. This can be achieved through improved coordination of end-to-end material scheduling, advanced analytics and a shipping platform. Data analytic can assist in optimisation between internal data (enterprise resource management (ERP) / productivity) and external data (BOM / maritime). The shipping platform can use this information to ensure matching of production orders to tide cycles to minimise the possibility of missed shipments and the significant associated costs.

Industry examples

Global Mining Company Shipping Platform – Australia

A platform was developed to track vessels in real-time to determine optimal loading dates and/or ports through the integration of the company's internal database and systems and multiple external sources to track customer/supplier patterns, market changes and weather conditions.

Autonomous Trains Rio Tinto - Australia

In 2017 Rio Tinto started using Autonomous trains in their Pilbara operations. Benefits from implementing autonomous trains include improve safety, reduced bottlenecks and increased productivity through reduced cycle time[5].

4.1 Integrated and optimised transport
Fewer total equipment hours per tonne produced

Potential Value

↑ ***Increased asset operating time*** – automating trains can lead to an increase in operating hours up to 20%

↓ ***Reduction in unplanned downtime*** – predictive maintenance strategies can lead to a 20% - 35% reduction in asset downtime

↑ ***Reduction in workforce*** – automation of trains can lead to a reduction in the rail operations workforce of up to 20%

↓ ***Reduction in missed shipment*** – optimised ship loading could lead to a reduction in missed shipment

Workforce Implications

Workforce number

- The adoption of autonomous trains will result in a reduction in traditional operators

Workforce capability

- Shift from traditional operator to management of autonomous trains
- There will be an upskilling of operators to manage the human-to-machine interface
- Increased requirement for advanced system development and integration to manage autonomous systems and shipping platforms

Workforce location

- Relocating operators to a remote operating centre would lead to a reduction in exposure to hazardous work environments (mechanical, chemical, dust, etc.), elimination of operators fatigue

5 Trading

5.1 Customer integration
Accurate forecasting and response to product demand

Current
- Significant paper documentation
- Difficulty tracking status of shipments as they move along the supply chian
- Fixed product scenarios

Future
- Access to niche spot sales market
- Auto-execution and contract transparency
- Customer requirements drive production decisions
- Bespoke products developed directly through production rather than through stockpile blending
- Customer integration upstream into the supply chain

Potential Value
- 5% - 10% cost saving through leaner, more automated and error-free processes
- Increased security and protection from fraud
- 7% - 15% reduction in rehandle cost
- 2- 5 % increase in margin for traded commodities
- Overall productivity improvement 5% to 10%

Industry Implications
- Change management required to instil a customer centric focus
- Increased demand for market forecasting and modelling
- Increased need for marketing professionals with integrated view and understanding of product development

	Opportunity	Benefits	Enablers	Value
1	Digital contracts and logistics	▸ Secure mechanism to ensure product delivery and authenticity ▸ Streamline cross-border trading and back-office processes (invoice generation, reporting etc)	▸ Block chain embedded smart contracts	▸ Increased security ▸ Reduced working capital ▸ Automated processes
2	Ability to fulfil on-demand products	▸ Access to niche spot sales market	▸ Market demand and price forecast modelling ▸ Integrated Operations Centre ▸ Integrated customer demand profile	▸ Increased margin through market pull products ▸ Reduced rehandling costs ▸ Reduced stockpiles
3	Tailored mining	▸ Mine what you can sell ▸ Sell what you can mine ▸ Reserve optimisation	▸ Integrated Operating Centre ▸ Holistic optimisation	▸ Reduced stockpiles ▸ Margin optimisation

5.1 Customer integration
Accurate forecasting and response to product demand

Digital contracts and logistics

Logistics processes are largely manual with information about the status of goods locked in organisational and process silos. The supply chain is slowed by the complexity and volume of point to point communication, causing friction in global trade. Blockchain technology provides an opportunity for logistics to move from an environment of poor tracking, siloed communication and no accountability to end-to-end track and trace will full visibility.

Smart contracts are reflected in the blockchain network where they can be automatically shared with key stakeholders based on defined rules. They provide the ability to replace manual data entry and paper based documentation creating a more efficient, error-free and automated process. Blockchain provides a secure tamper-proof documentation system that cannot be erased or modified. This is particularly beneficial in the traceability of high-value goods such as diamonds. The platform contains all information in a digital certificate from mine to customer and is visible to authorised users providing proof of origin and ethical sourcing.

This technology provides the opportunity to realise benefits in process efficiency and cost savings due to leaner, automated and error-free processes.

Ability to fulfil on-demand products

Stockpiles can provide advantages for mining companies including providing a buffer against supply fluctuations and enabling grade customisation through blending, however they hold significant working capital for companies, creating added cost. Blending on-demand provides an opportunity to access niche spot sales markets. Integral to this is accurate management of quality and quantity of ore in the stockpile, which is typically a challenge for mining companies. Several loads of ore are typically dumped onto one stockpile over an extended period time resulting in a variation of grade throughout the pile. Advanced technologies, such as drones, have recently been used to address this issue. Drones take aerial photographs to gain measurement data of the stockpile and in conjunction with advanced analytics provide the ability to generate real-time 3D tracking of stockpiles. Integrated quality management, enabled through an IOC, provides a means to effectively meet the demands of customers whilst reducing stockpile levels.

Tailored mining

Product customisation currently occurs through blending of stockpiles after the processing phase of the mining value chain. A reliable and well managed supply chain, supported through an Integrated Operating Centre, provides the opportunity to facilitate customer integration upstream in the supply chain resulting in the ability to drive production decisions through customer requirements. This involves tailoring mining of the ore body to match the grade required by the customer. This would lead to a reduction in stockpile inventory and consequent reduction in rehandling operations. Tailored mining through an IOC enables companies to develop bespoke products directly through production as opposed to stockpile blending, increasing margin through market pull products.

Industry examples

DeBeers Blockchain Traceability – Global

DeBeers developed a blockchain platform called Tracr. This platform creates a digital certificate of end-to-end documentation and transactions maintained by a network of computers resulting in an immutable and secure digital train of their diamonds. Benefits of this technology include verification of authenticity of diamonds, providing asset-traceability assurance and improved process efficiency[13].

Blockchain for smart contracts – Global

Maersk and IBM have started a venture to establish a global blockchain-based system for digitalising trade workflows and end-to-end shipment tracking. The system allows each stakeholder in the supply chain to view the progress of goods through the supply chain, understanding where the shipment is in transit[14].

[13] *Setting the standard for diamond traceability*, TRACER, URL: https://www.tracr.com/ ; Accessed: 23rd November, 2018
[14] *Maersk and IBM form joint venture applying blockchain to improve global trade and digitize supply chains*, IBM, URL: https://www.ibm.com/think/fintech/maersk-and-ibm-form-joint-venture-applying-blockchain-to-improve-global-trade-and-digitize-supply-chains/ ; Accessed: 23rd November, 2018

5.1 Customer integration
Accurate forecasting and response to product demand

Potential Value

Reduced costs – digitalising and automating paper based system can result in a cost reduction of 5% - 10%

Reduction in rehandle – reduced reliance on stockpiles and tailored mining to customer demand can result in a reduction of rehandle of 7% to 15%

Increased margin – tailoring mining to customer demand can lead to a improvement in margin of 2% to 5%

Workforce Implications

Workforce number

- Minimal impact will be seen on workforce number

Workforce capability

- Realignment of existing operating model. Shift from planning mining based on tonnes produced towards tailored mining to quality based on customer demand
- Increased focus on understanding customer demand

Workforce location

- There will be a centralised customer demand management and planning team located in an IOC but minimal impact will be seen on location of workforce

6 End-to-End Value Chain

6.1 End-to-end productivity
Application of manufacturing excellence practices across the mining value chain

Current
- Siloed approach to productivity within value chain elements
- Productivity improvement efforts not always complementary
- Poor compliance to plan across value chain and within value chain elements

Future
- Integration across all elements the value chain
- Visibility across the entire value chain
- Complex decision support
- Integrated and optimised, production, quality management and asset management

Potential Value
- 2% - 7% asset productivity
- 10% - 15% increase in throughput
- 2% - 5% increase in margin
- Overall productivity improvement 4% to 8%

Industry Implications
- Requires operating model alignment to remove silos
- Greater integration of roles and responsibilities across value chain elements
- Requires realignment of performance metrics and target setting

	Opportunity	Benefits	Enablers	Value
1	End-to-end optimised and integrated plan and schedule	▸ Stockpile elimination ▸ Reduction in bottlenecks ▸ Reduction in unplanned downtime ▸ Improved quality management	▸ Integrated Operating Centre ▸ Digital twin ▸ Advanced analytics and modelling ▸ Integrated planning, scheduling and execution management	▸ Increased throughput ▸ Reduced bottleneck ▸ Increased quality
2	Optimised response to Asset Health, process performance and geological variance	▸ Agile planning to material variability to meet product requirements ▸ Improved process/planning for downstream operations	▸ Integrated Operating Centre ▸ Digital twin ▸ Advanced analytics ▸ Upstream information	▸ Increased quality ▸ Increased throughput ▸ Improved processing productivity

6.1 End-to-end productivity

Application of manufacturing excellence practices across the mining value chain

End-to-end optimised and integrated plan and schedule

Traditionally it has been difficult to achieve an integrated view across the value chain and the contribution and influence of each element. Planning and scheduling has often been conducted in isolation within each part of the value chain with limited consideration for integration or overall optimisation. This has resulted in sub-optimal productivity outcomes at a business level. The establishment of an integrated mindset across the business for planning and scheduling presents an opportunity to optimise the value chain for whatever outcome required.

Integrated operating centres provide a central platform by which to optimise and manage planning, scheduling and execution across the value chain in a coordinated and complementary way. Digital twins and advanced analytics allow for the modelling of various scenarios across the value chain to determine optimal planning and scheduling outcomes. Increased optimisation will result in a reduction in bottlenecks and an increase in throughput, it also has the potential to reduce or eliminate the need for large stockpiles of ore.

Optimised response to Asset Health, process performance and geological variance

Without end-to-end visibility and integration across the value chain, the management of operational variables such as asset health, process performance or geological variance is often reactive, siloed and misaligned with downstream activities, creating disjointed end-to-end productivity. Through the implementation of integrated operating centres and by leveraging digital twins, upstream information and advanced analytics and modelling the management of production variables can be streamlined and optimised to determine the best long and short term management outcomes. This will result in decreased variability within the end-to-end system, increasing overall throughput. An improved understanding and optimisation of material characteristics and mineral flow through the system will increase overall product quality through the reduction of dilution with unwanted waste material. This in turn will improve processing productivity as greater certainty around ore quality will allow for better alignment of plant set points and quality management etc.

Industry examples

Integrated Operating Centre - Americas

A global mining company established an Integrated Operating Centre that combines skills, operations processes, and technology from across the business to deliver exceptional levels of collaboration and operations excellence. The Integrated Operating Centre led to significant value improvements across the complete value chain, increasing productivity through synchronisation and stability across the end-to-end value chain.

The centre established:

- weekly/daily scheduling from mine to port with real-time coordination and execution management
- optimised quality management to maximise value and optimise infrastructure of control centres
- effective execution of the agreed optimised plan and schedule through an integrated and rigorous planning and execution framework

6.1 End-to-end productivity

Application of manufacturing excellence practices across the mining value chain

Potential Value

Increase in productivity – implementing an end-to-end system management will resulting in an increase in productivity of 2% - 7%

Increase in throughput – a focus on end to end productivity will result in n increase in through put of 10% - 15%

Increased margin – the increase in ore quality delivered through improved end to end integrated operations and reduced dilution will result in an increases in margin of between 2% - 5%

Workforce Implications

Workforce number

- The introduction of integrated operations may result in a moderate reduction in workforce through de-duplication of roles, however most roles will be transitioned into integrated roles

Workforce capability

- The introduction of integrated operations will require the development of a supporting operating model to provide a foundation of workforce alignment and removal of historical silos
- Roles, responsibilities, performance metrics and target setting will be realigned to support the revised operating model
- Skilled mining professionals will be required to manage the increased complexity of planning, scheduling and advanced decision making

Location of workforce

- IOCs can either be on-site or remote depending on operational requirements. Support services such as modelling and analytics can be located within IOC or remote from a central functional base or third party

6.2 Integrated quality management
Effectively managing assets and material flows to optimise quality management

Current

- Limited understanding and siloed management of quality through the value chain (reactive practices)
- Additional costs associated with re-work and rehandle to maintain acceptable quality parameters
- Reduced asset productivity associated with reactive practices and remedial work

Future

- Detailed understanding of chemistry and material type well before excavation (as well as path, destination and customer)
- An opportunity to proactively characterize ROM material to optimize blast performance, plant performance and reduce quality variance at the source and throughput processes

Potential Value

- 2% - 4% increase in asset productivity
- 5% - 10% increase in throughput
- 3% - 5% reduction in rehandle
- 2% - 5% increase in margin
- Overall productivity improvement 2% to 8%

Industry Implications

- Integration and centralisation of decision making and accountability
- Operational roles focused on plan execution rather than plan development
- Change management required shift workforce focus of from a process specific to an end-to-end mind set

	Opportunity	Benefits	Enablers	Value
1	Integration of planning, execution and quality management	▸ Maintaining grade/quality ▸ Decision making based on real-time conditions ▸ Reduced deviations from schedule due to grade departures ▸ Reduced "grade catch-up" activities in rail and port	▸ Integrated Operations Centre ▸ Automated decision making / support ▸ Upstream information ▸ 3D simulation and modelling	▸ Increased throughput ▸ Increased margin
2	Integrated batch production order with customer integration	▸ Predefined "recipe" provide stability and predictability ▸ Higher equipment (primarily loader) utilisation	▸ Integrated Operations Centre ▸ Automated decision making ▸ Database of upstream data ▸ 3D simulation and modelling	▸ Increased margin ▸ Increased asset productivity
3	Improved (optimised) product quality management	▸ Potentially higher price realisation through reduced quality variance ▸ Potentially higher sales through quality reputation (reduced variability)	▸ Database of upstream data ▸ 3D simulation and modelling ▸ Integrated Operations Centre ▸ Forecast demand modelling	▸ Increased margin

Integration of planning, execution and quality management

Current value chain management approaches have limited visibility and understanding of ore quality across the value chain. This often results in reactive practises to various points in production to manage quality. Integration of planning execution and quality management presents an opportunity to improve end-to-end visibility of quality and provide an ability to actively manage it from a central perspective. Integrated operating centres will provide a means by which to maintain grade / quality across the value chain through a centralised and coordinated approach.

A coordinated approach will allow for real-time decision making, reducing schedule deviations from grade departures and grade 'catch up' activities and rehandling in rail and port activities. This will result in increased overall throughput.

Decision support within integrated operating centres will draw on upstream material characteristic information, 3D modelling and simulation and automated decision making capabilities to optimise production activities to the desired outcome and increasing overall margin.

Integrated batch production order with customer integration

The primary focus of many mining operations has traditionally been output (tonnes). The focus on tonnes has led to variability in the quality of ore subsequently sent downstream for processing. As a result of this processing is variable and less efficient and there is variability in the subsequent product, often requiring additional management e.g. stockpiles, rehandling etc. Integrated batch or 'recipe' production will provide a means to reduce the variability at the source and provide increased stability and predictability.

By integrating production with customer specific requirements ore can be mined to produce specific batches for required customer / end point requirements. Integrated operating centres will provide the means by which to manage the end-to-end batch production, with orebody modelling and simulation utilising upstream geological information providing decision making inputs. By better matching mining operations to customer requirements overall margin will be increased through price optimisation and asset productivity will be increased through improved utilisation of equipment and lower rehandling.

Improved (optimised) product quality management

Grade or quality optimisation across the mining value chain has previously been difficult due to the complexity of managing ore variability at operations and then through to delivery. Downstream operations have had to adapt operations to try and suit the ore presented from the mining process. There has been no effective way to reduce variation in product quality across the value chain let alone optimise it. End-to-end visibility and traceability, and improved understanding of upstream information (material characteristics) will provide an opportunity to achieve this.

Integrated operating centres will provide the mechanism through which customer quality requirements can be aligned to resource characteristics to determine the optimal quality profile and manage operations to achieve it. Advanced geological modelling and simulation utilising upstream material characteristic information will provide the technical basis for decision making. By optimising quality according to current and forecast, customer demand price realisation can be improved. The improved consistency of overall product quality would also provide a significant marketing advantage.

Industry examples

BHP Automated Decision Making - Australia

BHP uses Artificial Intelligence (AI) to schedule track movements and the dispatch of trains carrying iron ore between their mines and Port Hedland, WA. AI has reduced cancellations due to blockages and has increased in the number of trains running. The major benefit of this system is that is has allowed BHP to better manage it's stockpiles to make sure that the right product is presented at their ports at the right time to make sure the customer receives the correct quality of product.

BHP has introduced a similar system at one of their mines to determine crusher allocation for trucks. This allows different crushers to manage ore quality into stockpiles to make sure orders can be fulfilled correctly[15].

[15] *Creating the future of mining – integration and automation*, BHP, 1st November 2017, URL: https://www.bhp.com/media-and-insights/reports-and-presentations/2017/10/creating-the-future-of-mining-integration-and-automation ; Accessed on 22ns November, 2018

6.2 Integrated quality management

Effectively managing assets and material flows to optimise quality management

Potential Value

Increase in asset productivity – improved understanding of orebodies and ROM will lead to improvements of asset productivity of 2% - 4%

Increase in throughput – a focus on end to end productivity will result in n increase in through put of 5% - 10%

Rehandling costs – understanding the quality of ROM material and effectively managing it will see likely reductions in rehandling of 3% - 5%

Increased margin – the increase in ore quality delivered through improved end to end integrated operations will result in an increase in margin of 2% - 5%

Workforce Implications

Workforce number

- The introduction of integrated quality management may result in workforce optimisation as a result of the improved process efficiency, however significant changes are unlikely

Workforce capability

- Highly skilled mining professionals will need to be developed to manage complex analysis required for end-to-end quality optimisation
- Technical modelling and advanced geological and geo-spatial capability will be critical to support operational decision making

Location of workforce

- Much of the quality optimisation and analysis will be conducted within an Integrated Operating Centre this can be on-site or remote
- Technical decision support and modelling can be housed within the Integrated Operating Centre, operate remotely or conducted by a third party

6.3 Asset management
Optimised asset productivity and reliability across the value chain

Current

- Sub-optimisation by mining process due to siloes
- Reliance on preventative maintenance practices or run to fail practices
- Disaggregated strategy and tactics development
- Lack of asset lifecycle management and optimisation (e.g. sub-optimal decision making on parts)

Future

- Asset lifecycle optimisation
- Coordinated approach to strategy and tactics supported by advanced analytics
- Risk based on-condition/predictive strategies
- Real understanding of value of reliability in value chain optimisation

Potential Value

- 3% - 5% reduced maintenance costs per operating hour
- 5% - 8% lower operating costs per tonne
- 5% - 10% increased OEE
- Overall productivity improvement 5% to 8%

Industry Implications

- Centralised asset strategy and planning to Integrated Operating Centre or Centre of Excellence facility
- Change management and upskilling required for changes in asset management strategy and planning
- Need for greater cross group facilitation between maintenance, supply, workshops etc. - business partner type roles

	Opportunity	Benefits	Enablers	Value
1	Improved asset reliability (schedule ready assets)	▸ Higher compliance with operations schedule ▸ Fewer assets required	▸ Predictive analytics to drive improved decision making around strategy and tactics ▸ Integrated condition monitoring technologies ▸ Self diagnostic equipment capability ▸ Digital twin	▸ Lower maintenance costs per tonne ▸ Lower operating cost per tonne
2	Integrated lifecycle management	▸ Maximise value from assets deployed ▸ Provide discipline and coordination with asset support functions	▸ Lifecycle optimisation tools (modelling and simulation) ▸ Dynamic schedule optimisation (advanced analytics) ▸ Asset management standards/MOS	▸ Lower lifecycle asset management costs
3	Improved asset productivity (effective utilisation)	▸ Increased overall system/value chain productivity ▸ Increased schedule compliance / execution	▸ Autonomous decision making ▸ Integrated Operations Centres ▸ Centre of Excellence	▸ Increased system OEE

6.3 Asset management
Optimised asset productivity and reliability across the value chain

Improved asset reliability (schedule ready assets)

Currently, there is a reliance on time based or run to fail maintenance strategies without ongoing effective condition based strategies. This can result in high levels of asset downtime and high maintenance costs due to unplanned breakdown or unnecessary maintenance. Technologies including integrated condition monitoring, predictive analytics, self diagnostic equipment capability and digital twins provide an opportunity to move towards predictive/proactive maintenance strategies which can result in improved asset reliability.

Integrated condition monitoring refers to the continual monitoring of asset health through sensors. These sensors provide live data on the condition of the asset and provide early warning of equipment failure and abnormal operating conditions. This can lead to improved reliability with fewer outages, giving utilities the insight needed to avoid potential equipment failure and forced outages.

Predictive analytics can transform raw data collected through condition monitoring into easy-to-understand and actionable insights including predicting when and in what areas maintenance needs to occur. It also provides visibility into assets that previously were hard to manage due to factors including size and distance. This technology can lead to improved availability, reliability and decision making.

Self diagnostic equipment capability enabled through machine learning involves automatic recognition of known and unknown patterns that improve through experience, providing the ability for assets to determine when they require maintenance.

Digital twin technology enables the visualisation of the live data collected on the asset enabling simulations to be run to determine the likelihood of failure in the asset. This technology with further assist in the ability to predict when maintenance activities are required on the asset.

All of these technologies have the ability to eliminate unexpected downtime, reduce operating costs, increase availability and asset performance.

Industry examples

Centre of Excellence - Americas

A global mining company established a centre of excellence to drive asset productivity through a focus on core asset availability and effective utilisation. An operating model was established to drive value chain improvements on reliability and efficiency, improve operational performance, set standards and share best practice, challenge capability and concentrate experts to leverage knowledge. The Centre of Excellence added value through improved critical asset availability and product quality leading to increased OEE and lower OPEX through consolidated asset standards and lower percent of breakdown maintenance.

Major Mining Organisation Automated Railcar Maintenance Centre – Australia

A global mining company developed an automated rail car maintenance centre. The centre was able to identify cars required for periodic inspection and maintenance, take the off the train while it continued it's journey, perform the required activities and then reconnect the car at the end of the same train as it continued up to the port. Not only did this provide minimal impact on productivity but also increased asset life. The centre is fully automated, requiring only 2FTE to run the facility.

6.3 Asset management
Optimised asset productivity and reliability across the value chain

Integrated lifecycle management

Across the mining industry there is a lack of asset lifecycle management and optimisation. This is particularly evident in sub-optimal decision making on spare parts in maintenance. A lack of communication exists between the parties involved in maintenance leading to poor scheduling and standards and creating excess procurement and storage of spares and parts. With budget restrictions, maintenance operators must decide which parts to procure and when. If the part is not available when required, waiting for the part can extend asset downtime from days to months. Leveraging the information provided on assets through condition monitoring and predictive analytics through a Management Operating System (MOS) to improve asset lifecycle performance will allow for spares and parts to be procured just in time reducing working capital.

MOS provides a mechanism to integrated the elements of an operation and ensure these elements are optimised as a whole, rather than as a silo. Utilising predictive analytics to gain an understanding of when and what part of an asset requires maintenance, MOS provides the ability to optimise inventory levels through alignment of parts to forecast work, resulting in reduced working capital and can enable the sourcing of preferential parts to ensure optimised asset reliability.

Improved asset productivity (effective utilisation)

Sub-optimal mining processes currently exist due to the siloed nature of operations in the mining industry. This creates disaggregated strategy and tactics development. Centres of Excellence in Asset Management provide an opportunity for companies to take and end-to-end view of the value chain to improve system/value chain productivity and scheduled compliance and execution.

An IOC supports a collaborative decision making environment across the end-to-end value chain. A holistic view provides the ability to optimise scheduling and execution management to ensure the reduction or elimination of asset idle time, resulting in increased asset utilisation. When this is done across the whole value chain, it can realise significant improvements in productivity.

Industry examples

MOS for Global Mining Company - Global

The implementation of a Management Operating System (MOS) helped to deliver a consistent and repeatable way of working that delivers a high quality outcome. The design and implementation of the system led to improving scheduled work from 20% to ~70%, 50% reduction in idle time on shovels, 23% efficiency improvement in total tonnes handled, SAG mill operating time in excess of 98% and a more engaged workforce with improved clarity of roles.

6.3 Asset management

Optimised asset productivity and reliability across the value chain

Potential Value

***Reduced maintenance costs* -** Improving reliability of assets across the value chain could result in a reduction of maintenance costs of between 3% - 5%

***Lower operating costs* -** reduced maintenance costs will could see a reduction in operating cost per tonne of 5% - 8%

***Increased OEE* –** improvements in asset availability and utilisation will result on an increase in OEE of between 5% - 10%

Workforce Implications

Workforce number

- Efforts to improve asset management may see a small reduction of maintenance workforce however it is unlikely to result in significant changes in numbers

Workforce capability

- The shift in approach to asset management will require a level upskilling and change management for maintenance planners
- There will increased requirement for business partner type roles to liaise and align various parties involved in asset lifecycle management

Location of workforce

- There will be a centralisation maintenance planning and strategy, with a shift to an Integrated Operating Centre or Centre of Excellence type facility
- Maintainers will remain on-site

Conclusions

Productivity improvement

If the digital technologies highlighted in each case study were implemented, by 2030 significant improvement in productivity could be realised. The productivity improvements would seen at each element of the value chain, with addition improvements achievable a through the implementation of end-to-end solutions.

Value Chain		Opportunity	Productivity Improvement*
Exploration	1.1	Data enabled exploration	6% - 10%
Mining Operations	2.1	Integrated drill and blast	5% - 10%
	2.2	Autonomous and continuous mining	8% - 25%
	2.3	Underground mine of the future	4% - 15%
Processing	3.1	Fully integrated mine / plant	8% - 20%
Transport	4.1	Integrated and optimised transport	3% - 15%
Trading	5.1	Customer integration	5% - 10%
End-to-End	6.1	End-to-end productivity optimisation	4% - 8%
	6.2	Integrated quality management	2% - 8%
	6.3	Asset management	5% - 8%

Total overall improvement in productivity*

9% - 23%

* The range in productivity improvement reflects an aspirational upper limit of potential improvement and a lower limit that reflects a sensitised improvement based on historical application of technology and systems within the industry.
The total overall productivity was derived from an end-to-end value chain perspective, not cumulative perspective.

Investment required

The investment required by industry to achieve the potential value across each element of the value chain by 2030 is significant. The type of investment required in the period to 2030 will shift from current point technology solutions to a more coordinated and systemic approach. Significant investment in the capability and structure of the workforce will be required support the technology investment.

Value Chain		Opportunity	Technology Investment*	People Investment*
Exploration	1.1	Data enabled exploration	$60m - $100m	$60m - $100m
Mining Operations	2.1	Integrated drill and blast	$450m - $1b	$45m - $100m
	2.2	Autonomous and continuous mining	$3b - $10b	$1.5b - $5b
	2.3	Underground mine of the future	$2.5b - $10b	$125m - $500m
Processing	3.1	Fully integrated Mine / Plant	$40m - $100m	$40m - $100m
Transport	4.1	Integrated and optimised transport	$1.5b - $10b	$75m - $500m
Trading	5.1	Customer integration	$500m - $1b	$250m - $500m
End-to-End	6.1	End-to-end productivity optimisation	$500m - $1b	$2.5b - $5b
	6.2	Integrated quality management	$250m - $1b	$125m - $500m
	6.3	Asset management	$600m - $1b	$300m - $500m

Total estimated investment in technology required*

$9.4b - $35.2b

Total estimated investment in people required*

$5.0b - $12.8b

* The range in potential investment reflects an upper value based on the potential investment required for the aspirational productivity improvement and a lower value that reflects the potential investment required for the sensitised productivity improvement based on historical application of technology and systems within the industry

2030+

Trying to forecast potential innovation or changes beyond 2030 is difficult given the complexity from the wider application of technology across industry as a whole and changing societal requirements

Potential technology

- Advancements will occur in continued integration of current and emerging technologies further optimising mining operations
- Robotics and machine learning have already proved their potential to enable step change. The challenge will be to manage the acceleration of adoption
- Continued development and refinement of autonomous vehicles will likely see fundamental changes in asset design and operations (e.g. autonomous shipping)
- Adoption of alternative energy sources could also see significant changes to the fundamental of mining operations

Disruption

- Disruption is likely to be the biggest change beyond 2030
- As industry as a whole becomes more connected the traditional industry and business landscape we know today will change
- Different capital and resource ownership models are likely to develop from the traditional buy-build-return model
- This could see different participants enter the industry both in ownership and operating roles. These new disruptive players are likely to come from Technology providers, Service Companies, Sovereign States and Trading Houses

Other considerations

New opportunities

Technological advances associated with digital mining have the potential to alter the boundaries of what is possible within the mining industry

New mines

- Autonomous operations could significantly alter the viability of potential mining projects
- Through improved technology, the development mines that were previously uneconomical or too hazardous for manned operations could become viable – particularly underground and potentially seabed

Existing mines

- Productivity and savings benefits associated with integrated and autonomous operations could shift the profitability points of many mines
- This could improve the financial stability and/or extend the life of current operations
- It could also enable the recommencement of operations at mines that were previously placed into care and maintenance due to financial or operational constraints

Potential barriers

Whilst new technology and associated operational changes present the possibility of significant benefits, there are a number of barriers that could limit all benefits from being realised

Adoption

- A conservative or ineffective approach to investment in technology will obviously have a severe impact on the ability to realise benefits available
- Take up will primarily be focussed on new / newer operations. ROI on more mature operations will be compromised by limited lifespan

Licence to operate

- Operational and workforce changes associated with new technology may not align with existing social and political obligations (licence to operate)
- Continued active management will be required to align with community and political requirements

Collaboration

- The resources required to develop and apply new technologies is increasing substantially and out of reach for many individual companies - as a result collaboration across the industry will be required if the potential benefits are to be fully realised

Risks

The adoption of new technology and new ways of working brings a level of inherent risk that needs to be managed. The risk landscape for participants in the mining industry will be very different to the landscape they face today. Investment cannot be limited to the technology and systems themselves, it must extend to their protection from these risks.

Cyber security

- As systems and assets become increasingly connected and systems become more automated the risk of malicious or accidental disruption will increase
- The management of cyber security will become as critical as the management of the asset themselves

Safety

- Whilst many technologies will provide significant benefits to workforce safety, any operational changes will present new risks that will need to be effectively managed - as they are today

Environment

- Technology will allow mining to push the frontiers into areas that were previously not achievable, this will bring with it continued and new environmental risks as new resources are developed

Governance

- Technology such as automation and AI will significantly reshape they way mining operations are conducted, governance structures and processes will need to be realigned to these changes to ensure legal and social responsibilities are maintained

Appendicies

Rational for value benefits

Opportunity	Value Driver	Rational	Source information
1.1 Data enabled exploration	Reduced drilling costs of 10% - 15%	Drilling technologies lead to an overall 17 – 31% reduction in net cost per tonne. Industry wide this could represent a 10% - 15% reduction in drilling costs	http://www.baeconomics.com.au/wp-content/uploads/2010/01/Mining-innovation-5Feb12.pdf
	Improved productivity – 5% - 10%	Rio Tinto have seen a 10% improvement in productivity from their autonomous drills therefore industry wide an improvement of 5% - 10% can be realised.	http://www.austmine.com.au/Events/category/press-releases/bhp-buys-atlas-copco-robot-drills
2.1 Integrated drill and blast	Reduced drilling costs of 10% - 15%	Drilling technologies lead to an overall 17 – 31% reduction in net cost per tonne. Industry wide this could represent a 10% - 15% reduction in drilling costs	http://www.baeconomics.com.au/wp-content/uploads/2010/01/Mining-innovation-5Feb12.pdf
	Less explosives – 10% - 20% reduction	Orica Mining Services Electronic Blasting System resulted in a reduction in blasting cost of 21%. Therefore, industry wide a reduction of 10% - 20% could be seen.	https://www.oricaminingservices.com/uploads/Collateral/Metal/Shovel%20Loader%20Productivity/Fragmentation%20Improvement/CS/100016_Case%20Study_Reducing%20the%20Cost%20of%20Drill%20Blast%20Optimisation_Northparkes%20Open%20Cut%20Mine.pdf
	Reduced dilution – 10% - 15%	Anaconda Mining's Pine Cove gold mine reduced dilution from 20% to less than 5% and generated a 15% increase in recovered tonnes. Industry wide there is potential to reduce dilution by 10% to 15%.	https://blastmovement.com/open-pit-mine-reducing-dilution-ore-loss/
	Improved grade up to 7%	Cowal gold mine increased mill feed grade by 7% through blast movement monitoring. Industry wide there is potential to increase grade due to blasting by up to 7%	https://blastmovement.com/open-pit-mine-reducing-dilution-ore-loss/
	Improved productivity – 5% - 10%	Rio Tinto have seen a 10% improvement in productivity from their autonomous drills therefore industry wide an improvement of 5% - 10% can be realised.	http://www.austmine.com.au/Events/category/press-releases/bhp-buys-atlas-copco-robot-drills
2.2 Autonomous and continuous mining solutions	Reduced fleet size – 10% - 20% reduction	A global mining company implemented autonomous trucks and saw the potential to reduce their fleet by approximately 19%, therefore, industry wide a reduction in fleet size of 10 – 20% could be seen.	
	Improved productivity – 15% - 20% increase	Komatsu, Caterpillar and Hitachi have noted benefits in the role out of autonomous haulage systems up to 30% in some operations. Industry wide there is potential for a 15% - 20% productivity improvement.	https://www.idtechex.com/research/reports/electric-vehicles-and-autonomous-vehicles-in-mining-2018-2028-000597.asp
	Increased operating hours – 7% to 15%	The autonomous truck fleet had seen a 14 percent increase in operating hours. Industry wide this can result in a 7% to 15% increase in operating hours	http://australianminingreview.com.au/new-technology-provides-productivity-edge/

Rational for value benefits

Opportunity	Value Driver	Rational	Source information
2.3 Underground mine of the future	Reduced ventilation cost by up to 50%	Reduce ventilation costs by up to 75% due to electrification of fleet. Industry wide a cist reduction of up to 50% could be seen.	http://www.austmine.com.au/News/category/articles-editorials/innovating-the-electrification-of-mines
	Reduced headcount – 40 - 60% reduction	Automation is estimated to replace 40-80% of workers at a mine. Industry wide a reduction of 40% - 60% could be seen.	https://www.computerworld.com/article/3136675/it-careers/robotics-driverless-tech-are-taking-over-mining-jobs.html
	Reduced unplanned downtime – 15% - 35% reduction	Operators using predictive maintenance approach have experience 30-35% less unplanned downtime. Industry wide a reduction in downtime of 15% - 35% can be seen.	https://www.Intinfotech.com/blogs/predictive-analytics-to-reduce-unplanned-downtime/
	Reduced dilution – 10% - 15%	Anaconda Mining's Pine Cove gold mine reduced dilution from 20% to less than 5% and generated a 15% increase in recovered tonnes. Industry wide there is potential to reduce dilution by 10% to 15%.	https://blastmovement.com/open-pit-mine-reducing-dilution-ore-loss/
3.1 Fully integrated mine to plant	Improved productivity 7% to 15%	Digital twin technology has seen approximately 15% improvement in productivity. Across the mining industry this technology could see an improvement of 7% to 15%	https://about.bnef.com/blog/anglo-using-digital-twins-robotics-boost-mining-qa/
	Reduced unplanned downtime – 15% - 35% reduction	Operators using predictive maintenance approach have experience 30-35% less unplanned downtime. Industry wide a reduction in downtime of 15% - 35% can be seen.	https://www.Intinfotech.com/blogs/predictive-analytics-to-reduce-unplanned-downtime/
	Processing cost reduction 10% - 15%	Through effective sorting of ore, energy can be saved which can produce up to 20% reduction in processing costs. Industry wide a 10% to 15% reduction could be seen	https://www.australianmining.com.au/news/csiro-scanner-significantly-reduce-copper-waste/
	Increased throughput 10% - 15%	Global mining company saw a 10% - 15% increase in throughput from asset utilisation optimisation and plant set point management.	
4.1 Integrated and optimised transport	Increased operating time by up to 20%	AutoHaul has shown in trials that the autonomous trains delivered the product to the port nearly 20% faster than a manned train. Industry wide the adoption of autonomous trains could result in increased operating time by 20%	https://www.smartrailworld.com/mind-blowing-rio-tinto-autonomous-train-safety-approval
	Reduced rehandle – 7% - 15%	Improved muck pile profile reduced rehandle from 45-30%. Industry wide, rehandle can be reduced by 7% - 15%	www.esenmining.com/static/media/uploads/mining-case-studies/paper7.pdf
	Reduced workforce 10% - 20%	Reduction in rail workforce by 20%. Industry wide, automation of trains could result in a reduction in rail workforce by 10% - 20%	https://www.afr.com/business/rio-rolls-out-worlds-biggest-robot-in-rail-freight-gamechanger-20180713-h12n64
	Reduced unplanned downtime – 15% - 35% reduction	Operators using predictive maintenance approach have experience 30-35% less unplanned downtime. Industry wide a reduction in downtime of 15% - 35% can be seen.	https://www.Intinfotech.com/blogs/predictive-analytics-to-reduce-unplanned-downtime/

Rational for value benefits

Opportunity	Value Driver	Rational	Source information
5.1 Customer integration	Reduced costs due to automated paperwork of 5% - 10%	The cost of associated paperwork comes to 15%–20% of total costs. These costs can be reduced to zero by distributed ledger technology.	https://medium.com/@credits/how-blockchain-could-help-logistics-c3b2ab60be55
	Reduced rehandle – 7% - 15%	Improved muck pile profile reduced rehandle from 45-30%. Industry wide, rehandle can be reduced by 7% - 15%	www.esenmining.com/static/media/uploads/mining-case-studies/paper7.pdf
	Increased margin	Evidence in traded Iron ore of up to 5% price premium demanded for niche / targeted products on-demand.	
6.1 – 6.3 End-to-end productivity, integrated quality management and asset management		Data for the end-to-end case studies is representative of benefits realised from clients who have implemented Integrated operations.	

Glossary

Term	Definition
Artificial Intelligence (AI):	Technologies that are centred around systems that undertake tasks that would typically require human intelligence or input and ranges from Chatbots to software to predict next best actions. Machine learning and advanced analytics specifically refers to algorithms to enable or make decisions, learn through iterations of applying the algorithms and adapt without being explicitly programmed.
Assay	The analysis of ore to determine the presence, absence, or quantity of one or more components
Blockchain	Technology that enablers transaction/digital interactions to be recorded in a secure, transparent and efficient way
Centre of Excellence	A group of skilled workers who aim to supply their organisation with the best methodologies for a particular activity
Cloud computing	The use of virtual servers where users can access data through internet connection
Data analytics	Set of techniques and tools for the acquisition and transformation of raw data into meaningful and useful information and knowledge for construction analysis purposes. Real-time data analytics can provide historical, current, and predictive views
Data visualisation	Provides easy digestible, meaningful dashboards to support people in understanding big data and improve decision making
Digital twin	Refers to a digital replica of a physical asset, process, people, system or device that uses live data to run simulations to test different scenarios
Geological modelling	Creating computerised representations of portions of the Earth's crust
Hyper-spectral core imaging	An analytical tool that uses infrared light to produce a visual map of the minerals in a core

Term	Definition
Integrated Operating Centre	A facility that combines people's skills, operations, processes, and technology to deliver exceptional levels of collaboration and operations excellence. Planning, scheduling, execution, monitoring and analysis functions can be collocated
Internet of Things (IoT)	A future-facing development of the internet wherein objects and systems are embedded with sensors and computing power, with the intention of being able to communicate with each other
Predictive analytics	A type of advanced analytics that includes statistical analysis and algorithms to make predictions about the future and forecast expectations about the future effects of decisions
Remote Operations Centre	Provide constant, real-time monitoring of many locations through one central hub located away from the mine site
Robot Process Automation (RPA):	Software robotics used as a business-managed tool where software emulates humans, to do repetitive manual tasks across any time of system without undergoing complex system update/upgrade
Smart contracts	Self-executing contracts with the terms of the agreement between buyer and seller being directly written into lines of code which therein exist in a blockchain network
Virtual reality	An artificial, computer-generated simulation or creation of a real-life environment or situation

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