

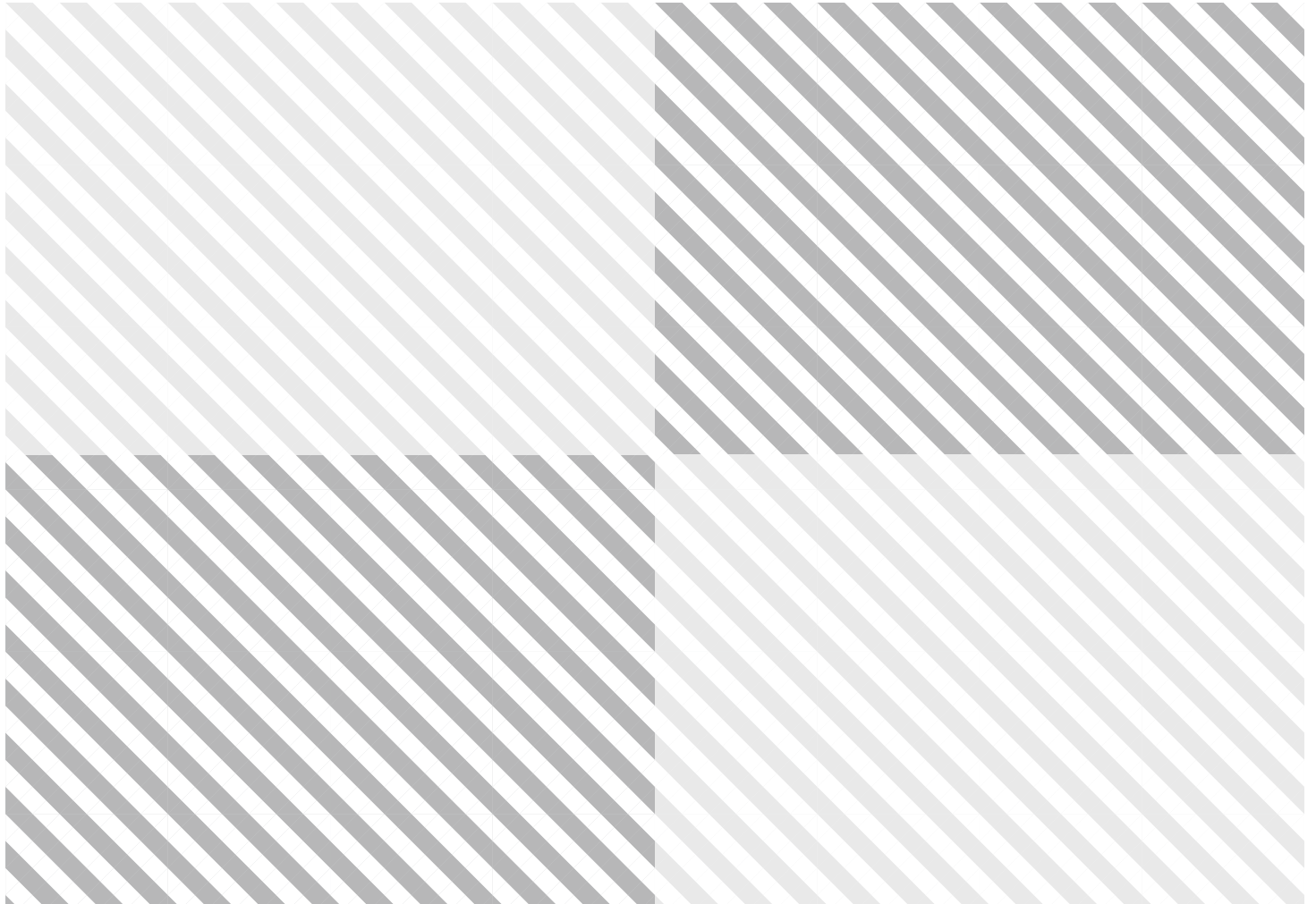
White Paper

Digital Transformation Initiative

Mining and Metals Industry

In collaboration with Accenture

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The Digital Transformation Initiative

The Digital Transformation Initiative (DTI) is a project launched by the World Economic Forum in 2015 as part of the System Initiative on Shaping the Future of Digital Economy and Society. It is an ongoing initiative that serves as the focal point at the Forum for new opportunities and themes arising from latest developments in the digitalization of business and society. It supports the Forum's broader activity around the theme of the Fourth Industrial Revolution.

To find out more about the DTI project, visit
<http://reports.weforum.org/digital-transformation>

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Foreword

Digital transformation is emerging as a driver of sweeping change in the world around us. Connectivity has the potential to empower millions of people, while providing businesses with unparalleled opportunities for value creation and capture.

Within the mining and metals industry, digitalization will be a force that changes the nature of companies and their interaction with employees, communities, government and the environment at every step of the value chain. From mineral exploration and valuation, through mining, ore processing and metals production, to downstream sales and distribution, digitalization is blurring traditional industry lines and challenging the business models of the past.

For companies that embrace digitalization, it offers the promise of a more nimble and profitable business, with improved decision-making and increased employee empowerment. More importantly, when designed and implemented correctly, digitalization can improve health, safety and environmental impact – saving lives, reducing injuries, lowering emissions and waste, and increasing transparency and sustainability.

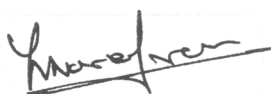
It is clear that digitalization will be a source of transformational change, but there are a number of challenges that need to be overcome. In many cases, the gains from digitalization have been inequitable, with the benefits not reaching those who need them most. As technology empowers some workers and creates new jobs, it could also threaten traditional roles. An exponential increase in global information flows has also generated new risks around data privacy and security. Meanwhile, businesses across sectors are grappling with challenges related to changing customer expectations, cultural transformation, outdated regulation and skill shortages, among others.

The World Economic Forum is committed to helping leaders understand the implications of digitalization and supporting them on the journey to shape better opportunities for business and society. The Digital Transformation Initiative (DTI) is a project launched by the World Economic Forum in 2015 to serve as the focal point for new opportunities and themes arising from the latest developments in the digitalization of business and society. It supports the Forum's broader activity around the theme of the Fourth Industrial Revolution.

In 2015, the DTI project analysed the impact of digital transformation on six key industries – automotive, consumer goods, electricity, healthcare, logistics and media, and on three cross-industry topics – digital consumption, digital enterprise and societal implications. In 2016, the initiative was extended to cover seven additional industries, including mining and metals, and two new cross-industry themes: platform economy, and societal value and policy imperatives. Through its broad focus, DTI has driven engagement on some of the most pressing topics facing industries and businesses today, and provided business and policy leaders with an informed perspective on how to take action.

The report was prepared in collaboration with Accenture, whom we would like to thank for their support. We also extend our gratitude to the members of the World Economic Forum's Mining and Metals DTI Advisory Group and the more than 40 experts from industry partners, government and academia who were involved in shaping the insights and recommendations of this project.

We are confident that the findings will contribute to improving the state of the world through digital transformation, both for business and society.



T.V. Narendran
Managing Director, India, and South-East Asia, Tata Steel
Co-chair of the World Economic Forum's Mining and Metals Industry



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Head of Digital Transformation
World Economic Forum

Executive Summary



Harnessing technology is central to making mining safer and more efficient – from proprietary technologies that help us locate deposits, to autonomous equipment and fatigue monitoring systems that protect our people, to social media that keeps us in close contact with our stakeholders. The key is to select the right technology and to make the best use of available data.



Gary Goldberg, President and Chief Executive Officer, Newmont Mining Corporation, USA

Five years after this century's commodity boom peaked in 2011, the global mining and metals industry is still adjusting to a set of strong headwinds. These include: anaemic global demand growth, as China's economy shifts away from resource-intensive manufacturing; massive excess capacity; weak pricing and increasing volatility; workforce skill gaps; increasing pressure from customer requirements; growing resource nationalism and regulation; declining resource access and quality; and mounting trade friction along all steps in the value chain.

Digital technologies is no evidence to suggest that these trends will reverse any time soon. On the contrary, they are likely to persist indefinitely, defining the industry's "new normal". Moreover, across industries, the current value-chain structure with incumbent businesses is being challenged not only by macroeconomic conditions, but by increasingly fast-moving and pervasive digitalization.

Digital themes

These digital technologies have tremendous potential to move beyond stagnant growth and deliver exceptional shareholder, customer and environmental value. In particular, there are four themes that are expected to be central to the digitalization of the industry over the next decade:



Automation, robotics and operational hardware.

Deploying digitally enabled hardware tools to perform or improve activities that have traditionally been carried out manually or with human-controlled machinery. Key initiatives in scope are sensors, robots and 3D printing.



Digitally enabled workforce.

Using connected mobility, and virtual and augmented reality to empower field, remote and centralized workers in real time. Key initiatives in scope are connected workers and remote operating centres.



Integrated enterprise, platforms and ecosystems.

Linking operations, IT layers and devices or systems that are currently separate. Key initiatives in scope are information technology (IT) and operational technology (OT) integration, asset cybersecurity and integrated sourcing, data exchange and commerce.



Next-generation analytics and decision support.

Leveraging algorithms and artificial intelligence to process data from sources within and beyond the traditional value chain to provide real-time decision support and future projections. Key initiatives in scope are advanced analytics, simulation modelling and artificial intelligence.

Putting a value on digital transformation

Our value-at-stake analysis is a quantitative model that aims to assess the cumulative value impact over the next 10 years of digital transformation initiatives on the mining and metals industry, its customers, society and the environment (See Section 5). Key findings from this analysis show that digitalization could generate:

- More than **\$425 billion of value** for the industry, customers, society and environment over the next 10 years (to 2025). This is the equivalent of **3-4% of industry revenue** during the same period.
- More than **\$320 billion of industry value** over the next decade, with a potential benefit of approximately \$190 billion for the mining sector and \$130 billion for the metals sector. The total for mining and metals is equivalent to **2.7% of industry revenue and 9% of industry profit**.
- A reduction of **610 million tonnes of CO₂ emissions**, with an estimated value to society and environment of \$30 billion.
- An improvement in safety, with around **1,000 lives saved** and **44,000 injuries avoided**. This equates approximately to a **10% decrease in lives lost** and a **20% decrease in injuries** in the industry.

However, the potential loss of about 330,000 jobs, or nearly 5% of workforce, over the next decade as a consequence of increased digitalization must also be considered and, where possible, mitigated.

Implications

Advances in digital technology could transform mining and metals as an industry and at the enterprise level. Though the digital technologies and capabilities discussed are in varying stages of maturity and usefulness, one can already see a vast difference across mining and metals companies in terms of testing, adoption and expected benefits. For those organizations that can move from being digital laggards to digital first movers, the value is real; a pro-forma projection of value at stake at enterprise level for an average mining and metals company showed a substantial increase in 2025 EBITDA of a digital first mover versus a digital laggard.¹ Companies – in collaboration with the larger community – must take steps to enhance their digital capabilities, helping them to improve their bottom line, become more responsive and resilient to industry challenges, and develop into more sustainable, transparent organizations.

Recommendations for a successful digital transformation

Successful digitalization will require collaboration between industry leaders, communities and policy-makers. The following are a set of considerations developed for both industry and other stakeholders.

For Industry Leaders

- **Align strategy and operations towards innovation:** Build a focused strategy that incorporates digital, and aligns it with their business model, processes and organization, to encourage digital usage and experimentation.
- **Look outside your current business:** Players that effectively connect outside their current portion of the value chain can extract further value, whether it be connecting or engaging in new areas with buyers, suppliers, customers or value added activities and products.
- **Improve data access and relevance:** Focus on getting real, applicable insights from data and sharing them clearly and effectively with the right levels of the organization.
- **Engage and train tomorrow's digital workforce:** Technology and innovation often fail not through lack of investment or weakness of the technology, but through a lack of cultural change. The digital worker of tomorrow must be engaged and prepared today.
- **Invest in alternative benefits, not just jobs:** Invest now in finding other ways to work with and compensate local stakeholders for the responsible use of their resources.
- **Forge new partnerships and strengthen existing ones:** Improving active and open partnerships is the foundation for best-in-class digitalization, stronger integration with local stakeholders, and even new models of operation and ownership of mining and metals fixed assets.

For communities, policy-makers and governments

- **Define effective digital standardization and regulation:** Define a set of data ownership and format standards that will encourage interoperability and the sharing of information across pieces of the digital ecosystem, while maintaining the levels of privacy and security that are needed.

- **Prioritize KPIs and aggregate data:** Though there are a number of possible key performance indicators (KPIs) that have been used to tie mining and metals to local development, there is no clear standard or repository that can give a full causal view or suggest how to best invest for industry and society.
- **Improve transparency and traceability:** Actively use digital platforms to trace and share information about sourcing, production, and environmental and community engagement.

Industry Situation and the Impact of Digital Disruption

A challenging outlook looks set to become the “new normal”. To thrive in this environment, mining and metals companies must seize the opportunities offered by digital technologies.

This white paper explores how digital technologies are transforming the mining and metals industry. At its heart is a detailed value-at-stake analysis that aims to assess the impact of different digital initiatives within the sector and quantify the value they could create for the industry and wider society over the next decade. The full mining and metals value chain falls within the scope of the analysis, including exploration, setup, mining, ore processing, metals smelting and processing, distribution, and sales and marketing. Industry partners and players outside of these areas have been considered in qualitative research, but excluded from the value-at-stake analysis. The products included in the analysis were ferrous (iron), copper, aluminium and precious metals, as they represent 90% of metal sales when thermal coal is excluded. Thermal coal was omitted from the analysis because of its function as an energy input.

a. Industry situation

Five years after this century’s commodity boom peaked in 2011, many segments within the global mining and metals industry continue to face severe challenges (See Figure 1). These include:

- Weak global demand
- Persistent excess capacity
- Increasing customer requirements
- Trade flow disruptions
- Growing resource nationalism and regulation
- Widening workforce skill gaps
- Declining resource access and quality

These challenges have caused severe price declines, increased volatility and low utilization levels that, in turn, have led to plunging profits and cash flows, steep cutbacks in capital investments, portfolio restructurings and weakened balance sheets, and share price collapses. There has also been widespread management turnover, and increased worker and societal unrest.

As these conditions persist and even intensify, there is a growing sense among industry participants that they are facing not the cyclical correction preceding a boom, but rather the onset of a fundamentally new and more permanent set of conditions. Indeed, there are strong reasons to expect that these conditions represent a “new normal.”

Weak global demand

There is no doubt that the global commodities boom of this century’s first decade was primarily driven by the rapid expansion of the Chinese economy, and particularly its infrastructure, construction and manufacturing sectors. Although few expected China’s appetite for commodities to continue to deliver double-digit growth, it was thought that other developing countries would pick up China’s mantle and drive future demand growth based on expanding middle classes, urbanization and manufacturing development.

However, several factors are combining to slow future demand growth for several key metals and minerals:

- **Product and technological advances.** Throughout the history of the modern mining and metals industry, there have been steady advances in both the properties of the materials and their engineered usage, such that consumption intensity (per application) has continued to decline. Examples include higher-strength/lightweight steel in automobiles, stronger and more ductile aluminium in construction, improved copper conductivity in better designed motors, and longer-lasting washing machine drums. This trend is ongoing and, while difficult to measure in isolation from other factors, is expected to continue.
- **Circular economy and sustainability.** A digitally enabled and sustainability-oriented economy is likely to show lower metal and mineral consumption intensity (per unit of per capita GDP) than in the past. Increased sharing, reuse, remanufacturing and recycling will reduce the demand for many virgin materials and metals. The circular economy and sustainability initiatives may increase demand for some metals (e.g. copper for non-combustion vehicle engines and renewable energy technologies, stainless steels for corrosive material processing), but the net impact on the sector is expected to be a reduction in the intensity of use.
- **Premature deindustrialization.** An increasing number of academic and policy research papers suggest that many developing economies could miss the traditional resource-intensive manufacturing phase of economic development, thus undercutting a potential driver of demand growth in global minerals and metals. Suggested reasons for this include: the inability to compete against large, global manufacturers that

are further along the experience curve (and have excess capacity); the availability of other economic development paths (e.g. services); skill and capital availability gaps; and the rapid adoption of technology advances and circular economy practices.

Excess capacity

The length of the preceding boom – and the historically high commodity prices that accompanied it – encouraged massive capital investment to expand capacity throughout most segments of mining and metals. Given long construction and start-up lead times, a significant proportion of projects started during the boom years did not reach production capability until after prices collapsed. In some cases, companies cancelled or halted projects as they immediately became economically unviable. For others, however, the need to maintain interest, social and/or royalty payments, and the lower cost of keeping new operations running has meant that much of the added capacity has remained open. The result has been significant global excess capacity for most (but not all) minerals and metals, creating further downward pressure on prices.

Customer requirements

For metal products companies in particular, there is never-ending pressure from customers for improved products and services. Closely linked to this are ongoing material substitution battles consisting of competition between metal products (e.g. steel and aluminium in automobiles), and between metal products and other materials (e.g. plastics, wood, carbon fibre, local materials). These battles help drive the innovation that leads to improved metal products, even if they reduce the total volumes consumed. It is likely that circular economy and sustainability pressures will intensify both inter-metals and inter-material competition, with recyclability, reusability, life cycle costs and environmental impacts receiving increased importance in customer purchasing decisions.

Trade flow disruptions

To some degree, the end of the commodities boom was hastened by a series of global financial crises that undercut economic growth throughout much of the world. In some segments of the industry – most notably steel and aluminium – the impacts of falling prices and underutilized capacity have been exacerbated by the rapid increase in exports from countries with significant excess (and inelastic) capacities. These have led to further economic dislocations such as plant idling and workforce reductions in many regions of the world. The fact that these dislocations intensified during a period when political sensitivity was in a heightened state (in the European Union, United States, Brazil and elsewhere) forced many governments to impose trade restrictions on raw materials, semi-finished and finished products. Consequently, trade flows and market dynamics have been disrupted, leading to a more complicated and volatile trading environment.

Resource nationalism and regulation

Resource nationalism refers to policies and regulations that seek to deliver the maximum benefit from the extraction and processing of ores and minerals to the host country. Although this is not a new phenomenon facing mining firms, it has been increasing in recent years in response to the economic dislocations noted above. Another contributing factor is heightened awareness and pressure from local communities regarding the economic, social and environmental impacts of extraction and processing operations.

More broadly, companies are facing stricter (and more costly) regulatory requirements in all areas of operations, with product traceability and corruption as major targets. In addition, while several leading mining and metals companies were vocal supporters of the Paris Climate Change Agreement in 2015, the agreement will clearly increase the challenges facing the industry in coming years if it is fully enforced.

Workforce skill gaps

The mining and metals industry faces several challenges relating to the composition of its workforce:

- The industry workforce is ageing. Experienced workers have deep industry knowledge, but may be less comfortable with digital tools or collaborative work.
- There is competition for qualified new talent. Millennials tend to have a strong understanding of all things digital, but may have a thin knowledge of mechanical-physical operations and be uninspired by traditional corporate hierarchies.
- Companies are encountering a skill gap, especially in the developing world, where they are struggling to recruit highly skilled workers to operate mines and metal plants that are being optimized with advanced technology.

These workforce challenges will likely affect the industry through increased costs in retaining talent, friction within the workforce, a need to increase worker productivity and the use of technology or external contractors to fill labour gaps.

Resource access and quality

Another challenge for mining companies is the fact that there are fewer and fewer high-quality ore deposits left to develop. Those that do exist are generally in more remote, difficult-to-access parts of the planet. And where geographic difficulties may be surmountable, country political risks can be severe. Consequently, the costs, lead times and risks associated with developing and operating new mines are increasing. For example, the average cost of producing copper has risen by >300% in the last 15 years, while grade has dropped by 30%.

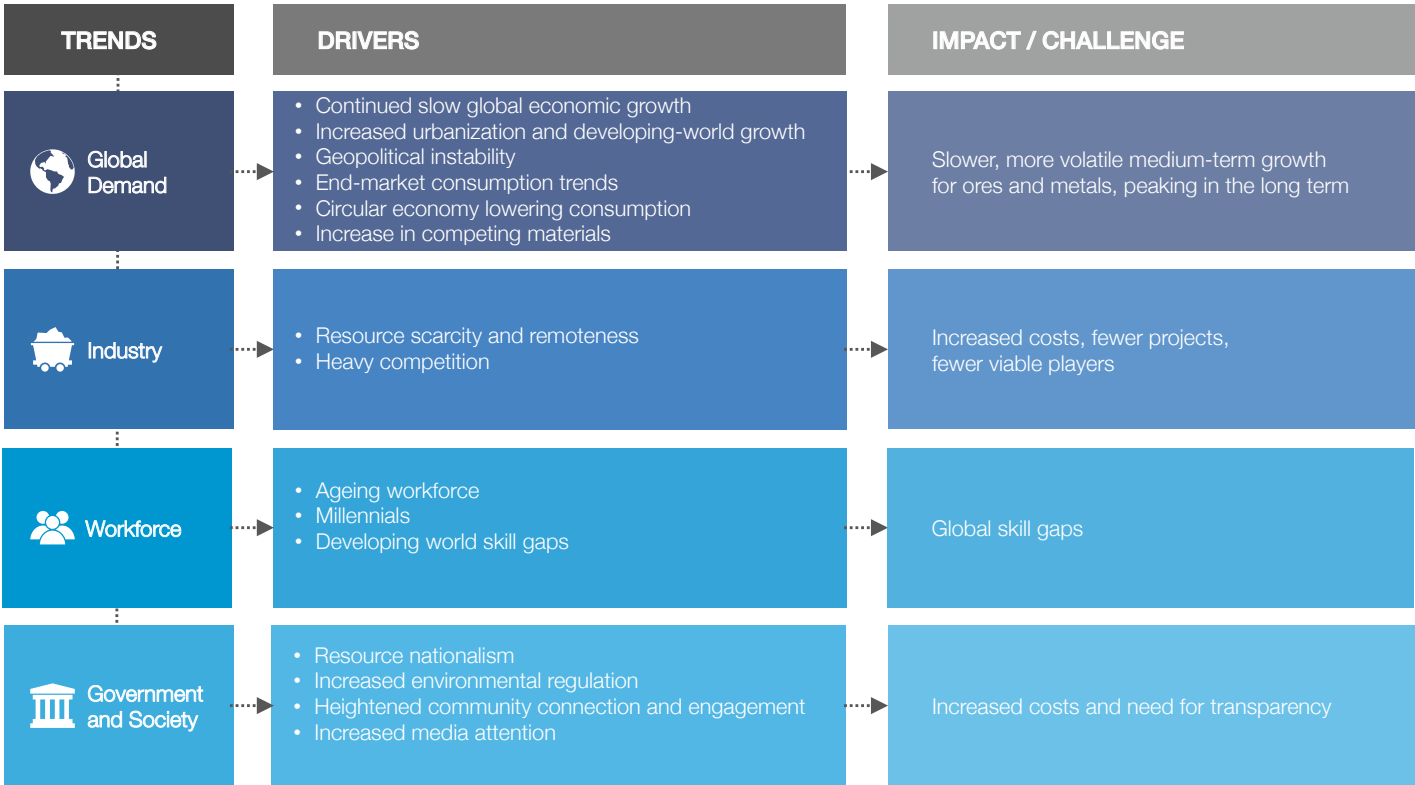
b. Emergence of digital disruption

The challenges that the mining and metals sector faces are not occurring within an industry vacuum. They are taking place in the context of – and to some extent being driven by – the broader technological and economic upheaval brought about by rapid and disruptive digital innovations across industries.

As with historical upheavals, technology has hastened the spread of ideas. The major difference between disruption today and in the past is the accelerating pace and pervasiveness of change. When analysing core digital technologies and the evolution of their capabilities over time, the speed of capability improvement, adoption and displacement by new technologies has quickened (see

Figure 2). Much of this acceleration has been generated by the falling cost of technology. For example, the cost per KWh of solar power has dropped from \$30 in 1984 to a mere \$0.14 in 2014.² Similarly, the cost of a drone in 2007 was nearly \$100,000, but by 2013 had fallen to \$700. Even the cost of industrial robots has dropped significantly, from over \$500,000 in 2007 to just \$20,000 in 2014. Moreover, when these digital technologies are used together, they generate “combinatorial effects”, which boost the capability of these technologies exponentially – and far more than if each was used in isolation (see Figure 2). These combinatorial effects are an additional reason for organizations to adopt digital technologies.

Figure 1: The Impact of Industry Trends on the Mining and Metals Industry

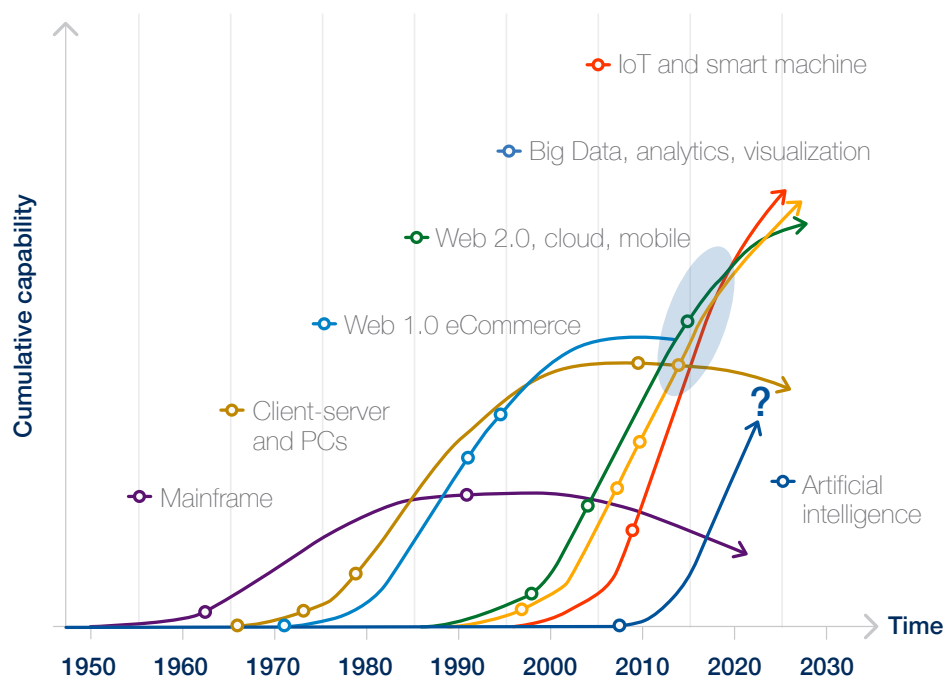


Source: World Economic Forum/Accenture analysis

Though the falling costs and combinatorial effects of digital technologies have not been the sole drivers of change, they have meant that the cycle of trial, adoption and rejection or further innovation is no longer only the realm of well-heeled incumbents. Low financial barriers to entry for new technology mean that smaller, nimbler players from within or outside an industry can quickly compete with larger incumbents. For example, though the transition from steam engines to internal combustion took decades, the adoption of car sharing as a new transport option has taken years. Likewise, Fortune 500 companies typically took nearly two decades to reach a valuation of \$1 billion, but Uber and other technology start-ups are achieving \$1-billion valuations – and “unicorn” status – in an average of four years.³

Regardless of the specific technology involved, the impact of digital is not confined to a few industries or geographies. Mobile devices and apps, cloud, analytics, sensors, advanced robotics, virtual reality, cognitive computing and artificial intelligence are all digital technologies that have quickly influenced and upended conventional business models, customer relationships and industry roles. The United States took a few decades to wire the nation with Alexander Graham Bell’s telephone lines, but in many areas of Africa, the telecommunications industry has moved with remarkable speed to put mobile phones and other wireless devices directly into the hands of the local population, even in areas with limited landlines. This has encouraged commerce, the spread of ideas, transparency and even new models of financing.

Figure 2: The Increasing Capability of Digital Technologies



Source: World Economic Forum/Accenture analysis

c. The industry's technological response to date

Historically, mining and metals companies have been technology innovators and leaders in some areas, and followers and late adopters in others. In recent years, the pace of digital technology-driven change has been shaped by several factors: capital availability; geographical dispersion of key operations; large differences in fundamental equipment and control technologies (in part the result of successive rounds of industry consolidation); managerial conservatism (as is often seen in capital-intensive industries); and the inherent complexity of some operations.

The result is that, compared to other industries,⁴ especially customer-facing ones, the mining and metals sector is considered to have lower levels of digital utilization. Though there is room to grow in digital mining and metals usage in a variety of areas, initial digitalization programmes are underway in some companies and are being used to improve operating efficiencies and address some industry-specific challenges.

- **Monitoring and automating heavy fixed assets**
The mining and metals industry has very costly fixed-asset operations and machinery, whose maintenance and depreciable life can substantially impact production output, operating costs and ongoing capital expenditure. Visual, thermal and tactile sensors on or near hardware connected to diggers, trucks, crushers, conveyors, plants and tailings treatment are used to gather and share information about machinery,


processes and environmental conditions. Moreover, for most mining and metals production or processing plants, digitally enabled automation means humans are now decision-makers and operation controllers, while machines do the physical work.

- **Connecting dispersed, diverse and remote operations**
As industry players have grown larger and more global, the first wave of digitalization connected disparate operations and aligned corporate processes and reporting via enterprise resource platforms (ERPs). In mining especially, this worldwide consolidation has meant heavy investment in digital infrastructure to connect sometimes remote locations to telephone, internet and video networks. Moreover, at a plant operations level, the manufacturing execution system (MES) is now the standard network to track processing and production.
- **Empowering and protecting workers**
As the target workforce for these industries has become smaller, more specialized and more expensive – especially in developed nations – digital tools have been used to inform management and local workers on operations, allowing them to better adjust production and troubleshoot problems. Given the dangerous working conditions on the ground and the risk to the local environment, connected sensors, monitors and alarms have become key tools for reporting potentially harmful events and conditions, and quickly alerting employees and leadership to possible issues.


Detailed Themes and Initiatives

We highlight the digital innovations that, over the next decade, have the greatest potential to create value for the mining and metals industry, its customers and wider society.


Digitalization is poised to affect the industry in a few key areas. Drawing on numerous interviews⁵ and in-depth research, four digital themes have been identified that are expected to play a crucial role in the digital transformation of mining and metals in the decade to 2025:




Automation, robotics and operational hardware. Deploying digitally enabled hardware tools to perform or improve activities that have traditionally been carried out manually or with human-controlled machinery.



Digitally enabled workforce. Using connected mobility, and virtual and augmented reality to empower field, remote and centralized workers in real time.



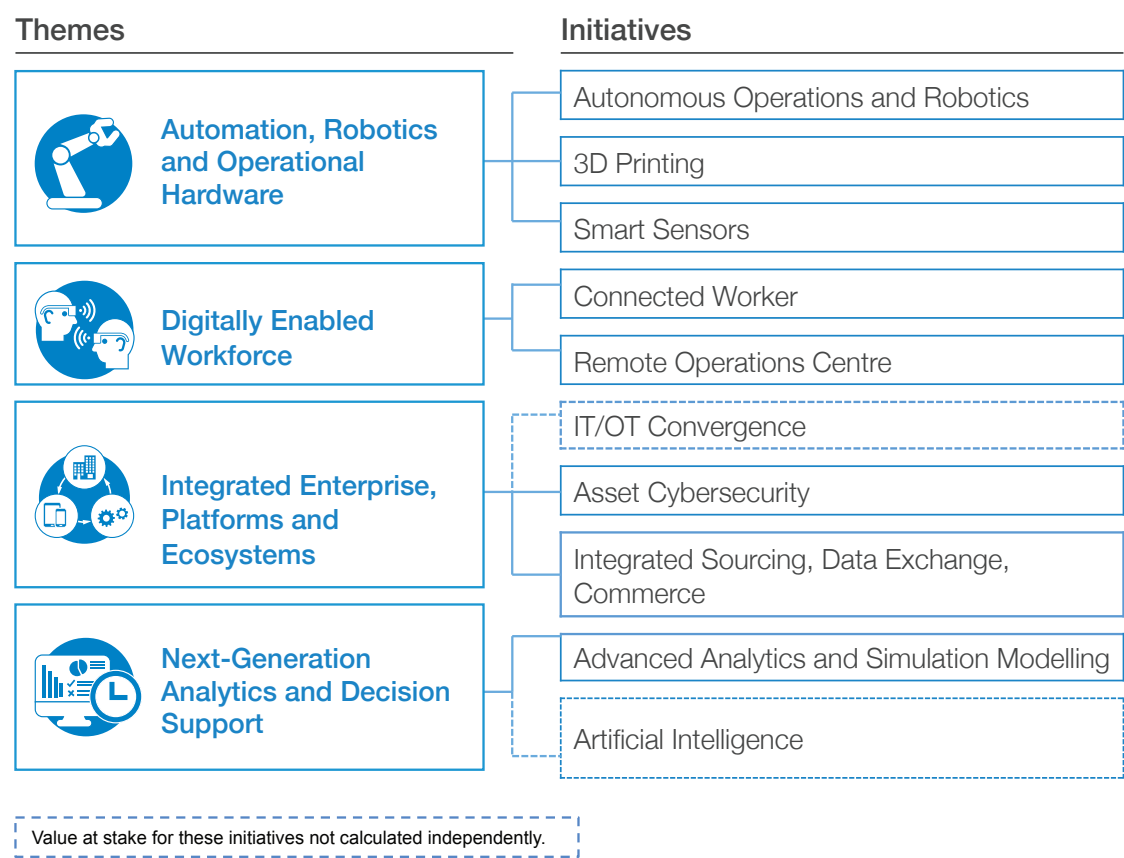
Integrated enterprise, platforms and ecosystems. Linking operations, IT layers and devices or systems that are currently separate.



Next-generation analytics and decision support. Leveraging algorithms and artificial intelligence to process data from sources within and beyond the traditional value chain, in order to provide real-time decision support and future projections.

Within each theme, digital initiatives (see Figure 3) define the technologies that are expected to have a significant impact on the industry’s value chain, its workforce, adjacent industries, the environment and wider society.

Figure 3: Digital Themes and Initiatives in Mining and Metals



How was the value of digital transformation in mining and metals calculated for the four themes and their initiatives?

Our value-at-stake methodology aims to assess the impact of digital transformation initiatives on industry, customers, society and the environment. It provides likely value estimates of global industry operating profits that are at stake from 2016 to 2025, and the contribution that digital transformation can make to customers, society and the environment in that time frame.

Value at stake for industry comprises two elements: first, the potential impact on an industry's operating profits that will be generated from digital initiatives (value addition); second, operating profits that will shift between different industry players (value migration). Value at stake for society measures the value impact of digital transformation for customers, society and the environment.

A full explanation of our value-at-stake methodology can be found in Section 5 to this report.



a. Automation, robots and operational hardware

Technologies such as robots, 3D printing and smart sensors offer opportunities for mining and metals companies to revolutionize their operations and create significant value.

The use of automation and robotics – digitally enabled hardware tools to take over activities traditionally carried out by human-controlled machinery – is already growing within the mining and metals industry. Important technologies in this area include 3D printing; automated exploration drones; robotic trucks, trains and diggers; autonomous stockpile management; autonomous robots for recovery of recycling material; and pit drones. These technologies are expected to be deployed more widely as their capabilities improve and cost drops.

This digital theme looks at condition monitoring, predictive forecasting and reliability-centred maintenance, all enabled by analytics and robotics.

Autonomous operations and robotics

In recent years, there has been a step change in the capabilities of robots and automated machines. Previously, automated hardware was restricted to carrying out the specific tasks it had been programmed to do. Today, a new generation of robots and machinery can perform tasks with a high degree of autonomy, working for extended periods without any human intervention.

The ability to gather information about its environment allows the robot or automated machine to move without human assistance and avoid situations that could be dangerous for itself or a human worker. Operational hardware is also increasingly capable of learning new methods for accomplishing tasks or adapting to changing surroundings.

Robots come in many shapes and sizes – from robotic diggers and trains to drones – and have numerous applications in mining and metals. Take drones: whether autonomous, semiautonomous or manually controlled, they can be equipped with additional technologies such as thermal cameras so that they can, for instance, monitor vast facilities or help with exploration mapping. However, regulatory barriers can make it difficult to test potential applications for drones.

Case Study: Freeport-McMoRan – Using Drones to Monitor and Evaluate the Rock Face in Real Time

Freeport-McMoRan uses drones to more closely monitor and evaluate the rock face at its mines in real time as it blasts away rock to build mine slopes. The data sent through drones is instantaneous and includes angles that humans cannot see. Using drones enables an objective, data-driven view of the slope angles. This means a more precise reading that enables Freeport-McMoRan to build steeper slopes, ultimately displacing less rock and expending fewer resources to access the ore body. The United States Federal Aviation Administration granted Freeport-McMoRan an exemption in May 2015 to use drones to take pictures and real-time videos for monitoring blasting operations, environmental conditions and mine security.⁶

Case Study: Anglo American – Autonomous Drills for Safer and More Precise Drilling

At Anglo American's Kumba Kolomela mine in South Africa's Northern Cape province, there is a new automated drill. Its operators can work from a clean, safe and comfortable command centre rather than at a dusty, noisy and unpredictable iron ore pit. Using advanced computers and screens, they operate the drill remotely. This autonomous drilling project is one of the first in South Africa. Workers were wary at first but then bought into the benefits that the robot brings. They now view it as a useful tool instead of a threat. In this instance, new technology improved rather than destroyed jobs, as operator and robot work side by side.⁷

Case Study: Rio Tinto – The Mine of the Future

Established in 2008, Rio Tinto's Mine of the Future programme aims to equip front-line employees with intelligent tools, helping them make decisions that improve performance based on contextual knowledge. Rio Tinto has the world's largest fleet of autonomous trucks to deliver loads more efficiently, minimize delays and reduce fuel use. The trucks are operated remotely, helping ensure greater operational safety. Rio Tinto relies on people and computers working together, one complementing the other, rather than viewing human and machine as mutually exclusive sources of knowledge. The company admits that skilled people will always be needed to oversee autonomous systems, noting that changing technology provides employees with the chance to develop and better use their skills in new work environments.⁸

Value-at-stake impact

- **Industry (value addition).** Greater use of autonomous machines could create \$56 billion of additional value for the industry, through an increase in output, since they can operate 24 hours a day, 365 days a year at a constantly high productivity level. In both mining and metals, increased automation will create value for the industry through reduced personnel costs (especially as employing on-site workers is a major cost driver for mining companies operating in remote locations). We expect the bulk of this value (\$47 billion) to be created in the mining industry, where automation can have a particularly significant impact in the extraction phase. Some tasks can also be performed more efficiently by machines than humans (e.g. drones for exploration). One of our key assumptions here is that the adoption rate for autonomous machines in mining will rise from 0.1% today to 25% by 2025.
- **Society (lives saved).** Autonomous operations can increase worker safety, especially in extreme conditions such as those found in underground mines or hot mills, reducing the number and severity of health and safety incidents. In mining, we estimate that about 120 lives will be saved and approximately 7,000 injuries avoided over the next decade. In metals, roughly 130 lives could be saved and an estimated 3,000 injuries avoided.
- **Society (employment).** We estimate that wider adoption of autonomous operations is likely to displace approximately 60,000 mining jobs (or 4% of the total) over the next 10 years, as fewer personnel are needed to supervise operations carried out by intelligent machines and robots. This could be particularly detrimental for local communities in remote areas where mines are one of the few employers.
- **Society (environment).** Greater operational efficiency is expected to reduce CO₂ emissions by approximately 400 million tonnes over the next decade. We expect the bulk of these emissions savings (about 340 million tonnes) to come from the mining industry, where autonomous machines consume less fuel than manual ones. In the metals sector, we estimate that reduced energy consumption in automated processes will save roughly 60 million tonnes of emissions.

3D printing

Metal 3D printing has potential applications in internal part production, downstream direct-to-customer and consumer printing. However, 3D printing of non-metals could encourage material substitution and have an adverse impact on the industry.

Today, metal 3D printing shows dramatic promise for metals companies and downstream consumers, but the technology is prohibitively expensive and lacks the speed and scale required for mass production. As a result, metal 3D printing has mainly been limited to prototyping for industrial design and to high-end, customized, small-batch manufacturing for industries such as healthcare and aerospace. If it becomes more economical, efficient and scalable,

Value at stake: Autonomous Operations and Robotics

(All figures cumulative, 2016-2025.)



there will be opportunities for mining and metals companies to use it in production and operations. For mining companies, 3D printing is an innovative way to source metal and plastic parts, offering quick access to a broad range of spare parts and machinery in remote and hostile locations.

Downstream, metals companies could leverage the emerging 3D printing market to sell new products, such as input materials for 3D printing (e.g. silver, titanium or steel powder), and devise new structures (e.g. hollow honeycomb structures with better strength-to-weight ratios).

As the technology improves and costs come down, mining and metals companies may consider selling raw products, either as supplies to 3D printing businesses or direct to customers and consumers. In this way, they could become integrated metals and 3D printing firms.

At the same time, as metal 3D printing improves, the mining and metals industry should anticipate an increase in material substitution from 3D printers able to use other materials. Currently, plastic, polymer, carbon fibre and other metal substitutes are being used in design, experiments and early production phases. As their molecular characteristics make them easier and faster to mould at lower temperatures than metals, they represent serious competition. This is especially true once they become comparable in terms of physical characteristics (e.g. tensile strength, weight, stress resistance).

Case Study: Airbus APWorks Light Rider – Producing a 3D-printed Electric Motorcycle

APWorks produces “bionically optimized” metal parts, inspired by organic structures, for a wide range of industries, from aerospace to automotive and robotics. It recently used a 3D printer to produce an electric motorcycle from tiny aluminium alloy particles. The motorcycle uses hollow-frame parts that contain the cables and pipes. The frame weighs about 30% less than conventional e-motorbikes, and the complex, branched hollow structure are impossible to construct via conventional production technologies such as milling or welding.⁹

Case Study: Arconic – Supplying 3D-printed Titanium Fuselage and Engine Pylon Parts to Airbus

Arconic has an agreement with Airbus to supply 3D-printed titanium fuselage and engine pylon components for commercial aircraft. The company, which expects to deliver the first additive-manufactured parts to Airbus in mid-2016, acquired RTI International Metals to expand its additive-manufacturing capabilities to include 3D-printed titanium and speciality metals parts. It will employ advanced CT scan and Hot Isostatic Pressing (HIP) capabilities at its advanced aerospace facility in Whitehall, Michigan. HIP strengthens the metallic structures of traditional and additive-manufactured parts made of titanium and nickel-based superalloys. Arconic is further bolstering its additive-manufacturing capabilities through a \$60-million expansion in advanced 3D-printing materials and processes at its technical centre near Pittsburgh, Pennsylvania.¹⁰

Value-at-stake impact

- **Industry (value addition).** We calculate that the wider adoption of 3D printing will lose approximately \$195 million of value for the mining and metals industry, largely from reduced demand driven by the replacement of metal products with non-metal substitutes that 3D printing enables. The picture is mixed, however, with 3D printing expected to create up to \$175 million of value for the

mining sector (assuming that the adoption rate for 3D printing in mining operations increases from 0.5% today to 20% in 2025). This value addition will come from reductions in maintenance, spare part inventories and – most significantly – unplanned downtime costs. We estimate that the metals sector will see a loss of about \$370 million, stemming from the substitution of metal products in key customer industries with 3D-printed non-metal replacements. We anticipate the biggest impact will come from the use of 3D-printed components in the automotive, transport and machinery production sectors. This will outweigh the value created for the sector from reduced maintenance and spare part inventory costs.

- **Society (customers).** 3D printing is expected to benefit customers by up to \$1.3 billion, as a result of customers substituting 3D-printed components for aluminium and steel products.
- **Society (environment).** More widespread adoption of 3D printing will lead to an estimated reduction of 60 million tonnes of CO₂ emissions. 3D printing creates far less waste material per unit produced than other manufacturing techniques. For example, typical production may involve 100 kilograms (kg) of metal to make a 3kg piece, whereas 3D printing may only require 3.5kg for the same item.¹¹ Coupled with the increased use of non-metal components, this will contribute to lower energy consumption and emissions savings of roughly 20 million tonnes in the metals sector.

Smart sensors

Traditional sensors have been used for decades to collect data for a wide range of applications. Smart sensors collect physical, biological or chemical input data and convert this into a digital format. They can also process the information they collect, make decisions based on it, and send and receive communications.

Companies can use smart sensors to get real-time insights into the performance of their infrastructure, derived from data about the physical condition and operational performance of machines. With every machine potentially producing a digital data feed, smart sensors become a primary data source for generating insights via big-data analytics.

In mining and metals, smart sensors have potential applications across almost the entire value chain. They can be deployed to support other technologies, such as robotics, and to collect real-time operational information that facilitates better decision-making and boosts efficiency.

Case Study: Goldcorp – Using Smart Sensors to Reduce Energy Costs

Goldcorp, a gold producer headquartered in Canada, is using smart sensors in its Éléonore Mine. The mine, which opened in late 2014, is used to extract gold from 4,000 feet below the surface. Management has deployed a network of sensors and monitors to ensure the safety and efficiency of workers and equipment. Smart sensors are combined with human geospatial tracking to turn on and off lights

and electricity when people are not in a particular area of the mine. Using the tracking system, the company can ensure that workers are clear during planned blasting work and manage the mine's air filtration system by sending fresh air to the areas that need it most. Prioritization of the air filtration system has delivered a 50% reduction in the amount of air required to service the mine, as areas where there are no operational personnel do not require the same air quality as those where workers are present. There are estimates that air filtration management delivers savings between \$1.5 million and \$2.5 million each year, and a sizeable reduction in carbon emissions.^{12, 13}

Case Study: Metso – Using Visualization Sensors in Metal Production for Bubble Monitoring

Metso is using visual sensors to enable clients to monitor the bubbles in their steel production. The amount of air and the size of the bubbles in a steel furnace affects the quality of the final product. However, the intense heat makes it hard to take readings from the molten metal. Visual sensors, coupled with heat sensors, can scan the surface of the molten metal and quickly assess the quality of the steel and automatically identify any adjustments to the process that are needed. The result: a higher-quality, more consistent product.

Value-at-stake impact

Deploying smart sensors in mining and metals operations opens up opportunities to unlock value for the industry and its customers, while also creating benefits for the environment and society.

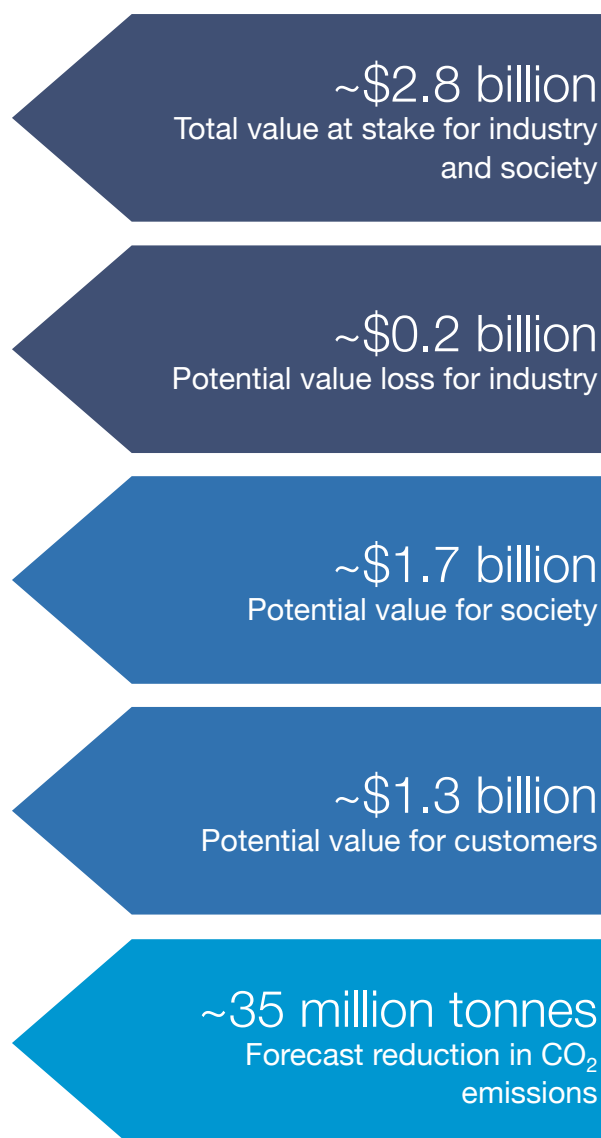
- **Industry (value addition).** Smart sensors have the potential to create approximately \$34 billion of value for the industry. They play an important role in predictive maintenance and asset management, which can significantly reduce costs, by improving equipment utilization, cutting downtime and equipment failures, and reducing the frequency of health and safety incidents.

We expect the bulk of this new value (about \$25 billion) to accrue to the metals sector, where smart sensors can contribute to reduced maintenance and energy costs, improved productivity and better product specificity from more precise monitoring of manufacturing processes. A key underlying assumption is that the adoption rate for smart sensors will rise from 1% today to 35% in 2025 for most of these applications.

Smart sensors can also create an estimated \$8.8 billion in value for the mining sector, primarily driven by increased operational efficiency, thanks to more precise monitoring of production processes and lower maintenance costs.

- **Society (environment).** The use of smart sensors can lead to greater operational efficiency, reducing energy and water consumption, and cutting the volume of waste generated. We calculate that the industry can save roughly 160 million tonnes of CO₂ emissions from more precise monitoring of production processes, with the majority of this reduction (about

Value at stake: 3D Printing (All figures cumulative, 2016-2025.)



135 million tonnes) coming from the metals sector. We estimate that smart sensors can also reduce the mining sector's water consumption by approximately 400 billion litres. Smart sensors can help reduce the metals sector's water consumption by an estimated 250 billion litres.

- **Society (employment).** Smart sensors have the potential to significantly improve worker productivity, which may lead to companies reducing headcount. Based on the assumption that adoption rates for connected worker technologies (incorporating smart sensors) reaches 25% for mining and 35% for metal companies by 2025, we anticipate roughly 40,000 jobs to be displaced.



b. Digitally enabled workforce

Together with remote control centres, digital technologies that empower field workers are set to revolutionize mining and metals operations.



Our ageing workers know the mines and our young guys know digital. When we have been able to have a cohesive cross-generational team, it has been stellar.



Duncan Wanblad, Chief Executive Officer, Base Metals and Minerals, Anglo American, UK

The rapid proliferation of mobile devices, coupled with impressive advances in their capabilities, has helped companies introduce digitally enabled ways of working. Important technologies in this area include remote operations centres, digital simulation training/learning, connected worker/mobile devices, logistics control towers, and virtual collaboration. Improvements in connectivity and breakthroughs in other technologies, such as wearable technologies, the Internet of Things (IoT), virtual reality (VR) and augmented reality (AR) have opened up further opportunities for innovation in this field.

Connected worker



We are empowering the different parts of the organization to take on projects rather than trying to drive all of them centrally. Driving centrally doesn't empower. We cheerlead and let the ideas bubble up.

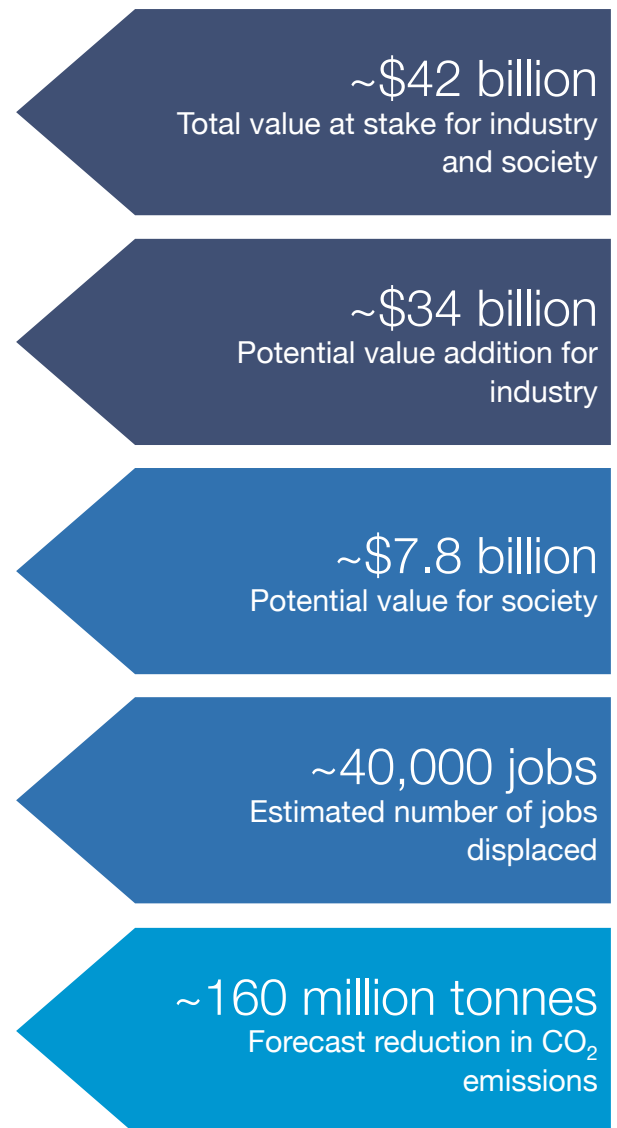


T.V. Narendran, Managing Director, India, and South-East Asia, Tata Steel, India

Connected mobility, VR and AR technologies can be used to empower and monitor field workers. These employees can benefit from on-demand, real-time push and pull information and use mobile and wearable technologies (e.g. tablets, wearable glasses, watches, and vital trackers) to interact with sensors, robots and other systems around them.

Connected worker technologies have numerous applications. For instance, equipping workers with connected, intelligent wearables and mobile devices allows mine and plant management to capture critical information in real time. It also

Value at stake: Smart Sensors (All figures cumulative, 2016-2025.)



enables seamless communication; immediate, remote expert assistance, diagnosis and real-time guidance or access to instructions to repair faulty equipment; and “follow-complete-document” workflows that can be carried out directly in the field.

As digitalization takes hold in mining and metals, the industry's workforce will need to develop a different skill set to fully exploit the digital opportunities they encounter. Connected worker projects have a role to play in easing this transition. Mining and metals companies will be looking to recruit digitally savvy workers – for example, those with knowledge of software development, analytics, artificial intelligence or design thinking. These new recruits may lack the mechanical know-how that existing workers have from working in mines and at plants. Connected worker technologies, such as VR or enhanced mobile tools, can be used to improve training on the job. Wearable technologies and mobile devices guide workers in performing new jobs, both on site and remotely.

Case Study: DAQRI – Making Helmets Smart and Improving Worker Safety

DAQRI is an American AR company founded in 2010 and headquartered in Los Angeles, California. Its smart helmets enhance human capabilities across industries by seamlessly connecting users to their work environment. The helmet, which complies with safety standards, includes a main logic board with twice the processing speed of a normal computer; a thermal camera for passive thermal monitoring of industrial equipment; an audio array board for advanced communications; 13MP HD cameras; an industrial infrared system; and an inertial measurement unit. DAQRI has also developed an operating system specifically designed and optimized for wearable computing.¹⁴

Case Study: Rio Tinto, Anglo American, Newcrest Mining – Using Smart Headwear to Monitor Fatigue Levels

Mining companies in Australia, including Rio Tinto, Anglo American and Newcrest Mining, are providing field workers with smart baseball caps (known as SmartCaps) that monitor their brainwaves to measure fatigue. The technology has been rolled out primarily with truck drivers and machinery operators, who are at risk from fatigue-related injuries. The SmartCap uses an electroencephalogram (EEG) and proprietary algorithms to calculate a risk assessment number, which corresponds to a worker's ability to resist falling asleep. The SmartCap provides an early warning when a driver is approaching microsleep. At Rio Tinto, truck drivers are required to discuss a fatigue management plan with supervisors if their SmartCaps show they have high levels of fatigue. Mining companies are using SmartCap data to better understand the dynamics of fatigue and improve workplace designs. Insights from the data have also shown that road characteristics can affect driver fatigue, encouraging designers to reconsider the design of roads and signage. SmartCaps have had a mixed reception. Some workers have objected to their introduction because of concerns over the information gathered being used for disciplinary reasons.¹⁵

Case Study: Tata Steel – Creating a Culture of Multi-Generational Digital Innovation

Tata Steel, an Indian iron ore and steel company with significant downstream presence and strong B2C brands, has made substantial progress in refocusing its internal culture to ensure a digital culture is enabled. As part of its plan to make the organization more aware of and better prepared for digital transformation, the company has tried to connect the younger generation of workers (aged under 30) with the older leadership team. In one of its major corporate initiatives, it created a reverse mentoring programme, in which younger employees spend time bringing upper-level leadership up to speed about trends and technology. The programme began with a competition for the top few hundred young employees, who were then hand-picked for the scheme. It serves both to motivate these employees through exposure to strong leaders and provide an avenue for older employees to become aware of relevant digital trends.

Value-at-stake impact

Connected worker technologies are expected to have a significant impact on efficiency, costs and workforce safety.

- **Industry (value addition).** A vast majority of the value that connected worker projects can deliver to industry will come via improvements in workforce productivity (approximately \$85 billion across mining and metals). These projects can reduce exploration and extraction costs, since these activities can be performed in a more targeted and efficient way based on real-time data. Maintenance costs can be minimized by reducing the duration of maintenance activities – for example, through supplying just-in-time instructions. Assuming that the adoption rate of connected worker equipment rises from 23% in 2016 to 50% in 2025, around \$57 billion of the mining sector's \$59 billion of added value could be realized through productivity improvements. In metals, if the adoption rate climbs from 12% today to 25% in 2025, the sector will enjoy productivity gains of about \$25 billion, with the remaining \$1 billion gain coming from reduced training costs.
- **Society (employment).** On the assumption that individuals on site are tracked – and thus can avoid blasts, be found faster after cave-ins and warned about dangerous situations – we believe connected equipment could save the lives of roughly 350 mining workers and 150 people working in metals. For injuries, the number is even higher, estimated at 22,000 injuries avoided. These numbers are enabled because connected intelligent devices increase worker safety in hazardous environments by monitoring and communicating environmental conditions such as heat and gas, triggering alarms if a hazard, such as the presence of toxic fumes, is detected. In the event of an emergency, the devices can provide information about the worker's location, aiding rescue operations. Connected worker technologies can help the workforce in other ways – for example, boosting demand for training through the provision of real-time assistance on the job – but they could displace approximately 130,000 metals jobs as productivity increases translate to headcount reductions. For the same reasons, connected worker technologies could also displace about 70,000 mining jobs.

Remote operations centre

Remote operations centres (ROCs) are centralized, connected control rooms for mines and metals plants, providing an off-site environment for personnel to collaborate on operations without travelling to the site itself. Thanks to improvements in connectivity, these control rooms can be located almost anywhere in the world.

ROCs provide real-time control over operations in remote locations where there is minimal infrastructure. By providing video feeds and other digital tools, they enable employees to monitor and control multiple aspects of operations simultaneously. ROCs also integrate diverse data sources to support decision-making based on real-time mine or metals treatment conditions, allowing the monitoring and coordination of multiple services.

Case Study: BHP Billiton IROC – Creating a Holistic View of the Iron Ore Supply Chain

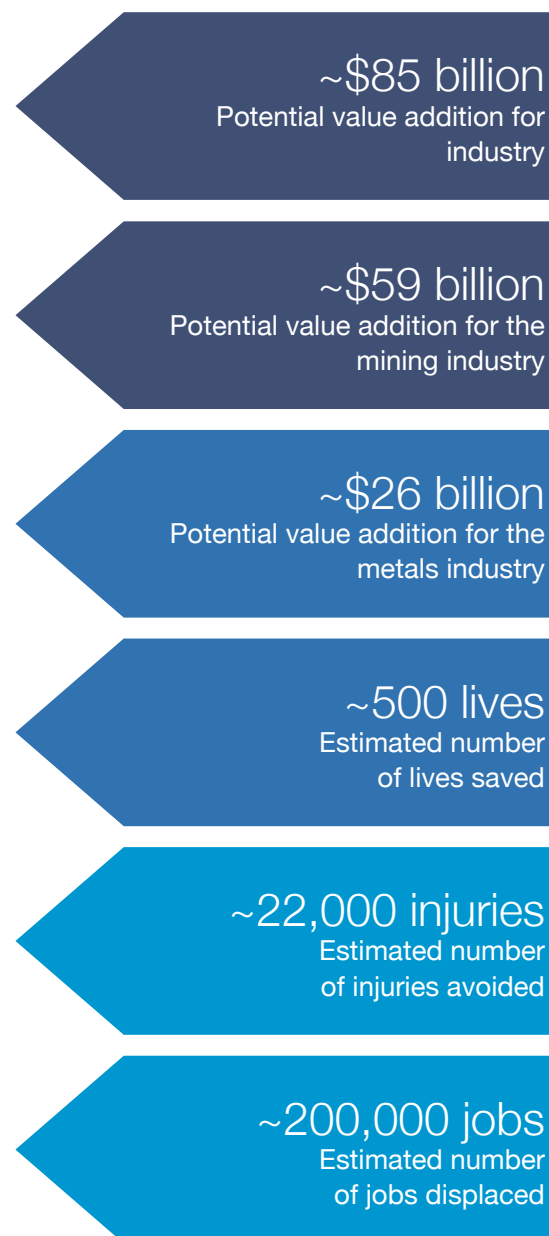
BHP Billiton is an Anglo-Australian multinational mining, metals and petroleum company headquartered in Melbourne. In 2013, it opened an Integrated Remote Operations Centre (IROC) in Perth. The IROC provides BHP Billiton with a real-time view of its entire Western Australia (WA) iron ore supply chain and allows it to remotely control its Pilbara mine, fixed plant, and train and port operations from one central location. It took 22 months for the centre to move from the concept study phase to becoming operational. IROC uses a mine fleet-management system, train-control and fixed plant-control systems for mine and port operations, while CCTV and radio systems are used to communicate with on-site personnel. The IROC employs 300 workers, who operate the entire WA iron ore network 24 hours a day, 365 days a year. The facility also provides training and upskilling opportunities for employees. By bringing control and operating staff together, the IROC encourages greater cooperation and collaboration among those working there.¹⁶

Value-at-stake impact

By helping optimize operations, ROCs can deliver approximately \$65 billion in industry value to mining (assuming an adoption rate of 50% by 2025) and about \$12 billion to metals (25% adoption rate by 2025). They can also benefit workers and help the environment. However, the societal impact of reducing employment in remote communities needs to be evaluated.

- **Industry (value addition).** ROCs avoid the need for highly skilled specialists to be on site at mines, while ensuring the availability of technical experts when needed. Having highly skilled individuals on site represents a significant cost for companies, which ROCs can minimize. Net savings in on-site housing, supply and transportation could reach an estimated \$40 billion for mining companies. Logistics control towers look set to be the significant value-adding factor in metals. Assuming 30% market penetration by 2025, they could deliver roughly \$12 billion in savings: \$10 billion as a result of better monitoring; \$2 billion as real-time visibility reduces fuel costs.
- **Society (employment).** ROCs promote knowledge transfer among mining employees. They also help new personnel quickly learn about best practices in the industry or a specific field. Teams working on emerging plays have easy access to the expertise and experience of other employees working at the ROC. Collaboration in the ROC can boost objective decision-making based on data rather than “gut feel” on the ground. Moreover, as the current mining workforce ages, ROCs allow mining and metals companies to increase their appeal by offering long-term and more flexible career options to workers without having to spend extensive periods in often remote and harsh locations. The hope is that this will encourage younger, more urban and female workers who traditionally have not been highly represented to consider joining the industry. ROCs can also improve safety by reducing the number

Value at stake: Connected worker (All figures cumulative, 2016-2025.)



of personnel who need to be present on site in potentially hazardous environments. We estimate they could save approximately 250 lives and avoid more than 12,000 injuries between 2016 and 2025. This will benefit local communities, of course, but those same communities, which are often in remote locations with few major sources of employment, are likely to bear the brunt of mining sector job losses caused by ROCs, which could total 12,000.

- **Society (environment).** ROCs reduce the land footprint of mining sites and lower the number of people required on site. This contributes to reductions in emissions and waste that would be generated to supply those people in remote regions. Lower fuel use and increased logistical efficiency could reduce the mining sector's emissions by about 7 million tonnes (a benefit we value at roughly \$300 million). Over the same period, the metals industry's CO₂ emissions could come down by an estimated 9 million tonnes (\$400 million).



c. Integrated enterprise, platform and ecosystem

By connecting IT to operational technology and exchanging data throughout the supply chain and beyond, the mining and metals industry could generate significant value for itself and for society.

This theme focuses on the linking of operations, IT layers and devices or systems within the value chain or the larger ecosystem. Important technologies in this area include integrated sales and operations planning; asset cybersecurity; information technology (IT)/operational technology (OT) convergence; plugged-in, cloud-enabled backbone; smart sensors; digital monitoring, tracking and analysis of environmental/health and safety indicators; integrated, agile supply chain; and advanced track-and-trace technology.

IT/OT convergence

This digital initiative looks at linking OT, IT layers and devices or systems that are currently separate. End-to-end integration can take place within the traditional value chain or the industry's larger digital ecosystem.

IT and OT are coming together via the Internet of Things (IoT), which connects objects to internet infrastructure via embedded computing devices such as radio frequency identification (RFID) chips and sensors.

Case Study: Schneider Electric – Using Integrated Planning to Optimize Mining Supply Chains

Schneider Electric's Integrated Planning and Optimization Solution (IPOS) is designed to optimize supply chain efficiency for mining companies. It aims to prevent problems in one area – such as delayed trains or ships waiting for products to arrive – from propagating through the chain. IPOS provides enterprise-wide visibility across product management, procurement, energy management and supply chain management. It claims to boost productivity by up to 20% through optimizing the resource-to-market chain. It might do this by helping reduce excess energy and water consumption, resolving maintenance and production conflicts that cause delays, or minimizing excess inventory resulting from unreliable supply chains.¹⁷

Value-at-stake impact

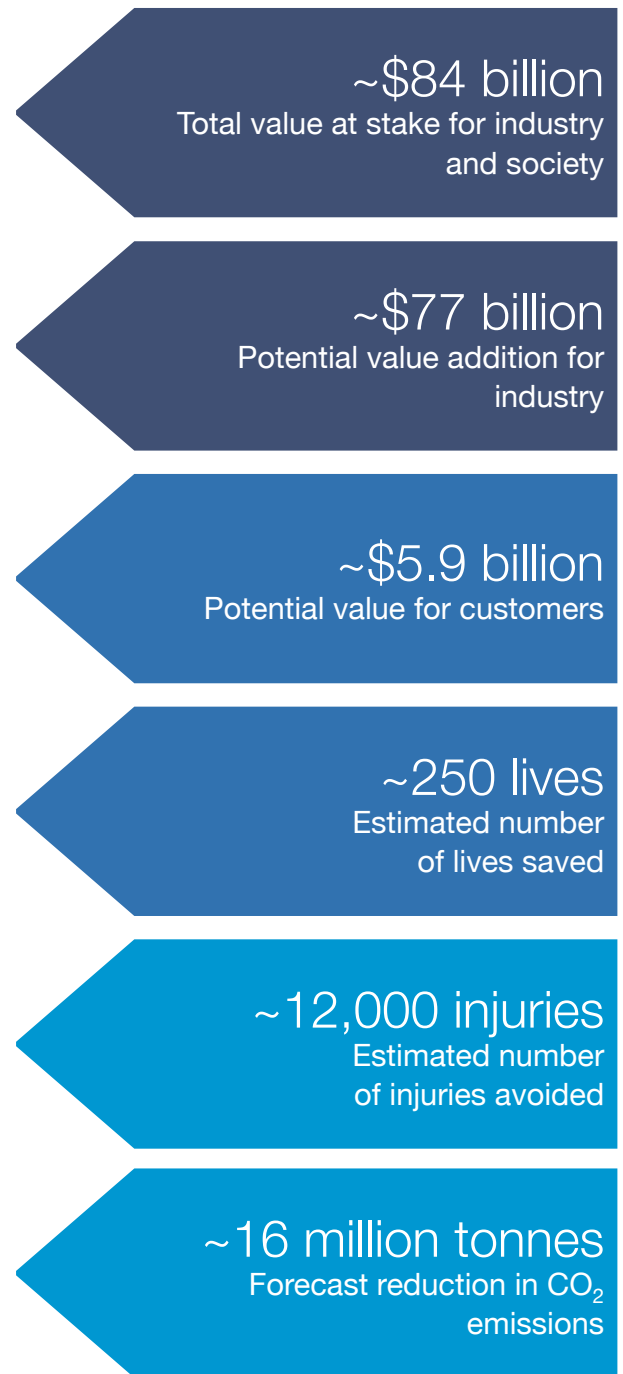
Value at stake for IT/OT convergence has been valued implicitly within other initiatives. To avoid double counting, we have not included a separate value at stake for this initiative.

Integrated sourcing, data exchange, commerce

This initiative focuses on leveraging technology to exchange or integrate data – and thus boost collaboration – across multiple steps of the value chain. This could take place across functions within one company or even beyond – including, for instance, key partners such as suppliers and customers. Digital technology is the enabler for all this, providing the platforms and the applications to generate value.

Value at stake: Remote Operations Centre

(All figures cumulative, 2016-2025.)



Within the supply chain, platforms can automate the exchange of information such as forecasts or delivery schedules with customers and suppliers. Beyond the supply chain, local communities are mobilizing digital platforms to inform and empower. Increased stakeholder access to data and information, and the ability to share in real time, can challenge mining companies and be an important tool for building transparency and trust.

Community platforms can leverage information from enhanced track-and-trace solutions across all phases of a product's life cycle – from raw materials to consumer receipt of the finished product. When physical tracking of an ore or

metal via sensors is combined with the ability to store and track distribution and transaction data through a value chain via metals accounting or technologies such as blockchain, it allows the community, governments, customers and the market to financially reward firms that are acting responsibly and discourage illicit or unsustainable mining practices.

Case Study: Klöckner & Co. – Selling Higher Value-added Products Direct to Customers via Online Platforms

Headquartered in Duisburg, Germany, Klöckner & Co. is an independent steel producer and metal distributor with a history that runs more than 110 years. It has realized that its key assets will soon be its platform and intellectual property. Under the kloeckner.i brand, the company has set up a separate entity to drive its digital transformation and create a leading internet service platform for the entire steel industry. On one side, it is integrating its suppliers – big steel producers and start-ups in scrap metals – and, on the other side, its customers. The platform includes a contract platform to get real-time information about contracts and enable direct ordering, a web shop, a mill certificate platform, later delivery notice, and 08:05 mailing on special offers (“daily deals”). The ambition of Klöckner CEO Gisbert Ruehl is that half of all transactions go through this platform.¹⁸

Case Study: Teck Resources – Using Real-Time Data Feeds to Increase Transparency

Canada’s largest diversified mining company, Teck Resources has used digital tools to build awareness and trust around the environmental impact of its operations. By using sensors with frequent data feeds in watershed management, the company has been able to find slight variations it was unable to identify through daily sampling techniques, while simultaneously sharing hourly results on dust particles and water quality near its sites at Carmen de Andacollo, Chile, and Elk Valley, Canada. This helps the local communities understand its impact and feel safe, and allows analysis and reporting by government.¹⁹

Case Study: Antofagasta Minerals – Using YouTube Channels to Increase Transparency

Antofagasta Minerals is a Chilean mining company that searches for, produces and sells copper and other minerals. In 2015, it started to use social media networks such as LinkedIn, Facebook, Twitter, YouTube, Flickr and Instagram more proactively. This has strengthened the link between the company and its stakeholders in these increasingly relevant forums. To further build community trust through transparency, the firm actively seeks opportunities to enhance their stakeholder engagement through digital media. For example, during a recent series of sessions to resolve longstanding differences with the community of Caimanes, their subsidiary Los Pelambres brought in the Chilean chapter of Transparency International to monitor and share information, making these meeting public by providing access to videos of these sessions on their website.

Value-at-stake impact

This initiative has the potential to benefit the industry, both financially and through improved relationships with local communities, while bringing even bigger value to its customers. Quantifying the impact of improved community relationships is difficult, though one recent study quantified every week of shutdown at a \$5 billion mine to be worth \$20 million.²¹

- **Industry (value addition).** Integrated B2B commerce platforms offer metals companies the opportunity to bypass traders and supply customers directly. This may require extra distribution and sales, but it could also increase margins and even volumes by “cutting out the middleman” and raising marketing and sales effectiveness. Disintermediation resulting from the use of these platforms could boost the metals sector by about \$22 billion between 2016 and 2025.

By exchanging and integrating data, integrated sourcing platforms can improve supply chain planning – mainly through better visibility, automation, synchronization and coordination – and thus reduce sourcing costs (on the buying side) and distribution costs (on the sales side) in both the metals and mining sectors.

Assuming that adoption rates for both B2B commerce and sourcing platforms climb from 3% today to 15% in 2025, we estimate that all platforms could add total value to the metals industry of approximately \$35 billion. Sourcing platforms alone will positively impact mining (\$2 billion).

- **Society (customers).** If metals companies pass on just 1% of the cost advantage of selling direct to customers, the financial benefit to those customers could reach roughly \$69 billion.
- **Society (employment).** As procurement and sourcing are streamlined, the need for personnel in those departments will decrease. In metals, we estimate net job losses could be 4,000 between 2016 and 2025.

Asset cybersecurity

The scale of cyberattacks by hackers, criminals and governments is unprecedented. Asset cybersecurity is the collection of tools, policies, concepts, safeguards, guidelines, risk management approaches, actions, training, best practices, assurance and technologies that can be used to protect the cyber environment, and an organization’s or user’s assets within. Those assets include connected computing devices, personnel, equipment infrastructure, applications, services, telecommunications systems, and the totality of transmitted and/or stored information in the cyber environment. Within mining and metals, the connection of network systems includes hardware and sensors of the manufacturing execution systems (MES) often used in ore and metals processing and plant production.

General cybersecurity objectives comprise availability, and integrity – which may include authenticity and non-repudiation – and confidentiality. In a mining and metals setting, the integration of plant operations technology with wider business and enterprise systems means systems that

were not historically connected to the web are accessible with few safeguards. They are an access point into other enterprise systems from which sensitive or non-public information could be stolen, data affected, production shut down or harm caused to workers.

Case Study: Cyberattack on a Steel Mill in Germany

A blast furnace at a German steel mill suffered "massive damage" from a cyberattack on the plant's network. A report from the German Federal Office for Information Security (BSI) said attackers used booby-trapped emails to steal logins that let them access the mill's control systems. This led to parts of the plant failing and meant a blast furnace could not be shut down as normal. The attackers used targeted emails and social engineering techniques to infiltrate the plant. In particular, said the BSI, a 'spear phishing' campaign aimed at particular individuals in the company tricked people into opening messages that sought and grabbed login names and passwords. The phishing helped the hackers extract information they used to gain access to the plant's office network and then its production systems.

Value-at-stake impact

Effective asset cybersecurity can mitigate against both the financial and less tangible damage that cyberattacks can cause.

- **Industry (value addition).** Mining and metals companies will suffer financial losses if money is stolen, information held captive or operations shut down as a result of a cyberattack. If private, competitive information is stolen, a company's returns or stock could be hurt. Assuming that asset cybersecurity centres can prevent 50% of cyberattacks, we estimate that, by 2025, they could have saved metals companies about \$16 billion in avoided costs. Under the same assumption, the mining industry could benefit from approximately \$5 billion in avoided costs.

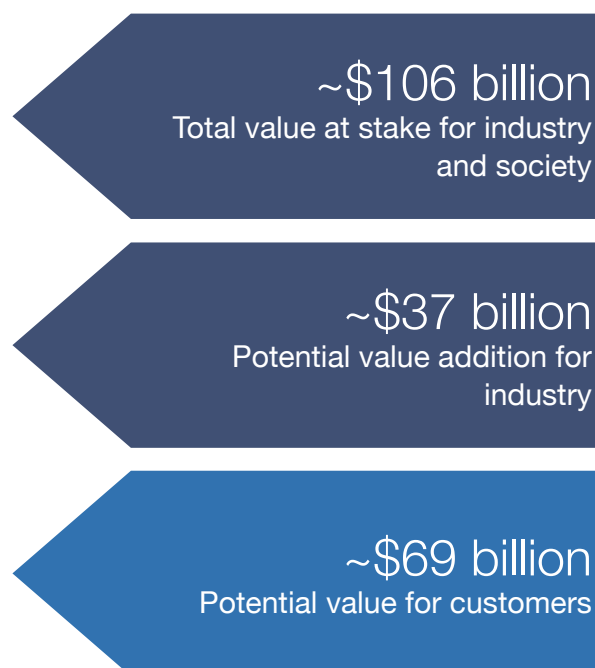


d. Next-generation analytics and decision support

Using algorithms and artificial intelligence to process data can help with real-time decision support and future projections.

Leveraging algorithms and AI to process data from sources within and beyond the value chain is increasingly important to provide real-time decision support and future projections. Important technologies in this area include exploration; ore valuation and build simulation modelling; field development planning, production forecasting and production; asset performance monitoring and predictive asset management/maintenance; advanced analytics for demand forecasting; integrated dynamic constraint optimization across the supply chain; digital twin simulation; digitally enabled fraud detection and anti-corruption traceability; advanced analytics for production optimization and maintenance; AI for operations support; and self-aware mine/cognitive networks.

Value at stake: Integrated Sourcing, Data Exchange, Commerce (All figures cumulative, 2016-2025.)



Advanced analytics and simulation modelling

The vast trove of structured and unstructured information that comes from research labs, business units, records or machines is only useful for generating insights when it is processed correctly and with a focus on outcomes. Advanced analytics can pull insights and identify relationships from disparate data sources. In day-to-day operations, it can look at immense data sets for trends and identify opportunities that humans cannot see. Mining and metals companies can use analytics and decision support to make better and faster decisions. From an input-process-output perspective, analytics can optimize materials sourcing, enhance predictive maintenance to increase machine uptime, or adjust processes to create tailored products and services for the customer.

Simulation modelling uses data to mimic reality. It projects operational performance by using what-if scenarios to test the outcomes of changing part or parts of an operation. For mining, it offers better understanding of key drivers, ore bodies or plant operations, and thus helps firms design, plan, decide and coordinate more effectively. In combination with 3D satellite imaging and large data sets, modelling can optimize design without drilling, thereby lowering the investment, waste and physical footprint of the operation.

The size, complexity and format of large data sets complicate the finding of causal relationships. In practice, this makes it difficult for humans to find certain drivers that may impact productivity without assistance from machines. For now, the ability to identify and share key findings and risks between humans and machine is still a work in progress.

Case Study: Mira Geoscience – Providing 4D Geotechnical Hazard Assessment

Montreal-based Mira Geoscience provides software and consulting services to mining industries. It supplies cost-effective, multidisciplinary, 3D and 4D earth modelling and data management solutions for exploration, resource evaluation and geotechnical hazard assessment. It integrates earth-modelling technology with advanced data processing across a range of geoscience applications. Mira forecasts geotechnical hazards quantitatively for design or real-time monitoring applications by combining all relevant geological and geotechnical observations (rock type, structure, rock quality, seismicity, deformation, support, geometry, production, and other data) into a set of spatially modelled, normalized and weighted hazard criteria that deliver an overall hazard estimation. Projects range from forecasting rockburst and water inflow hazards in deep Canadian mines, to slope stability hazards in large South African open pits, and roof fall hazards in Australian coal mines.²⁴

Case Study: Goldcorp – Using Advanced Analytics to Achieve Significant Energy Savings

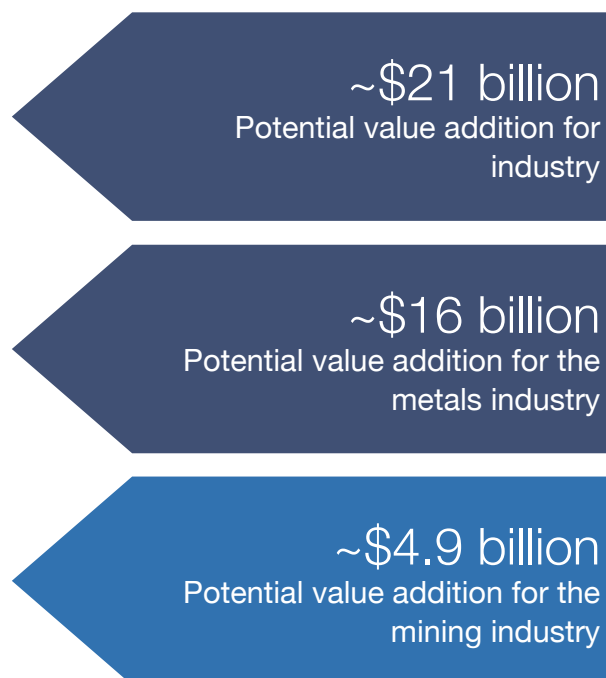
Gold producer Goldcorp was planning to build further diesel generators at its remote Musselwhite operations in Canada. Rather than just building the generators, it first “mined” historic data from sensors and records to identify energy waste and usage trends. By identifying energy savings of 30%, this analysis meant the firm did not have to build additional generators and, furthermore, could shut down current diesel generators except in emergency situations, benefitting the company’s bottom line while also lowering their environmental impact.²⁵

Value-at-stake impact

Though effective analytics are still in their infancy, they are starting to add value to mining and metals operations and are expected to grow in importance after 2025.

- **Industry (value addition).** Across mining and metals, advanced analytics can add value to plant and maintenance operations by identifying operational bottlenecks or waste patterns – after the fact or by predicting where issues are likely to arise. For mining, advanced analytics also promises to identify geological patterns during exploration, helping to more quickly and effectively identify ore value. Simulation modelling uses real-time what-if scenarios to identify the best way to run extraction, processing, production and distribution, based on situational or environmental conditions.
- **Society (environment).** More efficient resource allocation reduces land, water and energy use. In combination with other digital initiatives – particularly smart sensors – advanced analytics can reduce the risk of industrial disasters by enabling more accurate surveillance and prediction of equipment and asset failure.
- **Society (customers).** Customers benefit from the increased product quality that comes through more precise production processes.

Value at stake: Asset Cybersecurity (All figures cumulative, 2016-2025.)



- **Society (employment).** The greater operational efficiency that comes through more effective, automated planning and decision-making could reduce the number – or change the nature – of jobs.

Artificial intelligence

Definitions of AI differ widely, but generally refer to computer systems that can perform tasks that normally require human intelligence, including visual and speech recognition, decision-making and language translation. Greater computing power, big data and better algorithms have propelled recent breakthroughs in AI.²⁶ AI and machine learning are already being used in consumer-facing applications such as Apple’s Siri or Amazon’s Alexa. Interest and improvements in the technology are expected to continue; in 2015 alone, more than \$2 billion has been invested in AI applications by venture capital firms.²⁷

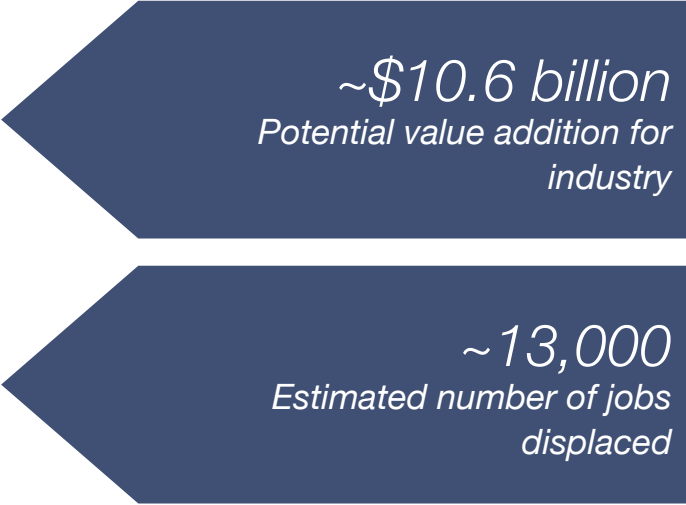
To support humans in the processes of problem solving, machines must analyse massive amounts of data from various input sources such as mining equipment, worker equipment and databases. In this way, AI can help decision-makers make more informed choices, optimize yields and minimize environmentally harmful inputs. It can also help companies exploit the full benefit of robotics by managing and continuously improving their performance. Computing power can surpass the processing capability of humans and fully run an almost completely independent, optimized operation that can learn and improve over time. AI can draw on disparate data sources to create a holistic view of historic, real-time and projected operations, and control a vast network of interconnected sensors and robotics within a mine or plant.

Value-at-stake impact

Though it was not quantified in this study due to the nascent and uncertain nature of AI within mining and metals in the next decade, AI promises to have an important impact on both sectors and, beyond that, on society and the environment.

- **Industry (value addition).** AI should boost efficiency through improved operational throughput, as de-bottlenecking is done intelligently on an ongoing basis. It should decrease waste in production processes, as input materials and stock levels per unit of output drop.
- **Society (employment).** Health and safety can be improved dramatically, as humans rarely have to be in dangerous locations. Whole mines can shift to be more process-oriented rather than people-oriented. Reduced human involvement in operations could mean fewer jobs, or a shift in the nature of those jobs towards non-routine activities.
- **Society (environment).** Environmental gains include much smaller carbon footprints, as mines can be dug steeper and deeper with fewer human safety considerations. Plant builders do not have to consider how people avoid workplace hazards such as furnaces, kilns and heavy machinery. Instead, by focusing on key performance indicators including the identification and correction of value and consumption leakage, AI can further reduce water and electricity consumption, and carbon emissions.

Value at stake: Advanced Analytics and Simulation Modelling (All figures cumulative, 2016-2025.)



~\$10.6 billion
*Potential value addition for
industry*

~13,000
*Estimated number of jobs
displaced*

Value-at-Stake Analysis

To quantify the impact of digitalization in mining and metals over the next decade, we have developed a detailed model of the impact on industry and wider society of each digital initiative in our study.

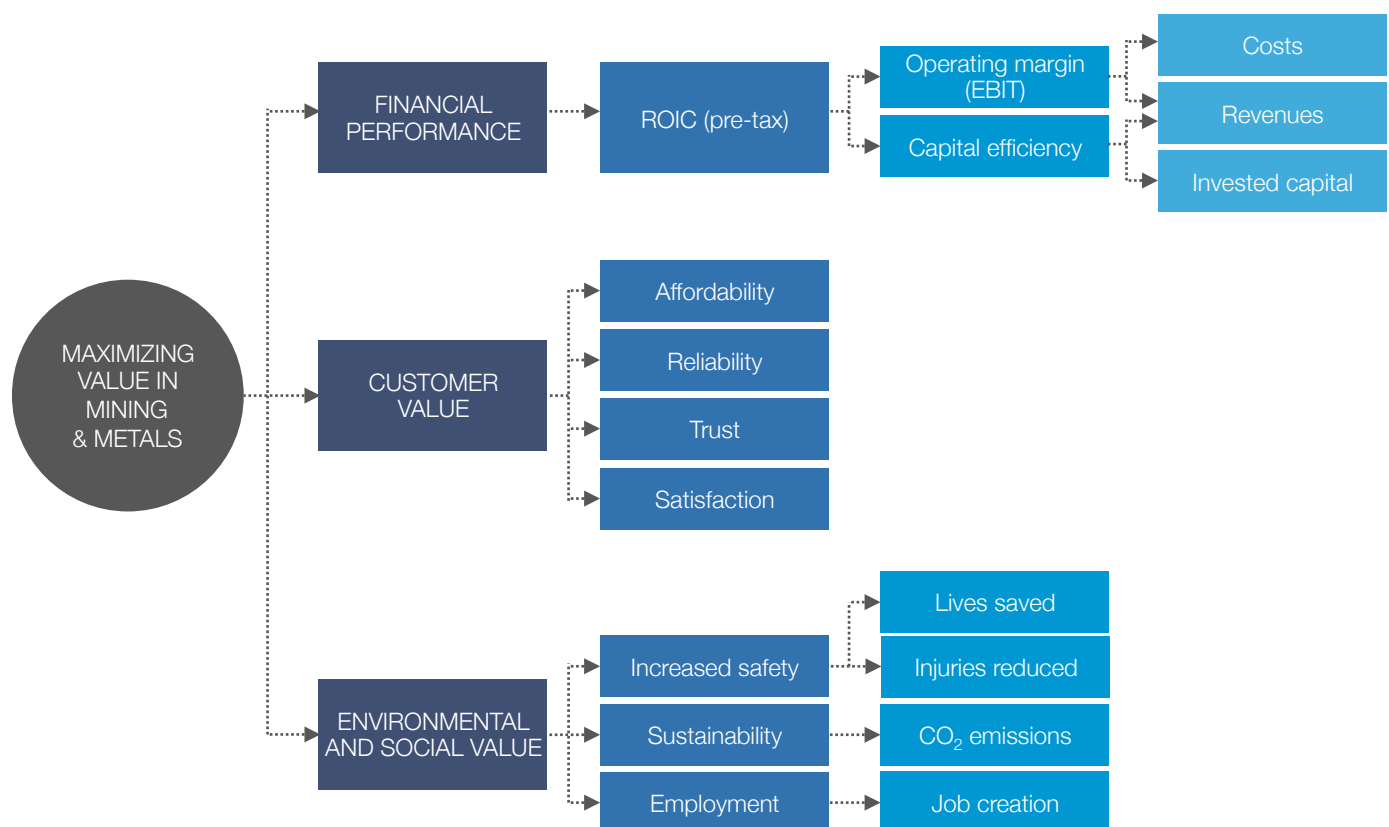
a. Methodology

Digitization does not have to happen outside of organizational priorities and, indeed, can play an important role in forming a cohesive response to these industry shifts. Digital technologies have tremendous potential to move beyond stagnant growth and deliver exceptional shareholder, customer and environmental value. Value creation in mining and metals is a function of financial

performance, and customer, environmental and societal value (see Figure 4).

Using these value drivers and a set of assumptions about the adoption rates of different digital innovations, we have developed a detailed value-at-stake model to assess the impact of digitalization. An explanation of our value-at-stake methodology can be found in the appendix.

Figure 4: Maximizing Value in Mining and Metals



Source: World Economic Forum/Accenture analysis

b. Value-at-stake findings

Value-at-stake headlines

Digital transformation represents a substantial opportunity for mining and metals. Across value migration and value addition to industry, and value shifts to customers, society and the environment, our estimate of cumulative economic value for the period 2016 to 2025 ranges from \$428 billion to \$784 billion.

In terms of non-economic benefits, digitalization has the potential to reduce CO₂ emissions by approximately 600 million tonnes, save almost 1,000 lives and avoid more than 44,000 injuries over the next decade. Balanced against this, we project that digitalization could lead to almost 330,000 job losses within the industry. To understand the scale of these impacts, these estimates equate to nearly 10% of lives that would have been lost, 20% of injuries that would have occurred and 5% of industry jobs that would have existed.

Key findings include:

- Digitalization could create more than \$320 billion of value for the industry over the decade to 2025, with a potential benefit of approximately \$190 billion for the mining sector and about \$130 billion for metals. The estimate of \$320 billion equates to nearly 3% of mining and metals revenues and 9% of profit during this period.

- Through productivity gains and personnel cost reductions, remote operations centres could deliver an estimated \$65 billion in value to the mining industry.
- If key customer industries adopt integrated platforms, customers can benefit from price reductions from mining and metals suppliers worth roughly \$69 billion.
- Autonomous operations have the potential to reduce fuel and energy consumption across the mining and metals sector, creating benefits for wider society that we value at about \$19 billion.
- Although productivity gains delivered by connected workers could bring approximately \$60 billion in value to mining and \$26 billion to metals, they could also result in the loss of roughly 200,000 jobs.

Value-at-stake adoption-rate and benefit ranges (2025)

To fully understand the impact of digitalization on mining and metals on an annual basis, a range of digital initiative adoption rates were also modelled through 2025. Figure 7 shows the 2025 annualized impact to industry and society, using a low and high adoption rate by industry players of digital initiatives. On an annualized basis, the economic value addition to industry, value shift to customers, and value shift to society and environment is approximately \$152 billion per year in the high-adoption-rate scenario. The annualized non-economic benefits are approximately 237 million tonnes of CO₂, 275 lives saved and 13,000 fewer injuries. However, we estimate the future impact on employment to be the loss of up to 89,000 jobs per year.

Figure 5: Cumulative Value at Stake from Digitalization in Mining and Metals (2016-2025)

	Adoption rate – mining, 2025 (%)	Adoption rate – metals, 2025 (%)	TOTAL ECONOMIC BENEFITS						NON-ECONOMIC BENEFITS			
			Value migration (\$ billion)	Total value addition – industry (\$ billion)	Value addition – mining industry (\$ billion)	Value addition – metal industry (\$ billion)	Value shift – society and customers (\$ billion)	Value shift – environment (\$ billion)	Reduction in CO ₂ emissions (million tonnes)	Lives saved (#)	Injuries reduced (#)	Jobs created (#)
(01) Smart Sensors	20%	22%	\$0	\$34	\$9	\$25	\$0	\$8	161	-	-	-39,826
(02) Autonomous Operations	25%	15%	\$0	\$56	\$47	\$8	\$0	\$19	396	257	10,076	-59,663
(03) 3D Printing	25%	25%	\$0	\$0	\$0	\$0	\$1	\$2	35	-	-	-
(04) Connected Worker	50%	25%	\$0	\$85	\$59	\$26	\$0	\$0	-	471	21,789	-200,541
(05) Remote Operations Centre	30%	30%	\$0	\$77	\$65	\$12	\$6	\$1	16	248	12,452	-11,910
(06) Asset Cyber Security	75%	75%	\$0	\$21	\$5	\$16	\$0	\$0	-	-	-	-
(07) Integrated Platforms	15%	15%	\$0	\$37	\$2	\$35	\$69	\$0	-	-	-	-5,110
(09) Advanced Analytics	25%	25%	\$0	\$11	\$2	\$8	\$0	\$0	-	-	-	-13,094
Cumulative total 2016 - 2025			\$0	\$321	\$189	\$130	\$76	\$30	608	976	44,317	-330,144

Source: World Economic Forum/Accenture analysis

Value-at-stake initiative-level highlights

Several key conclusions emerge from our analysis of the cumulative (2016-2025) and annual (2025) value at stake from digitalization in mining and metals:

- The two initiatives related to digital workers are the largest driver of value for the industry. Connected worker and remote operations centres represent a cumulative value to industry of \$165 billion and a potential annual value of \$53 billion by 2025. The improved productivity of workers from these two initiatives means that we expect them to also drive from half to two-thirds of job losses associated with digitalization.
- Integrated platforms represent the largest driver of value for the metals industry and its customers. These create an estimated \$35 billion of additional value for the metals industry and \$69 billion for customers, who receive better downstream value. Given the uncertainty surrounding this initiative, it is important to note that there is large variability in projections (\$3-\$15 billion).
- Autonomous operations add substantial value for the mining industry (\$23 billion per year in 2025) but, with nearly \$20 billion in cumulative value to environment, they also make up nearly two-thirds of the value shift to society and the environment. This is a result of smarter, more energy-efficient self-monitoring operations.
- The value impact of 3D printing is smaller than expected for a number of reasons. First, metal 3D printing is expected to remain very small in the next decade, and largely confined to high-cost, low-volume goods in the design, aerospace, automotive or medical device industries. Second, using 3D printing to replace current

parts is still very limited and prohibitively costly. Finally, any additional metal usage that may result from direct metal 3D printing is likely to be offset by competition from 3D-printed parts made of substitute polymers and plastics.

- Much of the transformational change to the industry from digitalization will impact people. Digitalization has the potential to help people, by avoiding injuries and saving lives, and harm them, by taking away employment. We expect the prospect of job losses to be a real threat in the short and long term.

In the coming decades, as digital technologies transform how we live, work and relate to one another in what has been termed the Fourth Industrial Revolution, the mining and metals industry should prepare for a "fusion of technologies that is blurring the lines between the physical, digital and biological spheres". As this digital fusion combines with current industry challenges, the scope and disruptive impact of this transformation to industry structure and enterprises over the next five to ten years are expected to be unprecedented.

However, the speed at which digital technologies are adopted and the extent to which the overall structure of the mining and metals industry is transformed are less certain. These topics are explored in this section.

Figure 6: Annual Value at Stake from Digitalization in Mining and Metals in 2025 Based on High and Low Adoption Rate Scenarios

	Adoption rate – mining, 2025 (%)	Adoption rate – metals, 2025 (%)	TOTAL ECONOMIC BENEFITS						NON ECONOMIC BENEFITS			
			Value migration (\$ billion)	Value addition – industry (\$ billion)	Value addition – mining industry (\$ billion)	Value addition – metal industry (\$ billion)	Value shift – customers (\$ billion)	Value shift – society and environment (\$ billion)	Reduction in CO2 emissions (million tonnes)	Lives saved (#)	Injuries reduced (#)	Jobs created (#)
(01) Smart Sensors	12%-50%	10%-45%	\$0	\$3-\$13	\$1-\$4	\$2-\$9	\$0-\$0	\$1-\$3	11-51	11-0	0-0	-1,758- -8,118
(02) Autonomous Operations	10%-40%	5%-30%	\$0	\$5-\$27	\$5-\$23	\$0-\$4	\$0-\$0	\$2-\$9	40-169	40-91	901-3,974	-7,189- -28,758
(03) 3D Printing	2%-40%	2%-40%	\$0	\$0-\$0	\$0-\$0	\$0-\$0	\$0-\$1	\$0-\$1	4-13	0-0	0-0	0-0
(04) Connected Worker	30%-65%	15%-40%	\$0	\$12-\$23	\$6-\$14	\$3-\$9	\$0-\$0	\$0-\$0	0-0	0-114	2,751-5,484	-22,894- -39,902
(05) Remote Operations Centre	20%-60%	20%-60%	\$0	\$10-\$30	\$9-\$27	\$1-\$4	\$1-\$2	\$0-\$0	1-4	1-70	1,256-3,768	-1,122- -3,366
(06) Asset Cyber Security	30%-80%	30%-80%	\$0	\$2-\$5	\$0-\$1	\$1-\$4	\$0-\$0	\$0-\$0	0-0	0-0	0-0	0-0
(07) Integrated Platforms	10%-25%	15%-35%	\$0	\$3-\$15	\$0-\$1	\$3-\$14	\$0-\$17	\$0-\$0	0-0	0-0	0-0	-348- -820
(09) Advanced Analytics	10%-50%	10%-50%	\$0	\$0-\$6	\$0-\$1	\$2-\$4	\$0-\$0	\$0-\$0	0-0	0-0	0-0	-1,579- -7,895
Annual total (2025)			\$0	\$35-\$119	\$21-\$71	\$12-\$48	\$1-\$20	\$3-\$13	56-237	52-275	4,908-13,226	-34,890- -88,859

Source: World Economic Forum/Accenture analysis

Pivoting to a Digital Future

a. Industry challenges revisited

The digital revolution will intensify and accelerate several of the key challenges facing the global mining and metals industry outlined at the beginning of this paper. Yet at the same time, digital technologies can provide mining and metals companies with tools to mitigate and counter these challenges. This dual nature of digital is summarized in Figure 7.

Digital is expected to contribute to weaker global demand for key metals-derived products as a result of digitally enabled consumer sharing models (e.g. Uber), “products as services”, improved supply-chain efficiencies and the expansion of the circular economy. The world will continue to require the output of the mining and metals industry, but per-capita usage in both mature and emerging economies will decline. This lowered demand will intensify current overcapacity in operations. Digital will also play a role in resource nationalism and regulation, as platforms provide capabilities for visibility and monitoring. Finally, digital will have an impact on the workforce, potentially creating a skills and pay gap between the highly skilled digital workforce and workers in the more traditional role that labour has played in mining and metals. This will be especially true in emerging economies.

Digital can, however, help industry and society players to combat or mitigate the negative effects of these industry challenges. It can assist companies in dealing with lower demand and excess capacity by enabling production and value-chain efficiencies. Digital can help companies to meet new customer requirements by encouraging faster innovation for new products. It can increase the industry's appeal to socially conscious customers and governments by empowering more sustainable operations, traceability of products through the value chain, and digitalized stakeholder management and reporting. If managed correctly, digital can be a tool to empower workers through better information and tools on the job, and to educate and train tomorrow's global workforce.

Digital can even play a role in dealing with non-digital industry challenges. It helps companies deal with possible trade-flow disruptions, through the use of analytics and modelling to project and prepare for disruptions, and to quickly respond through digital channels across the organization when these disruptions occur. Even for mining firms dealing with declining resource access and quality, digital offers an opportunity to better model and plan the extraction of ore bodies.

Figure 7: Digital Impacts and Responses to Industry Challenges

INDUSTRY CHALLENGE	INTENSIFIED / ACCELERATED BY DIGITAL	POTENTIAL INDUSTRY DIGITAL RESPONSES
WEAK GLOBAL DEMAND	<ul style="list-style-type: none"> Slower demand growth due to digitally enabled consumer sharing models (e.g. Uber), ‘products as services’, improved supply-chain efficiencies, and the circular economy. 	<ul style="list-style-type: none"> Improved products and value-chain efficiencies to win share from other materials or value chains. New business models based on value-chain disruption.
PERSISTENT EXCESS CAPACITY	<ul style="list-style-type: none"> Digital may improve the viability of weak assets and operations, thereby prolonging excess capacity. 	<ul style="list-style-type: none"> Fast adoption by industry leaders can increase the slope of the industry cost curve, further marginalizing weak players.
INCREASING CUSTOMER REQUIREMENTS	<ul style="list-style-type: none"> Huge disruptions emanating from end-user markets will flow back through the value chain, creating new requirements. 	<ul style="list-style-type: none"> Faster product innovation, new forms of customer service, and closer customer collaboration.
TRADE FLOW DISRUPTIONS	<ul style="list-style-type: none"> Not apparent. 	<ul style="list-style-type: none"> Digital tools to increase agility and mitigate impacts of volatility on operations.
DECLINING RESOURCE ACCESS AND QUALITY	<ul style="list-style-type: none"> Not apparent. 	<ul style="list-style-type: none"> Digital technologies for locating and optimally extracting and processing ores.
INCREASING RESOURCE NATIONALISM AND REGULATION	<ul style="list-style-type: none"> Digital enables greater visibility and monitoring of operations and societal impacts. 	<ul style="list-style-type: none"> Tools to improve stakeholder engagement and reporting.
WORKFORCE SKILLS	<ul style="list-style-type: none"> Gap between existing workforce skills and increasing technical requirements, especially in emerging economies. 	<ul style="list-style-type: none"> Digitally enabled workforce. Automation, robotics, and hardware.

Source: World Economic Forum/Accenture analysis

b. Digital adoption considerations

Our value-at-stake analysis indicated a potential range in the assumed adoption rates for the digital initiatives we assessed, which has an impact on their potential to unlock value for the industry and society. Numerous factors will influence adoption rates for specific technologies and for the overall digital transformation of the mining and metals industry. Two factors that stand out are the inherent complexity and scalability of the technologies themselves, and the transformation ambitions of company executives – recognizing that there will be differing degrees of freedom in this regard based on location, access to capital, legacy issues and other factors.

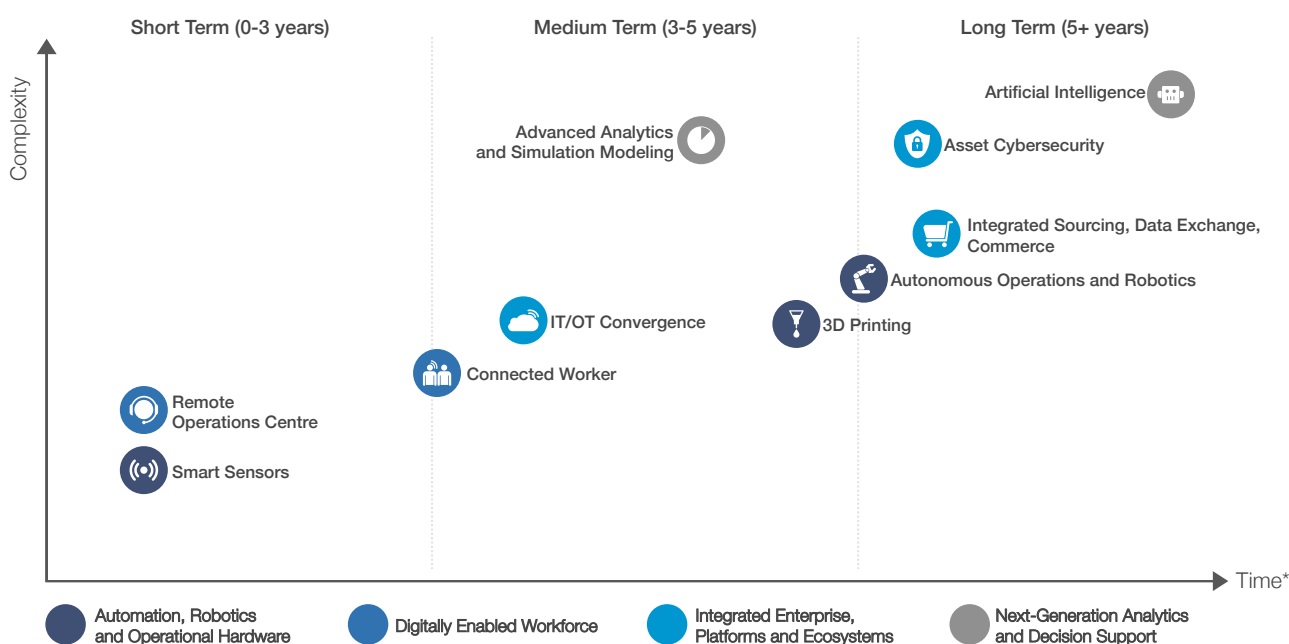
For the digital initiatives outlined in this section of the report, we have estimated the time required to bring these technologies to scale in the mining and metals industry. As Figure 8 illustrates, the complexity of each digital technology and its implementation has a major impact upon the time frame for widespread adoption of that technology.

Digital technologies related to connecting workers and hardware are likely to become more widely adopted in the short term, as they are easier to implement and scale. Technologies related to networks or data are still maturing and are not expected to be reach scale within the industry as quickly.

Another key determinant is the willingness of company executives to commit their companies to digitalization. The digitalization of a company is a journey, not a destination, and we already can see significant disparity across organizations as to how much progress they have made on this journey. Although the use of digital technologies varies across, and even within, companies, we can classify enterprises into three broad categories based on their digital maturity:

- **Digital first movers**
These leaders are able to best respond to digital disruption, using digitalization as a tool to unlock value. First movers are heavy experimenters and adopters across their organization. They actively invest in trial-and-error approaches, and their people are encouraged to collaborate and test ways to use digital. The first mover often has a well-integrated system network and is able to gather data and gain insights from disparate parts of their operation, and quickly respond through digital means – whether centrally at headquarters or in the field through mobile. The first mover is also open to responding to external stakeholders or those outside the firm via social platforms. They can react to changing macroeconomic conditions through digital channels, and even considers realigning their business model to use digital in that response.
- **Fast followers**
These companies are using digital effectively, as a tool in operations. They are comfortable with tested technologies, such as smart sensors or remote operating sensors, but slow to adopt the untested. Employees understand and accept the technology that they use within their role or process. The fast follower often has clear information at the level of a department, asset or value-chain step, but has not yet integrated operational data across the enterprise.
- **Business as usual**
These organizations are not yet digital. Though they may have used traditional sensors or some enterprise-level systems, digital technology is used and consumed in local silos. In response to technology, many disparate small systems and solutions have cropped up to deal with local problems, and employees often use manual workarounds and are distrustful of technology. What digital information can be gleaned from local sensors or sources must be created on an ad-hoc basis from disparate, unstructured sources.

Figure 8: Time and Complexity for Digital Initiatives to Reach Scale



Source: Accenture/World Economic Forum analysis, industry SME interviews and press searches

Figure 9 characterizes each of the four digital themes within the framework of these three “adopter archetypes”. Needless to see, a company may display first-mover characteristics for one part of its business (e.g. a given operation, location or process) and business-as-usual characteristics for others. The journey toward digitization is neither uniform nor smooth.





However, as mining and metals firms put in place strategies and actions to move from one level of digital maturity to the next, the benefits will increase for themselves and society.

Case-in-Point Analysis: Pro Forma Extrapolation of Mining and Metals Value-at-Stake Analysis to an Industry Company

For the industry and an enterprise, the benefits of digitalization are concrete. To understand what value digital adoption might unlock for an individual company, the value-at-stake methodology and technology adoption rates were applied on a pro forma basis to indicative mining and metals companies. Each had 2016 revenues of \$10 billion and a financial structure based on the value-weighted average of firms processing the major mining and metals commodities.

Adoption rates and benefits from digitalization were then applied through to 2025 based on our projected average adoption rate to simulate today’s business-as-usual, fast follower and first mover digital adopters. The results were significant for both mining and metals firms. A fast follower mining company more than doubles its earnings (measured as EBITDA) to 25% versus a business-as-usual organization’s 11%. A first mover more than triples its earnings to 35%, returning to margins more closely associated with the commodity boom years. Though this did not take into effect the capital investment required or competitive responses from other industry players, it is indicative of the potential value a mining and metals company could capture through digital adoption.

Figure 9: Digital Maturity Archetypes in the Mining and Metals Industry

	Business as Usual	Fast Followers	Digital First Movers
 Automation, Robotics and Operational Hardware	<ul style="list-style-type: none"> Traditional disconnected sensors at site level Heavy human involvement combined with automated mechanization in select process steps 	<ul style="list-style-type: none"> Smart sensors within departments Selected processes are automated, with experiments in areas such as autonomous robotics / drones 3D printing under consideration 	<ul style="list-style-type: none"> Integrated enterprise-level smart sensors Integrated automation across sections of value chain, while using robotics / drones in operations Experimenting with 3D printing for production / operations and evaluating potential downstream disruptions
 Digitally Enabled Workforce	<ul style="list-style-type: none"> Little or no use of connected devices to support day-to-day workforce jobs Low worker awareness and willingness to leverage mobile and other digital technologies 	<ul style="list-style-type: none"> Using mobile technology in selected applications Using near or on-site connected operating centres Employees aware and trained at basic level on how to use digital technologies 	<ul style="list-style-type: none"> Integrated mobile technology with remote operating centres, providing real-time information, both push and pull Digitally native workforce is well trained in and actively using technology. Empowered to trial new opportunities for digital
 Integrated Enterprise, Platforms and Ecosystems	<ul style="list-style-type: none"> Systems are siloed within operations Shadow IT solutions rampant No dedicated cybersecurity Connection to outside suppliers, customers and stakeholders is largely manual 	<ul style="list-style-type: none"> Partial connection across levels of IT and operations technology Effective IT standards and processes A few key data interfaces with important customer and supplier accounts Push corporate marketing information out through digital channels Cybersecurity team with IT focus and coverage 	<ul style="list-style-type: none"> Real-time enterprise-level view of operations via fully connected IT cloud enabled platform Key supplier/customer data and systems are fully connected Processes and standards focused on interoperability and flexible integration of new technology Community engagement with digital platforms, including real-time social media listening and transparent environmental/operational data exchange Dedicated cybersecurity team and resources focused on security within IT, operations technology and connecting platforms
 Next-Generation Analytics & Decision Support	<ul style="list-style-type: none"> Decision-making based on disparate data sources manually adjusted on an ad-hoc basis 	<ul style="list-style-type: none"> Combining data from many sources into a few pre-defined static views and KPIs 	<ul style="list-style-type: none"> Automatically identifying insights from data and translating into relevant and useful information for decision makers across levels Use full data sets and analytics to identify areas of improvement, simulate scenarios and projects, and identify optimal decisions Actively research artificial-intelligence options

Source: World Economic Forum/Accenture analysis

c. Digital transformation and industry restructuring

The adoption of digital technologies will modify and accelerate the transformation of the metals and mining industry structure. However, it is not yet possible to identify a single, overriding trajectory or end state since there are multiple, and in some cases contradictory, trends underway. These include:

- **Industry consolidation.** Dispersion in digital adoption rates and the ability to respond to industry and local challenges, combined with slow demand growth, will likely lead to a clearer demarcation of industry winners and losers. This is expected to drive further industry consolidation through M&A and the elimination of unviable businesses.
- **Disintermediation.** Digitally enhanced operating and commercial capabilities will put pressure on existing business models, particularly at the boundaries of value-chain stages. For example, steel and aluminium producers may be able to profitably supply the smaller customers who they had previously ceded to distributors. For miners and early-stage metal processors, 3D printing may enable them to bypass traditional (capital-intensive) metal manufacturing operators.
- **Vertical integration.** The same pressures at value-stage boundaries may also lead to increased vertical integration. The mining and metals industry has a long history of vertical-integration cycles: periods of scarce “upstream” supply and high prices leads to backward integration by midstream companies; periods of slow demand growth and over-supply lead upstream producers to forward integrate. Digital has the potential to strengthen the trend toward vertical integration as a strategy for some companies to respond to industry disruptions.
- **Entry of industry outsiders.** Amazon, Alibaba and other cross-industry platforms have already embarked on the sale and distribution of metal products. Their success is by no means guaranteed, but they are starting to have a disruptive impact. New entrants employing new, lower-cost technologies are emerging at each production stage. Other examples include: “micro miners”, 3D-printing companies and end-of-life recovery companies.
- **New partnership models.** Opportunities for virtual M&A – both horizontal and vertical – will become more prevalent on the back of digitalization. Increased value-chain collaboration, using proprietary and industry-wide platforms, represents one avenue for partnerships, while increased asset sharing is another. It should be noted that while the mining industry (including upstream aluminium) has a long history of co-ownership of assets, this model has seen limited uptake in the steel industry. This, however, is likely to change with digital transformation.

Over the next decade, a plethora of new business models and commercial and technical platforms will spring up, leading to a somewhat confused industry structure. However, these changes are likely to coalesce into one of three different scenarios that could play out within the mining and metals value chain:

Scenario 1: Low disruption

The slow uptake of technology and sluggish pace of change maintain the status quo, as a small number of medium and large companies dominate their separate, specialized parts of the value chain.

Scenario 2: Medium disruption

Metals companies move downstream into value-added services or partner/move upstream to protect supply and pricing. This is the beginning of downstream disintermediation and partnerships that push metals companies closer to customers and to more value-added production. Stricter regulation, higher costs, increased competition, lower demand and depressed prices spark creative disruption. A smaller, leaner field of low-cost or innovative companies emerges. Enterprises expand their use of contract workforces and partners. Larger companies move into the scrap and recycling section of the value chain, enabling them to forge partnerships to provide inputs directly into metals production.

Scenario 3: High disruption

Enterprises move to an asset-light model, as increased risks, higher capital intensity, and more testing compliance with regulations and local licences to operate encourage companies to drastically overhaul their operating model. They begin using close partnerships to run their operations. An increasing amount of work at, responsibility for and ownership of the mine or metals plant is taken over by OEMs (original equipment manufacturers), EPCMs (engineering, procurement and construction management companies), contractors or local labour companies. Disintermediation is complete, and platforms allow direct contact with customers and additional opportunities to sell ore or metal directly through 3D printing. The value chain for metals is greened, and scrap and recycling integrate fully into metals production.

Recommendations for a Successful Digital Transformation

The full value of digitalization will only be unlocked through collaboration. Here are our considerations for mining and metals companies, communities and policy-makers.

a. Recommendations for industry

“

I think there has to be a simple tinkerer mentality and the value has to be evident.

”

Stephen Potter, Global Director, Strategy, Vale International, Brazil



Align business to use innovation in operations and innovate on the side

To take full advantage of the promise of digital, companies must move beyond one-off investments in technology. Instead, they need to build a focused strategy that incorporates digital, and aligns it with their business model, processes and organization, to encourage digital usage and experimentation. For some companies, this could be a robust digital strategy for their current organization. For others, this may mean a separate innovation or technology group that looks across operations and IT.



Look outside of your current business

Players that effectively connect outside their current portion of the value chain can extract further value. For some mining and metals companies, this may mean effectively combining buyer and supplier platforms to integrate and optimize the full value chain. For others, this may be a move downstream, closer to customers and consumers to:

- Differentiate products from commodities
- Move into more value-added or synergistic parts of the value chain
- Draw deeper insights from customer data



Improve data access and relevance

Relevant and reliable information is a cornerstone of mature digital performers. Focus on getting real, applicable insights from data and sharing them clearly and effectively with the right levels of the organization. Hardware, software, network platforms and people are only as good as the information that guides their decision-making and operations.



Engage and train tomorrow's digital workforce

Technology and innovation often fail not through lack of investment or weakness in the technology, but through a lack of cultural change. The digital worker of tomorrow must be engaged and prepared today. Young workers need to be actively pulled into the industry and those populations that do not have the digital knowledge, such as in the developing world or ageing workers, must be trained for digital work internally or through practical educational partnerships.



Invest in alternative benefits, not just jobs

Digitalization will empower some workers, but many of the local jobs of the past may not exist in the future. Invest now in finding other ways to work with and compensate local stakeholders for the responsible use of their resources. Initiatives could include developing infrastructure, supporting education or building expertise.



Forge new partnerships and strengthen existing ones

Digitalization offers opportunities to overcome challenges such as industry specialization, the increased importance of local communities and high capital intensity. Improving active and open partnerships is the foundation for best-in-class digitalization, stronger integration with local stakeholders, and even new models of operation and ownership of mining and metals fixed assets that might lower capital intensity.

b. Recommendations for communities, policy-makers and governments



If we don't want to be sitting here talking about the same thing in another 15 years, we need to be smarter, more sustainable, more responsible in what we do.



Brent Bergeron, Executive Vice-President, Corporate Affairs and Sustainability, Goldcorp, Canada



Define effective digital standardization and regulation

Data exists in vast quantities, but it is often not in a usable or accessible form. The wider community should help define a set of data ownership and format standards that will encourage interoperability and the sharing of information across pieces of the digital ecosystem, while maintaining the levels of privacy and security that are needed.



Prioritize KPIs and aggregate data

Though there are a number of possible key performance indicators (KPIs) that have been used to tie mining and metals to local development, there is no clear standard or repository that can give a full causal view or suggest how to best invest for industry and society. Specifically, environmental and developmental KPIs may be a way to improve sustainability while simultaneously strengthening the new investment potential of responsible industry players.



Improve transparency and traceability

Actively use digital platforms to trace and share information about sourcing, production, and environmental and community engagement. Digital can be a tool to provide better production and supply chain monitoring, while simultaneously building trust. It can also be a way to establish and promote better use of existing data, from historic exploration data to establishing and maintaining legitimate property rights.

Appendix

Value-at-stake methodology overview

Value at stake is a framework designed for assessing the impact of digital transformation initiatives on the industry, customers, society and the environment. It provides a differentiated and evidence-based understanding of the extent of the impact that digital transformation will have on the industry, and where potential value-creation opportunities exist. It provides likely value estimates of global industry operating profits that are at stake, from 2016 to 2025, and the contribution that digital transformation can make to customers, society and the environment in that time frame.

Industry value

Value at stake for the industry comprises two elements. First, the potential impact on the industry's operating profits that will be generated because of the digital initiatives (value addition). Second, operating profits that will shift between different industry players (value migration).

Value to society

Value at stake for society includes three elements: customers, society and the environment. Each element is measured as follows:

1. Value impact for customers: the potential gain to customers (both B2B and B2C) in the form of cost and time savings, discounts and ability to earn additional profits (for B2B only).
2. Value impact for society: the financial and non-financial impact of digital initiatives on productivity gains and jobs.
3. Value impact on the environment: the estimated impact of the digital initiatives on increasing or reducing CO₂ emissions.

Approach

Value at stake has been calculated using a top-down approach involving three key steps:

1. Identification of the total addressable market and the adoption / penetration rates over the next 10 years for each digital initiative based on secondary research, industry reports, existing use cases and interviews with subject and industry experts.
2. Creation of a value tree to represent the different industry and society value categories mentioned above.
3. Testing, revision and validation of assumptions and results with Accenture experts, DTI working group members and select Industry Partners of the World Economic Forum.

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Endnotes

¹ EBITDA differences in the final year of the analysis (2025) were 70%-200% higher for digital first movers versus laggards. This number does not include an analysis of possible competitive responses or one-time capital investment, therefore could turn out to be lower.

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