



# Agile crocodile

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*The modern metals & mining sector and its future*

January, 2019

**Arthur D Little**

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# Preface and introduction

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Modern crocodiles are unique creatures. They are the current reflection of the ancient eras, the least changed from their prehistoric relatives that lived 250 million years ago.

However, they have not been static since they first appeared on the evolutionary scene. Despite looking almost the same as they did millions of years ago, the species we see around us today is completely different in essence to those that once existed; they are specialized creatures in their own right, rather having had stagnant development since ancient times. And given how much they've changed since their origin, we can't even imagine what might happen in the future.

The mining industry, like the crocodile, is one of the oldest types of human activity, dating back to ancient times. Since civilization began, people have used mining techniques to access minerals in the earth. Long ago the sector was underdeveloped, complex and dangerous. Now we see a completely different animal, dramatically improving year on year. Modern mining might conceptually look the same as the version 1,000 years ago, but its essence is completely different.

It is still believed that the metals & mining sector is quite slow when we talk about quick adoption of new technologies.

However, we can clearly see that over the past decade the major mining companies have started to adopt high-tech digital inventions. They are running pilots in different areas, and assessing and feeling the real impact of the fourth industrial revolution on their supply chains, operations, safety and overall process efficiency.

# 1. Four industrial revolutions and their impact on the metals & mining sector

The world has witnessed three industrial revolutions in the past 200 years, and is on the brink of the fourth one, mainly driven by digitalization.

Each revolution has been enabled by technological advancements and led to fundamental changes in the ways industries functioned. The first revolution was heralded by the invention of the steam engine in the 18th century, which enabled massive industrial production and rapid mechanization in manufacturing. The second revolution was caused by electrification, which brought about the use of machines powered by electricity and led to mass production based on division of labor. The third revolution, enabled by software and electronics, led to full automation of industrial processes.

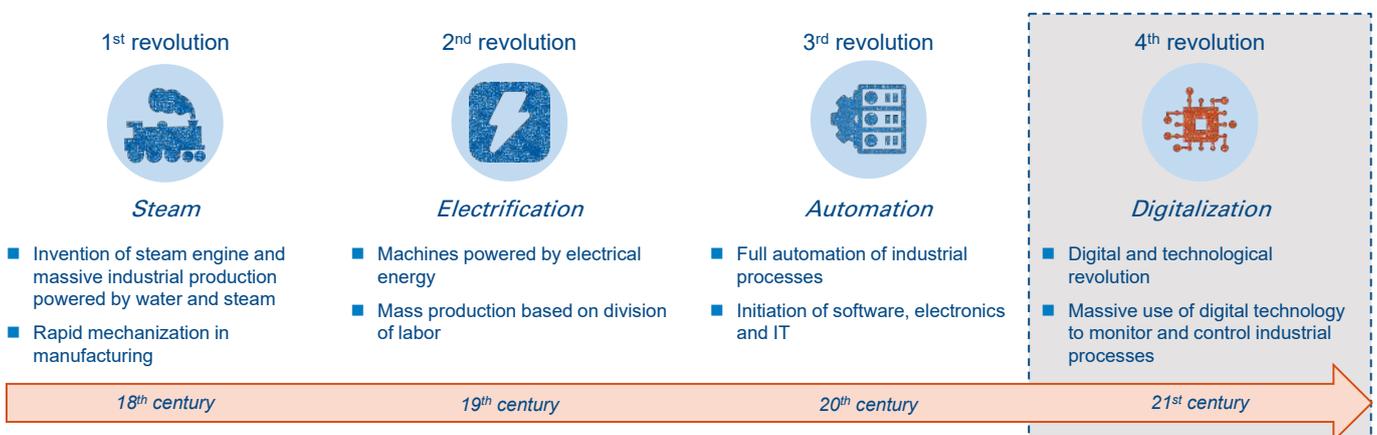
Now, in the 21st century, we stand at the forefront of the next industrial revolution, which will be powered by digitalization. Digital technology will be used on a massive scale to monitor and control industrial processes. Autonomous and connected systems will be able to work independently, powered by large volumes of information and analytics. Humans and these systems are envisioned to work seamlessly together.

The industrial revolutions have transformed the metals & mining industry, which is also moving to a 4.0 state driven by digitalization.

The metals & mining industry has been significantly transformed by the industrial revolutions of the past. Mining 1.0, the first transformation, was enabled by the advent of mechanical production through hydraulic drills and steam-powered engines. Mining 2.0 and Mining 3.0 leveraged the key inventions of the corresponding industrial revolutions – mass production and automation, respectively.

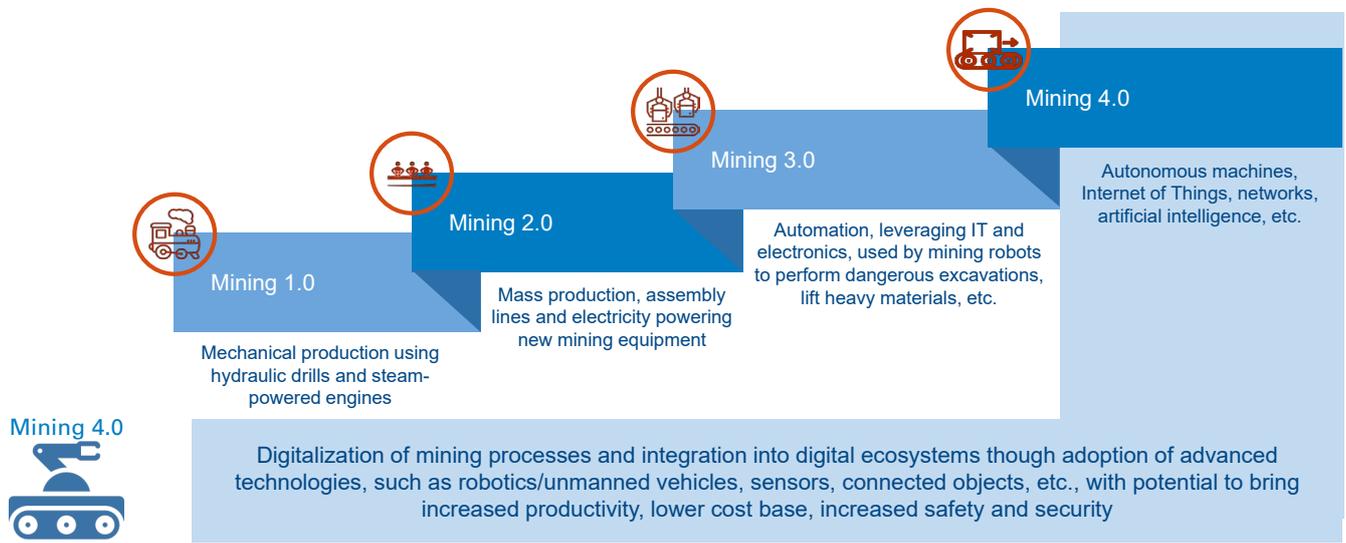
We expect the mining industry to undergo another transformation soon – Mining 4.0 – enabled by the fourth industrial revolution. Mining 4.0 will be about using the power of digitalization to transform the value chain. This will be driven by the digitalization of mining processes and integration of the industry in digital ecosystems, through adoption of advanced technologies that have the potential to bring increased productivity, lower cost bases, and increased safety and security.

Figure 1: The four industrial revolutions



Source: WEF, Arthur D. Little analysis

Figure 2: The mining sector is moving to digitalization



Source: Arthur D. Little

## 2. Modern digital technologies and how quickly the sector can digest them

Digital technologies transforming the mining industry are in different stages of development, with some having immediate impact.

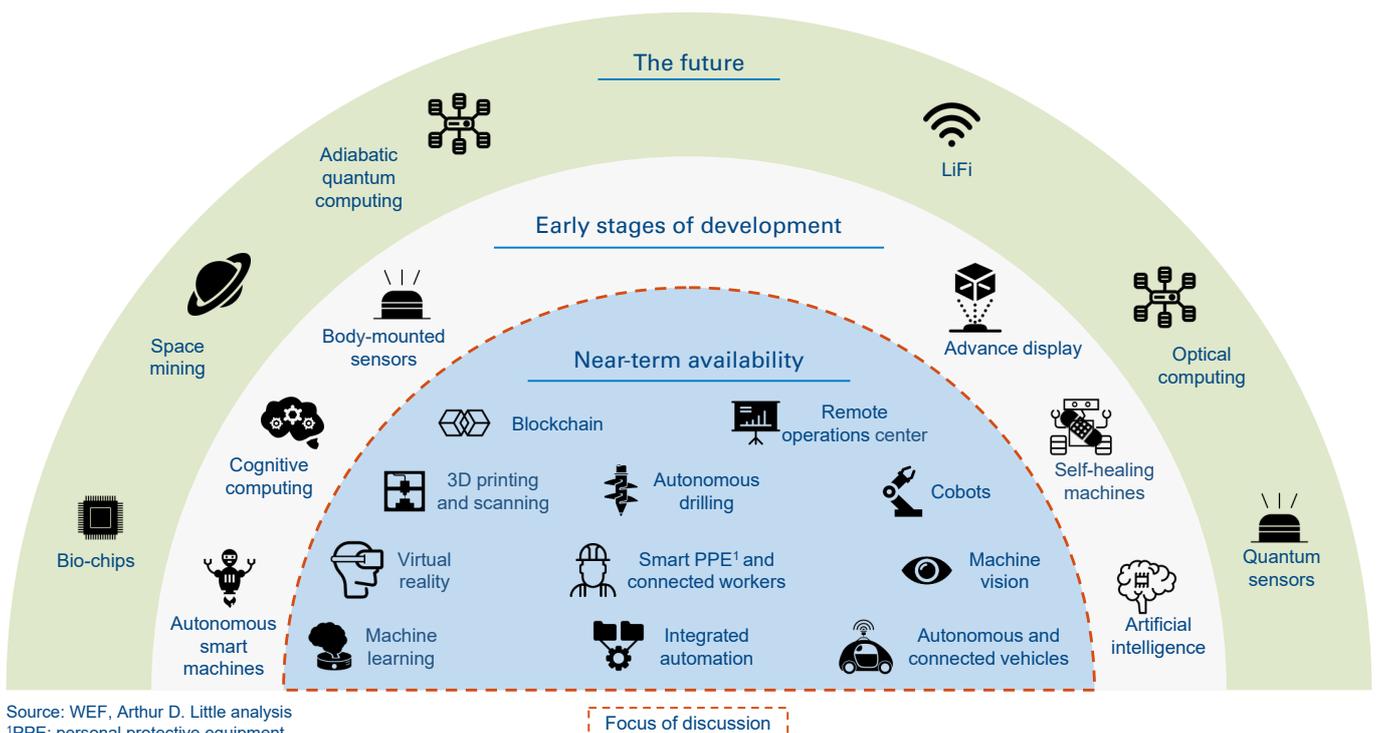
We have attempted to highlight the key technologies across three phases (see Figure 3):

- The first wave refers to technologies with near-term availability, i.e., technologies that are being deployed by selected players or use cases that are being tested. These technologies are the current hot topics, the most promising ones over the next two to three years.
- The second wave refers to technologies that are in the early stages of development. They hold potential but are expected to take a few years to reach the market as large-scale, viable solutions.

- The third wave corresponds to technologies that could redefine the future and exist at a conceptual level.

The focus of this viewpoint is on near-term technologies, as they hold immediate potential for generating value for the mining industry. Some of the technologies in this wave – AV/VR and autonomous vehicles – have started seeing industry implementation on a small scale. The near-term technologies will form a foundation for more advanced transformation, and in the future, we can expect to see space mining, bio chips and optical computing impacting the metals & mining industry.

Figure 3: Stages of the key digital technologies in relation to the metals & mining sector



Source: WEF, Arthur D. Little analysis  
<sup>1</sup>PPE: personal protective equipment

### 3. The current hot topics, most promising over the next two to three years

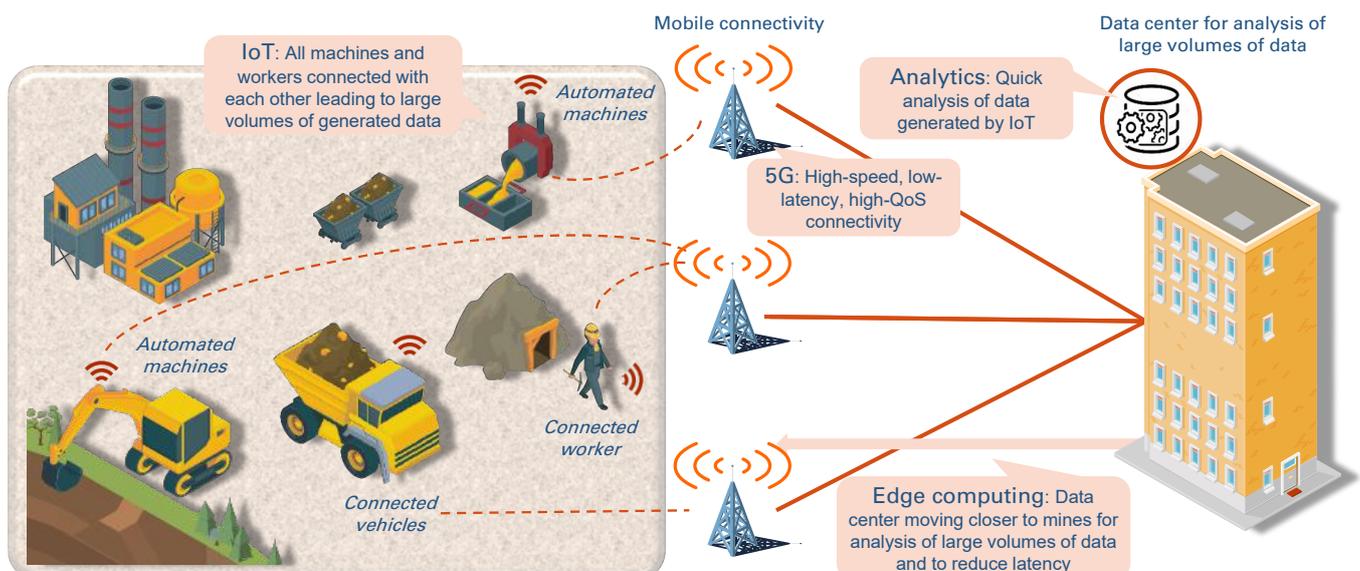
A digital mine is when everything is connected and most of the processes are autonomous. Connected workers facilitate real-time tracking and monitoring of their health essentials, which improves worker safety and performance. Most of the machines are autonomous – either working by themselves or controlled by a remote operations center (ROC).

The various types of equipment used also communicate with each other and with the ROC. The workers, machines and vehicles use mobile connectivity to send data to the analysis center, where complex calculations and sophisticated software facilitate real-time decision-making backed by data. The Internet of Things (IoT) is enabling connection of all workers and equipment to each other, which is resulting in efficient mining and safer working environments.

The fundamental technologies currently underpinning the digital mine are the IoT, analytics, edge computing and 5G.

- **The IoT:** Every device and worker is connected. The IoT provides the platform for connecting multiple sensors that generate large volumes of data.
- **Analytics:** Data generated by IoT devices is analyzed to derive meaningful insight, and this is performed in real time in some cases. For example, analytics coupled with AI helps enable autonomous vehicles and machines.
- **Edge computing:** Analytics need to be performed closer to the location where the data is generated. This ensures real-time analysis and insight generation. Therefore, data centers are moving closer to mines for faster data processing.
- **5G:** Large-scale data communication will require high-quality and reliable connectivity, which will be supported by 5G technology.

Figure 4: Near-term opportunities for the metals & mining sector enabled by the IoT



Source: Arthur D. Little analysis

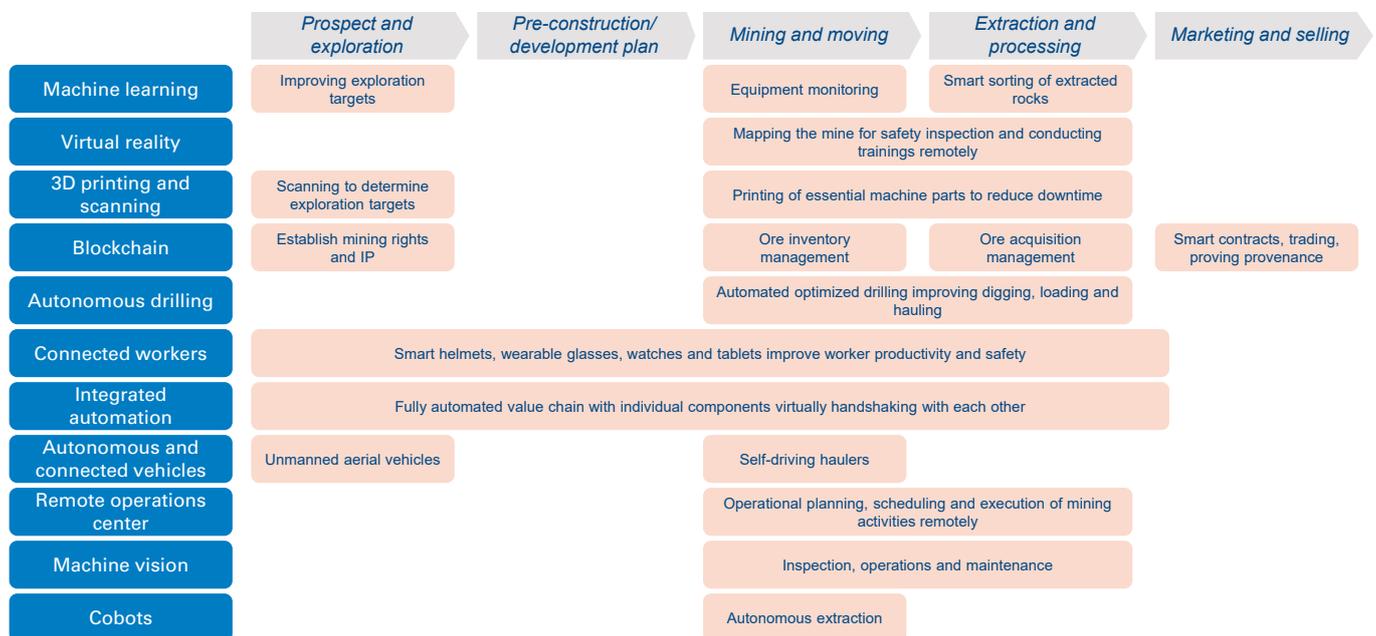
# 4. Current use of digital technologies across the metals & mining value chain

Certain digital technologies have already found their applications across the value chain, from exploring for potential minerals to selling the processed metals in the market. Some of these technologies, such as blockchain and machine learning, have multiple use cases.

Machine learning can be used for smart sorting and extraction, thereby improving ore recovery rates. Additionally, the technology could ensure selection of sites with higher success rates for exploration, with the support of artificial intelligence and analytics.

Blockchain can find potential usage in selling metals via smart contracts and improving the sales of metal/minerals, for which the seller could prove its provenance to provide assurance around the final product. The technology can also be used to reduce the cost of international payments and managing inventory at different locations.

Figure 5: Examples of digital technologies across the metals & mining value chain



Source: Arthur D. Little analysis

## 5. Where is the money, and what are the financial gains?

Digitalization is expected to result in substantial financial gains, as significant value will be created through revenue enhancement, cost reduction and efficient use of capital.

Revenue can be enhanced through higher sales volumes and commanding a price premium. Blockchain technology has the potential to reduce trading barriers, thereby increasing trade volumes. High-quality metals and minerals extracted through machine learning, cobots (collaborative robots), etc., can command premium prices in the market.

Companies can realize significant savings across various components such as processing, labor, transportation and energy costs. For example, lower equipment downtime due to automation supported by 3D printing will help significantly drop relevant expenses. Major improvements in labor productivity can be achieved by conducting advanced safety inspections and training workers remotely, enabled by virtual reality and connected-worker solutions.

Reduced working capital requirements free up more funds for the company and ensure higher liquidity. Managing inventory of spare parts efficiently by using 3D printing lowers current assets, bringing working capital down. Spare-part requirements could be further reduced by using machine learning and machine vision, which could predict when an asset or any of its components needs to be replaced. In addition, capex could be saved in the long term through improved investment decisions, by adopting advanced exploration technologies to identify the most suitable target sites for mining activities.

Figure 6: Areas of specific impact on mine performance from the new technologies

	Area of impact	Application	Technology
Revenue	Higher volume	Trading potential enhancement of metals and mining resources through smart contracts	Blockchain
	Higher price and vol.	Higher sales through clear supply chain mapping and proving provenance	Blockchain
	Higher price	Using improved sorting and extraction techniques to obtain high-quality final products	Machine learning, cobots
	Higher price and vol.	Enhanced availability of supply-constrained metals via efficient extraction	Multiple technologies
Opex	Lower SG&A	Reduced international transaction costs	Blockchain
	Lower production costs	Low downtime of equipment due to automation, supported by 3D printing	Multiple technologies
	Lower production costs	High recovery rates	Machine learning, machine vision, cobots
	Lower transportation costs	Optimized fleet usage	Autonomous/connected vehicles
	Higher labor productivity	Improved safety inspections and trainings for laborers	Virtual reality, connected workers
	Higher labor productivity	Improved utilization of labor resources for operations and maintenance	Remote operations center
	Lower labor costs	Reduced labor requirement through fully automated value chain with virtual handshaking	Integrated automation
	Lower procurement costs	Supply-chain fool-proofing for raw materials and equipment	Blockchain
Working capital	Higher current liabilities	Automated ore management at ports and inventory management at warehouses	Blockchain
	Lower current assets	Improved spare-parts inventory management	3D printing
Capex	Lower investment	Improved exploration targets leading to effective capex deployment	Machine learning, 3D scanning, autonomous vehicles
	Lower equipment cost	Optimized asset replacement and reduced asset failure	Machine learning, machine vision

Source: Arthur D. Little

# 6. Case studies: What has been achieved so far

We have compiled a set of recent case studies illustrating the current advances and technology usage in the sector.

It can already seem that the new technologies are used successfully at all the stages of mine development: from prospecting and exploration to sales & marketing.

- **Prospecting and exploration:** Severalmaz is piloting drones for aerial survey of diamond mines in Lomonosov, Russia.

*Prospect and exploration*

*Pre-construction/development plan*

*Mining and moving*

*Extraction and processing*

*Marketing and selling*

- Severalmaz, a subsidiary of Russian state-owned diamond mining firm Alrosa, is testing unmanned aerial vehicles for surveying mines
  - The company carried out the survey at the Lomonosov mine in Russia, employing a Geoscan 401 Geodesy quadcopter and Geoscan 101 Geodesy aircraft
  - Preliminary estimates of the results show that use of drones for site exploration is very promising



**Benefits**

- ↑ Increased survey accuracy: The survey measurement error was within acceptable limits
- ↑ Improved safety: Worker safety increases considerably as on-ground human involvement decreases

- **Pre-construction and development:** Rio Tinto is using 3D mapping technology to improve mineral recovery at its mines.

*Prospect and exploration*

*Pre-construction/development plan*

*Mining and moving*

*Extraction and processing*

*Marketing and selling*

- Rio Tinto is using 3D mapping technology through RTV's software to identify the size, location and quality of the ore in real time, which results in greater certainty of the nature of the deposits at early stages of the mine development phase
  - Rio retrieves data from automated trucks and drills operating on mines
  - In 2014, it enabled Rio Tinto to increase iron ore mining at its Pilbara operations by 250,000 tons; trials are also taking place in other Rio product groups, including copper, diamond and minerals



**Benefits**

- ↓ Cost reduction: As focus is more on high-value ore, waste and operation costs reduce
- ↑ Productivity gain: More metal extracted due to more accurate drill blasting and sharper boundary identification

■ **Mining and material moving:** BHP is using autonomous drills at its mining sites that are controlled by a remote operations center.



- Machine learning
- Virtual reality
- 3D printing and scanning
- Blockchain
- Autonomous drilling**
- Connected workers
- Integrated automation
- Autonomous and connected vehicles
- Remote operations center
- Machine vision
- Cobots

- BHP Billiton’s blast hole drills are being converted to autonomous operation
  - BHP is already using autonomous drills in certain locations. These drills are controlled from a remote operations center 1,300 km away in Perth
  - BHP has reported 20% improvement in the optimization of its current drills
  - The industry has successfully tested new autonomous drills that can be run from a remote distance of 8,100 km
  - BHP believes autonomous drilling has enormous potential and a lot of value to be gained



**Benefits**

- ↑ Higher accuracy: Rocks can be cut with precision
- ↑ Safety gain: On-site accidents can be averted once drilling is controlled entirely from a far-away operating center

■ **Mining and materials moving:** Rio Tinto is testing the world’s first fully autonomous heavy-haul, long-distance railway system.



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- Rio Tinto is experimenting with autonomous, unmanned freight trains to move materials from its mines in Australia
- In 2017, the company completed its first test of a fully unmanned rail journey in Pilbara, Australia, covering 100km
- Rio Tinto is pushing ahead with its AutoHaul program to be completed in 2018; once completed, it will be the first fully autonomous heavy haul system
  - ~ 50% of Rio’s pooled fleet rail kilometers are completed in autonomous mode. However, they still have drivers on board
  - 90% of pooled fleet production tons were AutoHaul enhanced



**Benefits**

- ↓ Cost reduction: Additional capacity is provided without investment in more trains
- ↑ Safety gain: Accidents due to driver fatigue on long journeys are circumvented

■ **Extraction and processing:** Smart sorting via sensors improves the quality and grade of the extracted copper ore at BHP Billiton's mines.

- Machine learning
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Prospect and exploration

Pre-construction/development plan

Mining and moving

**Extraction and processing**

Marketing and selling

- As part of its precision mining project, BHP Billiton is using smart sorting via sensors to measure the magnetic properties of copper, maximizing output and reducing costs for processing
  - BHP has attached sensors to bulk mining equipment in its Escondida mine in Chile, through which it is able to analyze the copper grade
  - The technology allows for improved quality of raw materials delivered to plants and, hence, reduced energy and water usage to process these



**Benefits**

- ↑ **Productivity increase:** Use of sensors improves quality and grade of ore extracted
- ↓ **Cost reduction:** Reduced energy and water usage

■ **Marketing and sales:** Blockchain helps mining companies execute buying and selling transactions faster and ensure ethical working standards across the value chain.

- Machine learning
- Virtual reality
- 3D printing and scanning
- Blockchain**
- Autonomous drilling
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- Machine vision
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Prospect and exploration

Pre-construction/development plan

Mining and moving

Extraction and processing

**Marketing and selling**

- Blockchain is in early stages of development and industry acceptability. However, the metals and mining industry provides multiple potential applications for the technology
  - Smart contracts and ledgers: Sellers upload their metal specifications and buyers upload their buying requirements on blockchain. A match between the two results in a virtual contract being formed
  - Proving prominence: Verifying the mining source of a diamond to ensure for ethical mining and extraction



**Benefits**

- ↑ **Authenticity increase:** The buyer is sure of the metal's source and its authenticity
- ↑ **Revenue increment:** Metal sellers can demand a premium on metals for which mining of metals involved safe and ethical working conditions

# 7. What does this all mean for organizations?

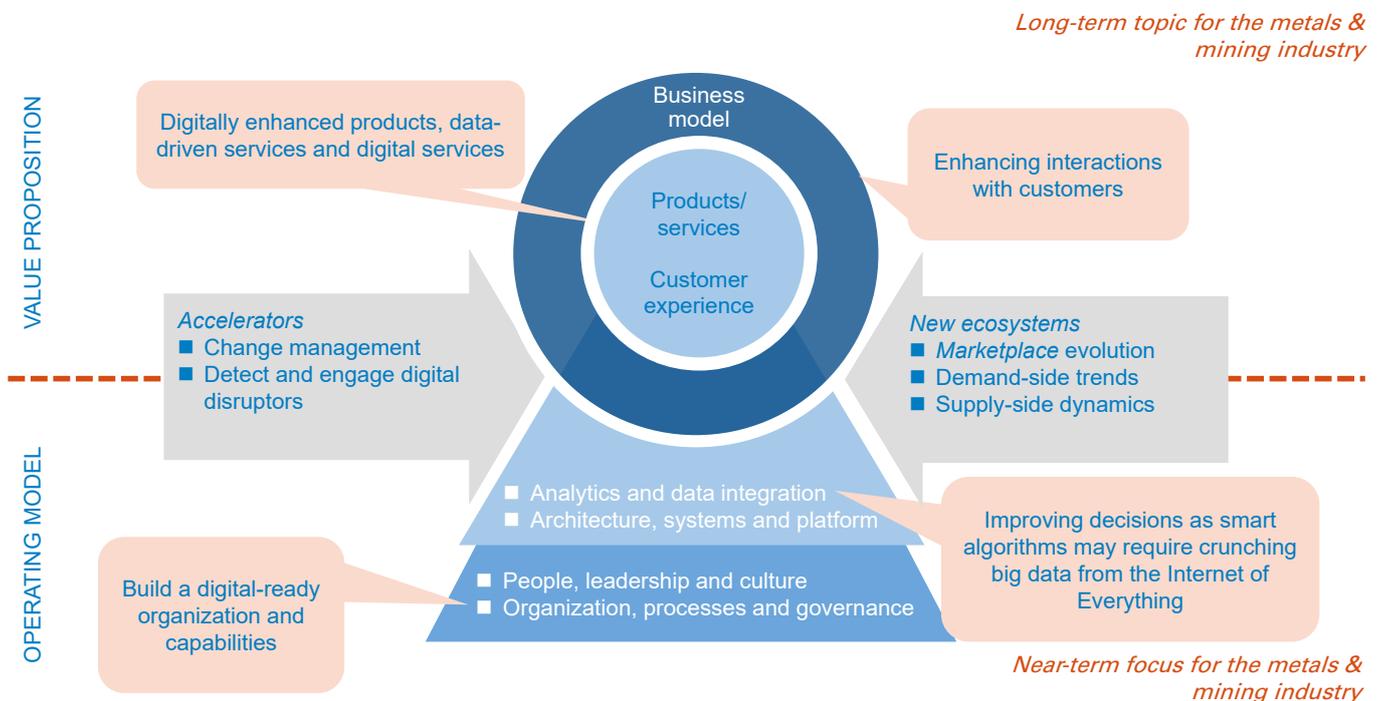
Succeeding in digitalization requires mining companies to rethink their operating models.

Along with adopting the latest technologies, a successful digital transformation requires changes in the operating model of the organization. As with any large endeavor, the people and the culture form the backbone of a digital transformation, and the organization should acquire the right capabilities to succeed. Processes should be adapted to enable data-driven decision-making. The whole transformation may require revamping of the core systems and platforms.

Transforming the business model is part of the long-term topic for the metals & mining industry. This refers to digitally enhanced products and offering digital services. It requires demand to emanate from the ecosystem level (across customers, suppliers, etc.), and would be more difficult to drive for small players.

Digitally enabled organizations are the ones that will succeed and dominate in the future.

Figure 7: Adjustments needed for operating models to succeed in the digital era



Source: Arthur D. Little analysis

# 8. Moving from “digital aware” to “digital native”

The organization should transform from digitally aware to digital native.

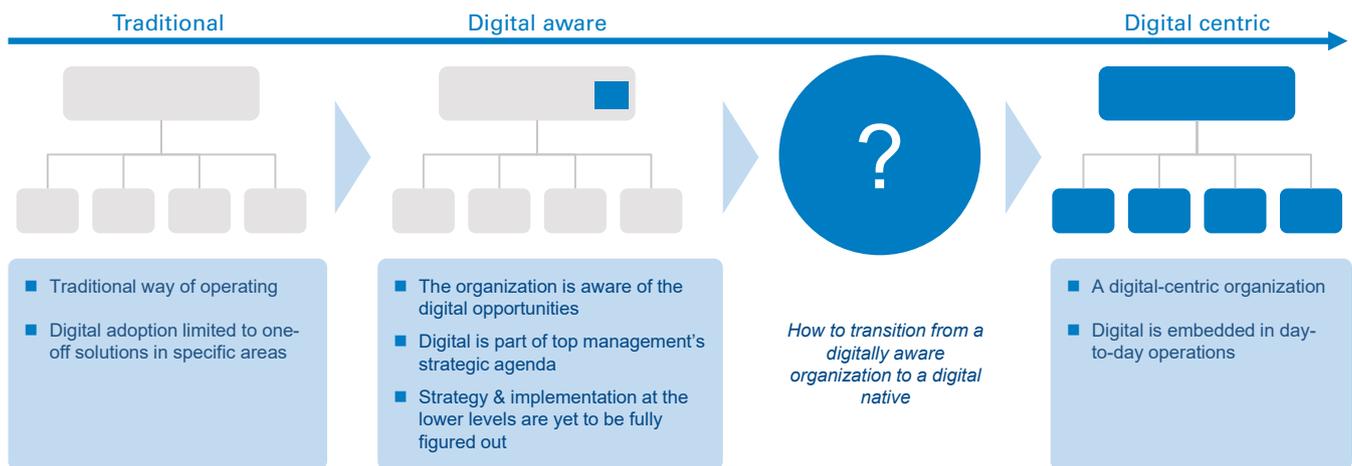
Introducing digitalization from an organization structure perspective will be an evolving process. Metals & mining companies will move from traditional organizations to digitally centric organizations of the future.

- **Traditional organization:** This represents the “as-is” structure of the organization. There is no dedicated department for digitalization, and digital adoption is limited to one-off solutions in specific areas.
- **Digital-aware organization:** The organization is aware of the digital opportunities and digitalization forms an agenda for top management. However, digitalization is more top-down in the absence of a coordinated strategy. Implementation of digitalization at lower levels of the organization is limited.

- **Digital-centric/digital-native organization:** In a digital-centric organization, every level is focused on digitalization and digital is embedded in day-to-day operations. This is the final state for any organization that aims to undertake the digitalization journey.

The key question is how an organization can move from a “digital-aware” to a “digital-native” state.

Figure 8: Moving from a traditional to a digital-centric organization



Source: Arthur D. Little digital competence center

■ Digital presence

# 9. How to enable successful transformation?

Successful transformation of the metals & mining sector should be enabled by the adoption of suitable organizational options.

Typically, organizations follow one of three structural options for digitalization:

### Centralized model

In this model, a separate central digital department is created within the organization to drive digitalization initiatives. This model is applicable when the organization is new to digitalization or embarking on a full-fledged digitalization program. This option is suitable when central steering and transformation support are needed. As there is a separate digital unit to drive the digitalization agenda, there is very clear accountability. However, there is also high resistance to change as everybody thinks they know better than the rest.

### Integrated model

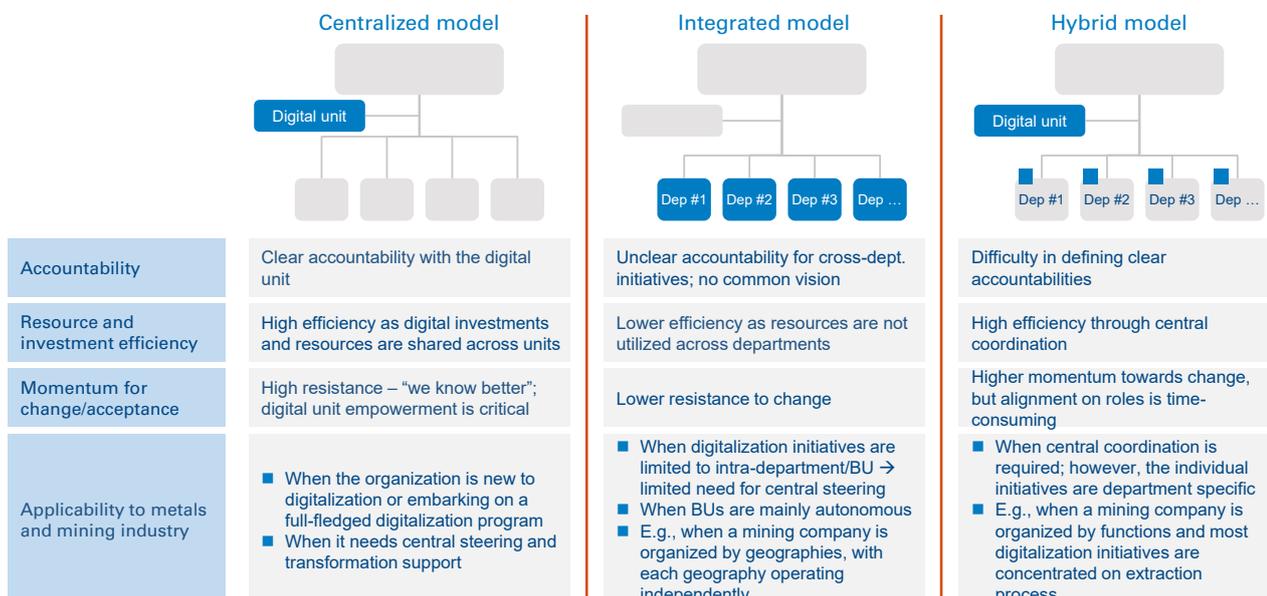
In this model, each individual unit is made responsible for its own digitalization initiatives. This model is applicable when digitalization initiatives are limited to intra-department or business units and therefore have limited need for central

steering. It also works when the departments/functions are autonomous. For example, when a mining company is organized by relatively independent geographies, each geography can drive its own digital agenda. As there is no central digital unit, there is unclear accountability on cross-functional (or cross-department) projects. However, there is also lower resistance to change and new, function-specific digital initiatives find higher acceptance.

### Hybrid model

This is a combined version of centralized and integrated models. There is a central digital unit and each department has a digital office. This model is applicable when central coordination is required, while the individual initiatives are department specific. For example, when a mining company is organized by functions and most digitalization initiatives are concentrated on one step of the value chain (such as the extraction process), the individual unit can implement the digital initiative while the central unit performs strategic steering. A downside of this model is difficulty in defining clear accountabilities across the central and individual units. This model could have higher momentum towards change, provided that the central unit and departments are aligned on their roles in the digitalization process.

Figure 9: Organizational options available



Source: Arthur D. Little digital competence center

# 10. Key suggestions for navigating successful digitalization

Arthur D. Little suggests a phased approach combining technological and softer aspects for the mining companies looking to adopt digitalization.

## As-is assessment

Assess the maturity of the metals & mining organization with respect to digital capabilities and analyze existing operations to identify enhancement areas.

## Opportunity identification

Identify digitalization opportunities, evaluate and prioritize them based on the organization's digital vision, detail the opportunities for adoption, and identify requirements across organization, capability, and technology dimensions.

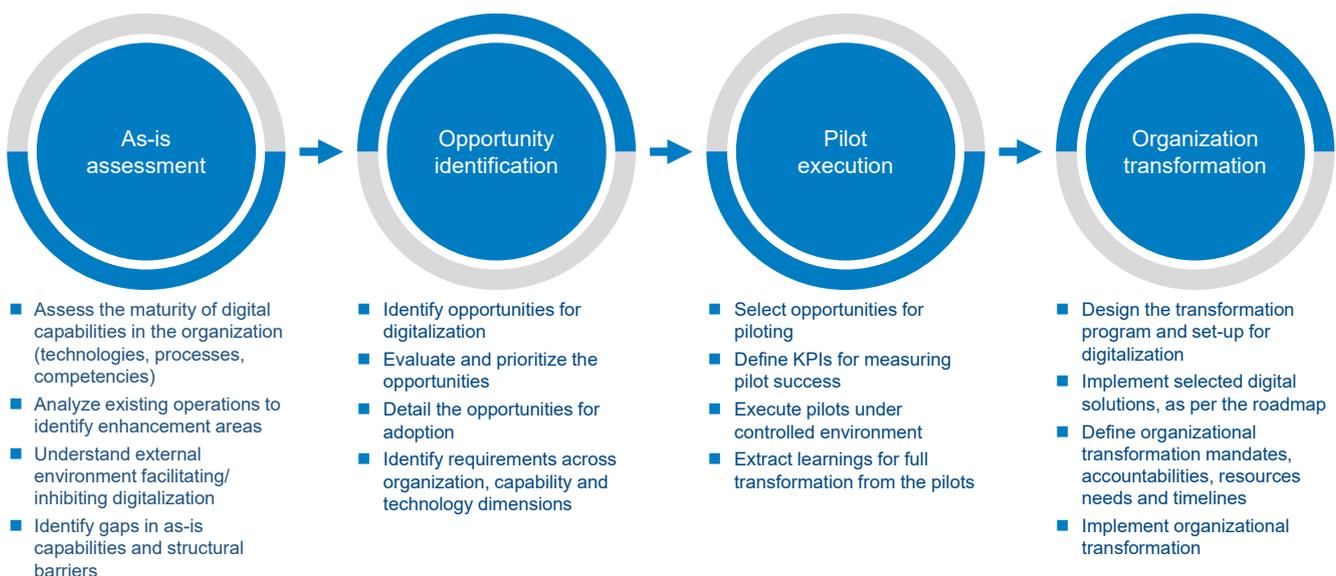
## Pilot execution

Select opportunities for piloting, define KPIs for measuring success, and execute pilots in a controlled environment. After the pilot, extract the key learnings.

## Organization transformation

Design a transformation program; develop a roadmap and implement selected digital technologies; define transformation mandates; resource needs; and implement the organization transformation model.

Figure 10: ADL's approach to combining technological and softer aspects for mining companies looking to adopt digitalization



Source: Arthur D. Little analysis

# 11. Our experience in the metals & mining sector

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Arthur D. Little is one of the leaders in innovation consulting, covering various aspects of Industry 4.0 across a broad range of sectors.

We work extensively across the above-mentioned topics, helping global metals & mining, as well as broader industrial goods clients, to achieve excellence in operations, capital stewardship, procurement and supply chain, and organizational and technological development. Our experts have delivered successful projects across the mining value chain and beyond, covering ferrous, base and precious metals, energy (thermal coal), and other minerals.

# Notes

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### Agile crocodile

The modern metals & mining sector and its future

### Arthur D. Little

Arthur D. Little has been at the forefront of innovation since 1886. We are an acknowledged thought leader in linking strategy, innovation and transformation in technology-intensive and converging industries. We navigate our clients through changing business ecosystems to uncover new growth opportunities. We enable our clients to build innovation capabilities and transform their organizations.

Our consultants have strong practical industry experience combined with excellent knowledge of key trends and dynamics. ADL is present in the most important business centers around the world. We are proud to serve most of the Fortune 1000 companies, in addition to other leading firms and public sector organizations.

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