



MINING 4.0: A ROADMAP FOR DIGITAL TRANSFORMATION

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1. Introduction

1.1. Evolution of Industry 4.0 in mining

Site surveying drones, autonomous trucks, AR / VR for workforce training, advanced analytics, and artificial intelligence - mining is adopting advanced technologies to propel itself into Industry 4.0. The mining industry has always been tech-friendly, constantly evolving – albeit slowly – to improve efficiencies: from steam engines to electrification to smart mining. Now, mining companies which were laggards are focusing on continuous innovation, and partnering with technology providers. Significantly, mining is exploring how new technologies such as labs, automation mines, asset performance, and AI applications can ensure business continuity in a circular scale.

1.2. Our study

In this white paper, we studied 20 mining companies based on market capitalization and digital initiatives. We assessed their

digital solutions to evaluate the role played by Industry 4.0. We conducted secondary research from analyzing companies' public information, journal websites, annual reports and sustainability reports, studies, and news reports.

We also referred to the Acatech Study (2020) stages in the Industry 4.0 development path for assessment, a digital score card to evaluate the companies, and creating opportunities for Industry 4.0 embedded in the mining value chain.

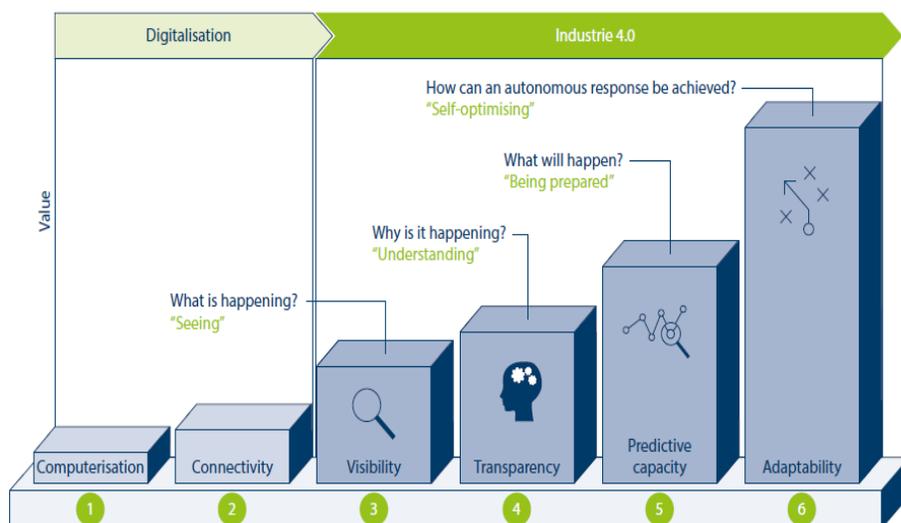


Figure 1: Stages in the Industry 4.0 development path (source: FIR e. V. at RWTH Aachen University)¹

1.3 Trends shaping the mining industry

The illustration below summarizes current market trends for a better understand of the mining industry’s digitalization journey.

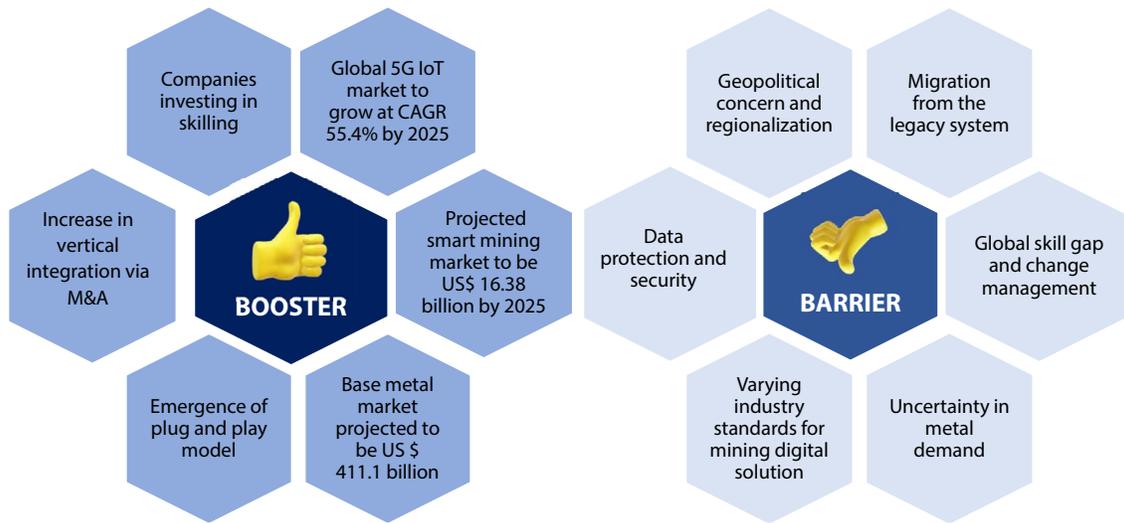


Figure2: Boosters and barriers

2. Assessing Industry 4.0 in a mining enterprise

2.1. Understanding assessment model

Assessment is key to understand the technology know-how within the enterprise and establish its status quo. We developed a framework addressing mining management from an Industry 4.0 perspective.

- The sole aim is to develop a digitally integrated and cost-effective Industry 4.0 solution to connect the subterrain to the

cloud

- To create an efficient and holistic platform to utilize data at various levels of the enterprise for monitoring, analyzing, and reporting

A brief explanation of the components of the assessment model:

Mining management capabilities help to assess a mining enterprise with respect to Industry 4.0. Capabilities are defined to deep dive into mining management and address the need to build solutions that are robust, flexible, scalable, and interoperable.

Mining management is divided into two

categories: business management and site management.

Industry 4.0 technologies are further categorized into enablers and accomplishers.

Enablers are the foundational infrastructure and support systems for implementing Industry 4.0. They consist of two parts: information technology and communication, which complement accomplishers.

Accomplishers are technologies that shape a capability by increasing its efficiency to maintain a healthy demand-supply model.

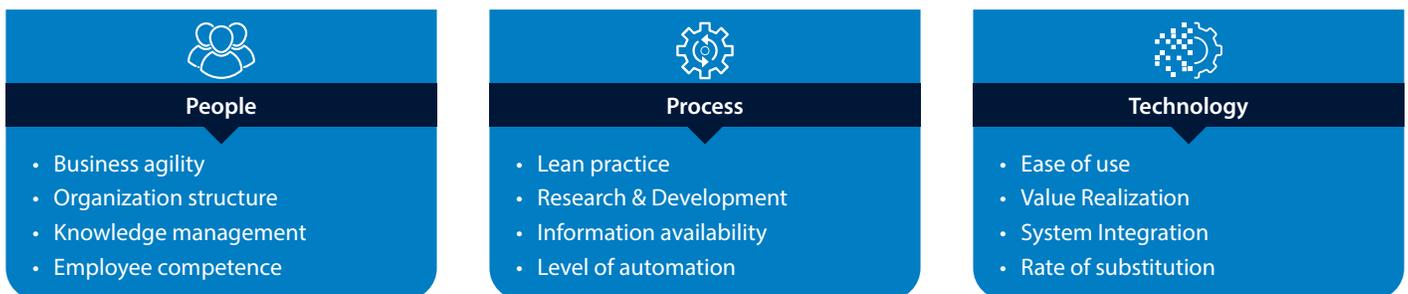
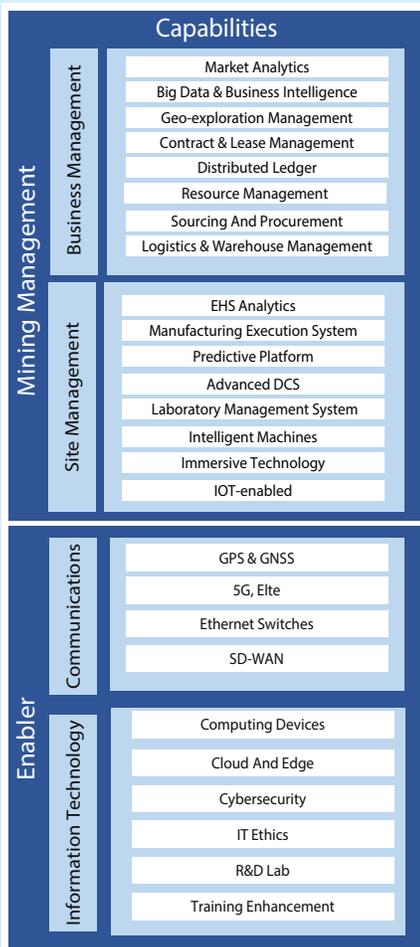


Figure 3: Factors for successful Industry 4.0 implementation

People, process, and technology are considered to be key pillars for a successful Industry 4.0 implementation. The sub-factors for each are mentioned in figure 4. The factors considered for capabilities are surveyed and quantified to arrive at an assessment model. After assessment of these factors, a gap analysis is performed by benchmarking applications, then an action plan is formulated to kickstart Industry 4.0 within the enterprise.

2.2. Assessment model



Mining management can be divided into two categories:

- **Business management:** The goal is to manage market dynamics and corporate affairs to yield the best margins
- **Site management:** The responsibility is optimization of the mine site and production operations

Capabilities for both site and business management (shown in the table to the left) are divided into people, process, and technology factors.

Enablers are the foundation infrastructure and support system - the low hanging fruit - essential for implementing Industry 4.0:

- An underground mine communication and network system for smart operations
- Computational devices to implement Industry 4.0 solutions
- Cloud and edge devices for optimized cost and speed
- Cybersecurity to protect data from cyberattacks
- Innovation for opportunity creation, leveraging best-in-class technology
- Multi-skill enhancement programs and R&D² to adopt newer technologies and change management at various skill levels of the workforce

Accomplishers include technologies which provide the enterprise with a superlative mining experience:

- IoT enablement to make data ubiquitous through the mining lifecycle
- Applied AI³ is the inflection point which helps in the creation of predictive and prescriptive analytics for optimized decision making
- Blockchain platforms ensure end-to-end transparency and seamless transactions
- Business intelligence enables descriptive analytics, making data interpretable, dynamic, and scalable
- A cloud orchestration layer to create a cyber physical system
- Descaling of Industry 4.0 for value-added tasks

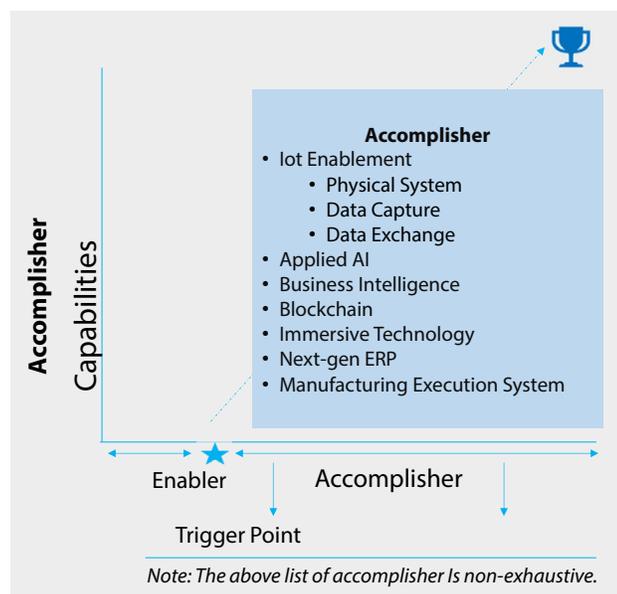


Figure 4: Assessment model



2.3 Assessment formation

Assessment formation⁴ provides a step-by-step procedure to assess Industry 4.0 within a mining enterprise. It consists of three parts: establish enablers, IoT enablement, and data utilization, all of which play equally important roles in Mining 4.0.

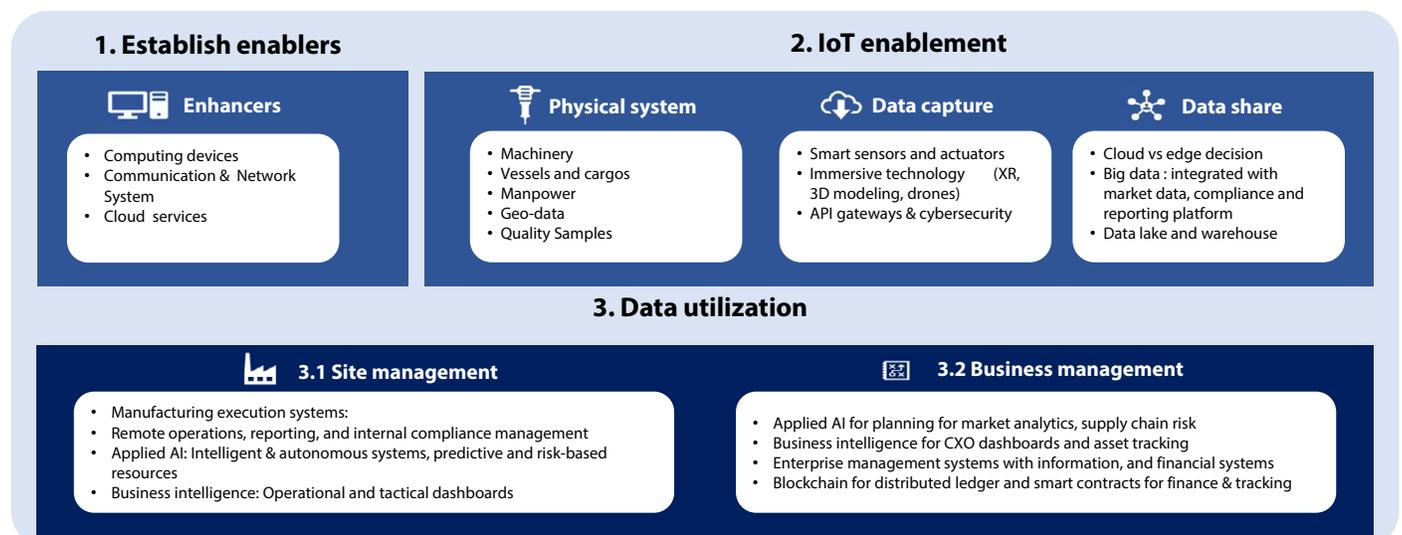


Figure 5: Assessment formation for Industry 4.0

2.4. Value creation in Mining 4.0

Mining enterprises are adopting agile methodologies embedded in Industry 4.0 which demands value creation for a sustainable business model.

- Synergy across the primary activities in the value chain helps in achieving cross-functionality in the enterprise. The established synergy ensures availability of optimized information, enabling proactive decision making, and reducing risks
- Intrinsic values are created by establishing a communication protocol and accountability through a digital framework. It reduces manual effort, and provides operational and financial benefits, and also helps in preparing the next generation of the workforce to work safely in remote environments
- Value creation also helps in shaping digital initiatives, making it customizable according to the needs of mining companies

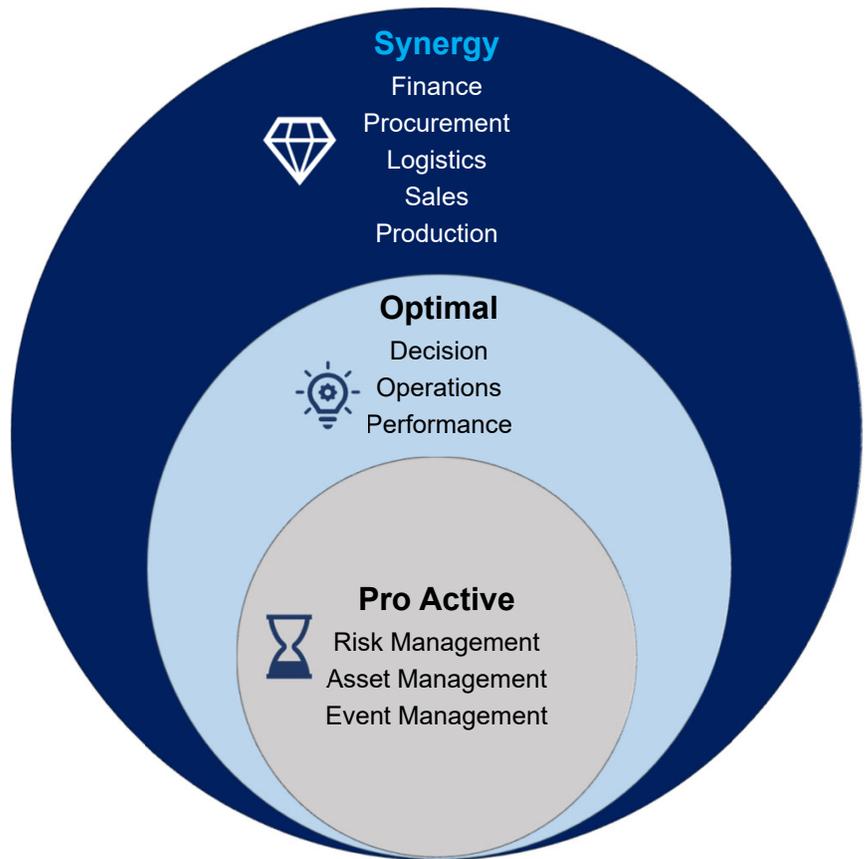


Figure 6: Value creation in Mining 4.0

3. Industry 4.0 landscape in mining

3.1. Mining 4.0 quotient

- We calculated the digital score by allocating a score of 1 if the technology as mentioned in the formula card was involved in the implemented solution, 0.5 for pilot implementation or in-progress work, 0.25 if the technology is in the research and development phase
- The sum of the scores for each enabler, site management, and business management are divided by the maximum possible score to arrive at the final score

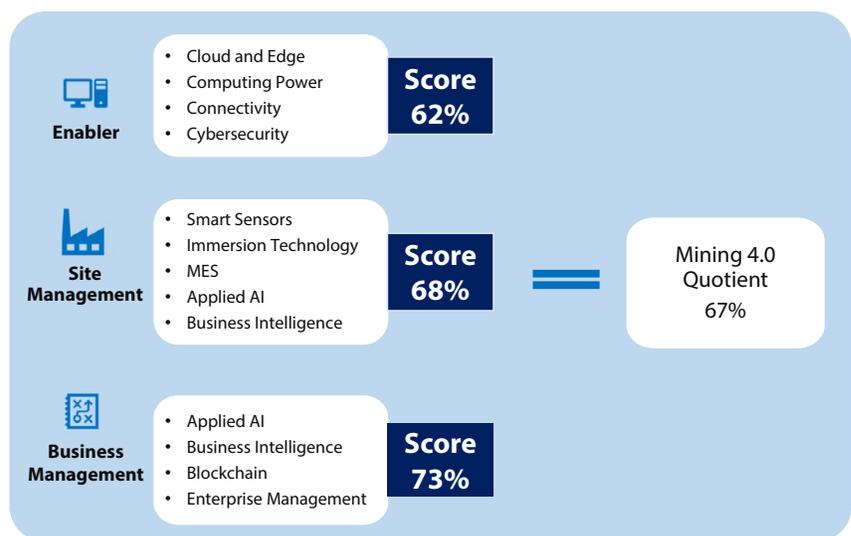


Figure 7: Formula card for Mining 4.0 quotient

3.2. Observations

- Enablers have gained in importance in the past decade because of implementation of cloud-based platforms, which provide computation and cybersecurity, shifting IT managed services responsibilities to new technology service providers.
- Transition from legacy systems, uninterrupted communication systems, and optimizing data usage via the cloud and edge are work-in-progress.
- Site management Industry 4.0 applications have gained momentum due to the need for automation, smart decision-making tools, human-machine interface (HMI) upgrading, and IoT enablement.
- Predictive and prescriptive applied AI are gaining importance due to an increase in equipment utility and optimized utilization.
- The industry outlook is fluid because of inherent risks involved. Data from both markets and mining pits (opencast / underground) need to be analyzed to present system risks via applied AI and BI for strategic decision making.
- Next-generation ERP solutions and blockchain are connecting the mining pit to the marketplace for supply chain efficiencies and transparency.

3.3. Technology interdependency in Industry 4.0

We evaluated technologies from a holistic angle by looking at their convergence. The magnitude of their dependency was deduced from the following analysis:

Correlation:

- *Operational technology (OT) data is aided in modeling predictive and autonomous systems, thus increasing the need for data sense*
- *Analytics and enterprise core applications being deployed on the cloud are preferred, especially when hosted across the value chain*

Business analytics on cloud	0.62
Enterprise core on cloud	0.52
Artificial intelligence with data sense	0.43

Regression:

- *Inference points for any digital initiative taken focus more on business analytics and data sensing*
- *We found that adoption of artificial intelligence was either in the form of work-in-progress or pilot projects, leading to a lower beta coefficient*

R squared	.93
Dependent variables	# Initiatives
Independent variables	Coefficients
Applied AI	0.032
Data sensing	0.64
Business analytics	0.82



4. Mining 4.0 in present context

4.1. Defining solutions via capability

In order to generate and analyze data and implement the corresponding decisions, the existing resources – i.e. all personnel, machinery and equipment, tools, materials

and products – must acquire certain competencies or be upgraded with the relevant technological components. These basic requirements for information-based working and learning are collectively referred to in the model as digital capability.

Mining technology solutions and

service providers analyze an enterprise's capabilities and identify bottlenecks in mining management³. They then develop solutions which enable the mining enterprise to be a cost-differentiator in the market. The figure below offers solutions that help mining enterprises differentiate themselves from their peers:

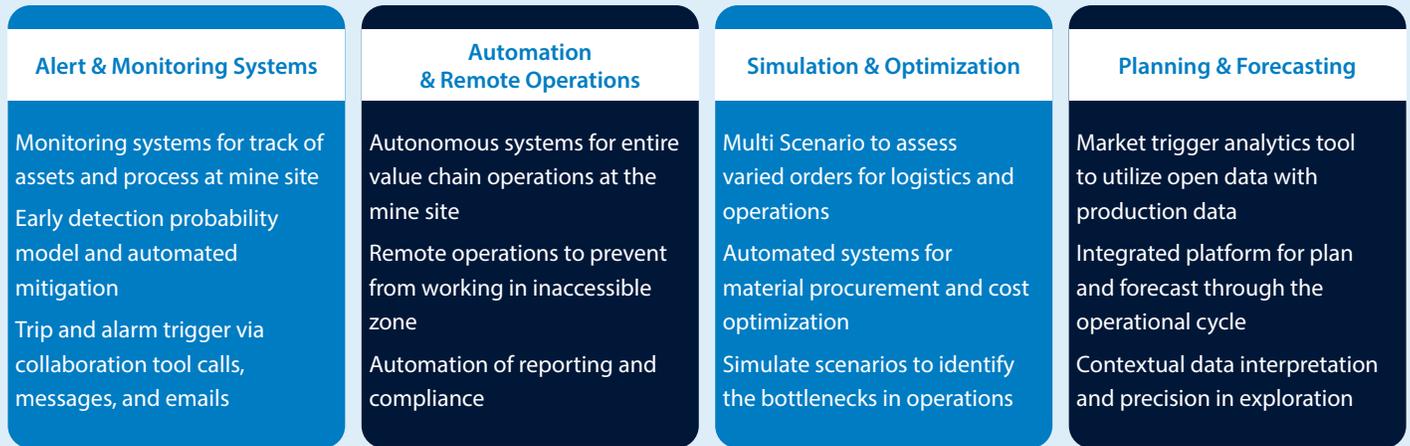


Figure 8: Solutions via capability

4.2. Market trend-based offerings and adoption

We selected trends in mining by identifying the technologies based on the frequency and relevance in the research. Industrial automation, business analytics, and enterprise core are widely adopted by mining enterprises. Cloud and enterprise core with a set of go-to-market strategies are making it easier for implementation, with service-level agreements being defined competitively by service providers. Artificial intelligence and connectivity are gaining prominence in the form of proof of concept (POC), minimal viable products, and pilot implementation due to a wide range of applications that enhance performance across the value chain of operations.

- GPS-less-based tracking systems are being introduced to the market as POC to overcome connectivity problems in closed-pit mining
- Underground mine communication

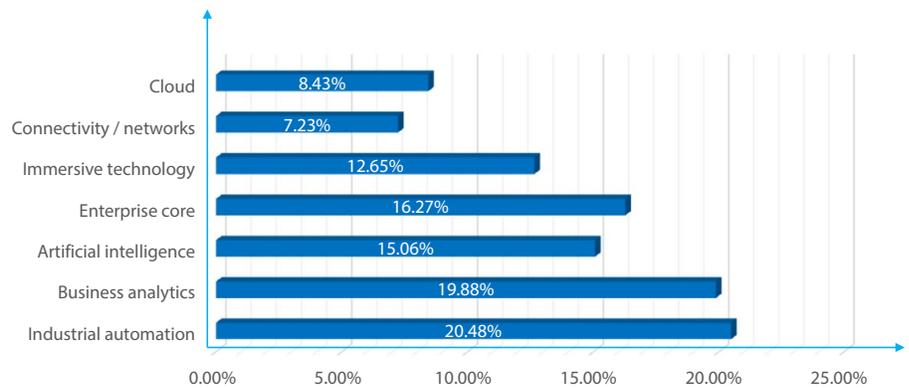


Figure 9: Technology adopted in % frequency per solution

systems for harvesting and analyzing of mine data to improve the throughput rate and plan for forecasts

- Remote operations, predictive maintenance, asset performance management, and advanced distributed control system (DCS) systems make it easier to plan and meet production targets
- Production dashboards, energy management, environment management software enable business

intelligence in mining

- Immersive technologies provide an advanced user experience, improving productivity via safety and operations training, boosting the productivity and safety at operational sites and for the mining workforce
- Advanced CCTV cameras, sensors, actuators, and satellite technologies have helped plan and schedule logistics with warehouses, ports, large trailers, railroads and air transport

5. Applications in Mining 4.0

5.1. Prevailing applications

A mining value chain was modeled to capture the best practices in the industry. The study helped us analyze the prevailing applications which are feasible, implemented, and provide benefits across the value chain. ^(6,7,8,9,10)

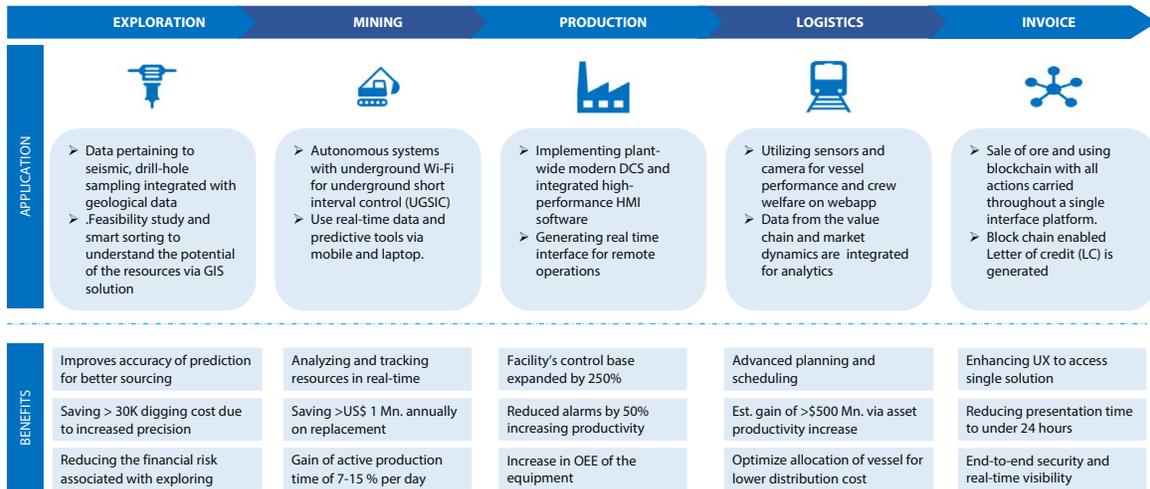


Figure 9.1: Prevailing applications

Enhancers are the practices that have been catalytic in fostering Industry 4.0, giving additional capabilities to the enterprise with added value.

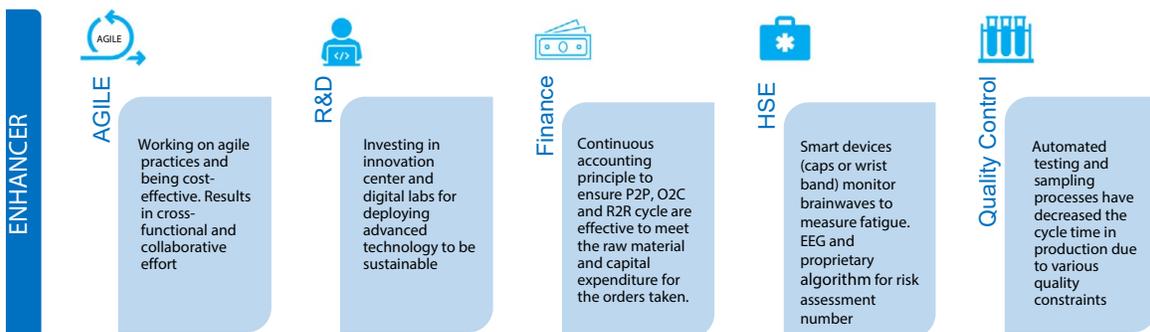


Figure 9.2: Prevailing applications

5.2. Potential applications

The potential applications of technologies have been listed that could benefit companies in shaping the future of mines. The recommendations shared below are based on their fitment in the Specific, Measurable, Attainable, Relevant, Time (SMART)-based framework. The emphasis is on utilizing the vast amount of data useful for creating applications with the characteristics of being futuristic, differentiator, and the market leader. ^(11,12,13,14,15,16)

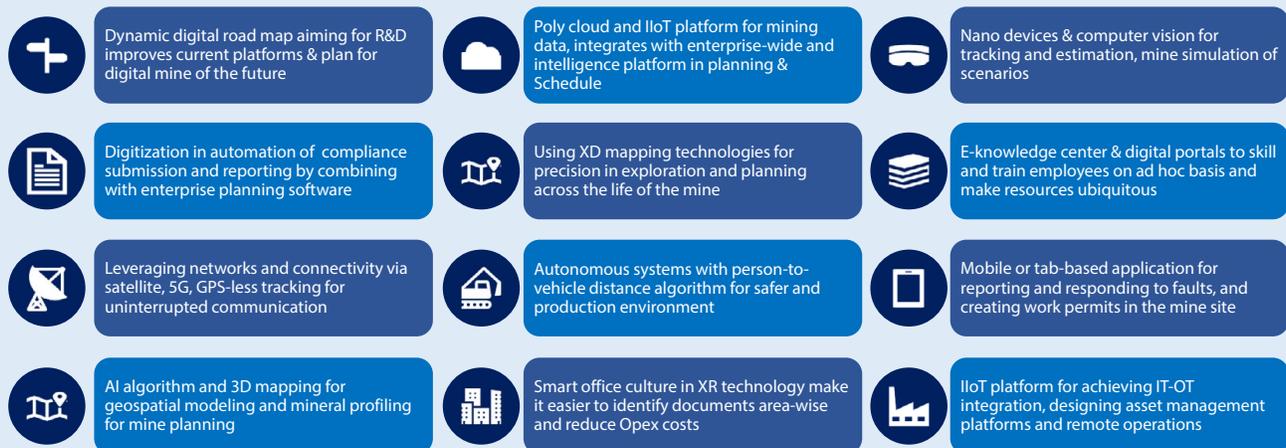


Figure 10: Potential applications

5.3. A holistic view of mining 4.0

As mentioned in section 2.3: Assessment formation for Mining 4.0, we have established enablers, IoT enablement, and mine management as key components. The key pillars of success (figure 3) are assessed based on three factors: people, process, and technology in target and existing state, target state being the ideal

one. The factors and sub-factors are scaled uniformly from 0% to 100% with weights assigned to each and weighted averaged to arrive at the score. The applications are divided into three categories for gap analysis: prevailing applications (figure 8.1 and 8.2), potential applications (figure 9), outdated applications (which are not prevailing or potential applications). After

the gap analysis, strategic decisions on the next set of action plans is undertaken. The possible actions are new addition of technology, operational gains through efficiencies, and creating redundancy for outdated applications. We have modeled the assessment formation, maturity index, gap analysis and action plan as the essential foundation for a holistic view of Mining 4.0.

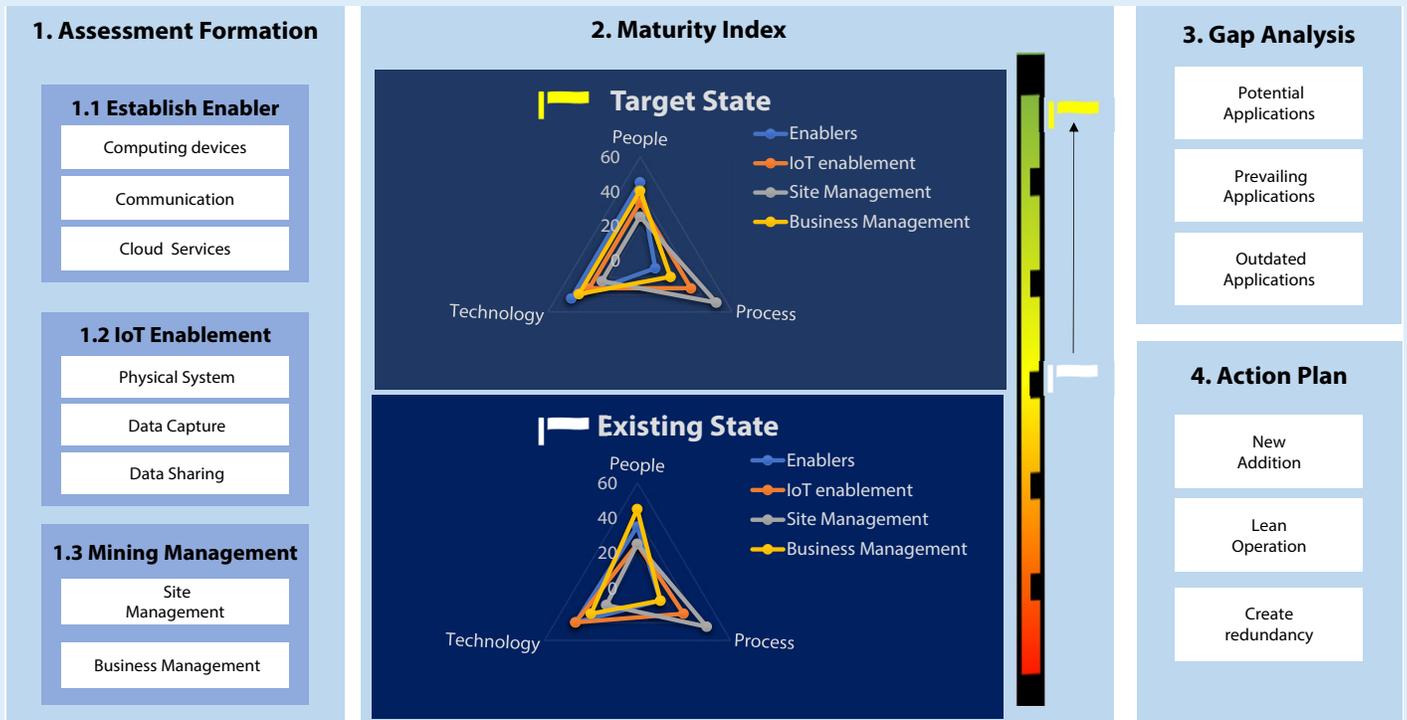
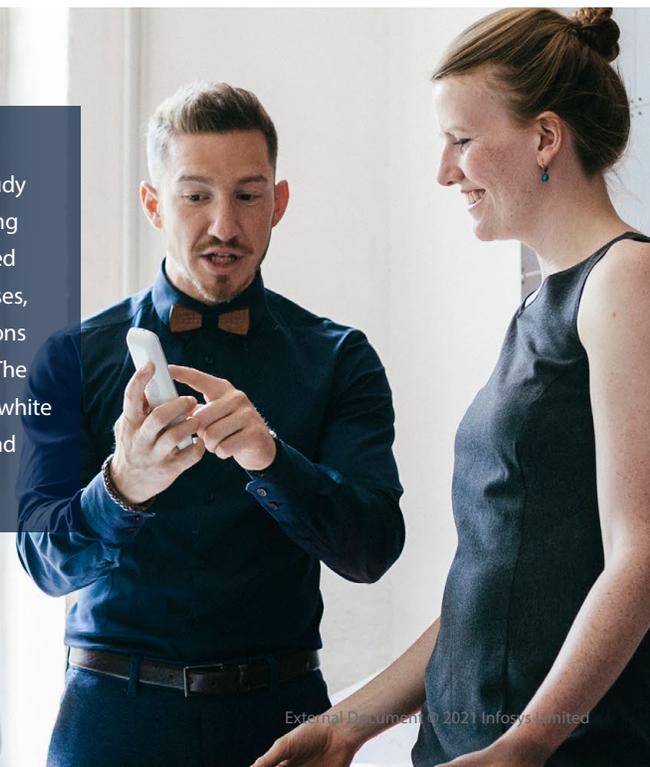


Figure 11: A holistic view of Mining 4.0

6. Conclusion

Mining companies are embracing Industry 4.0 to shape the next generation of the mining lifecycle. The industry is responding to digital needs, and taking it to the next level by adopting state-of-the-art technology for sustainable future operations. Industry 4.0 has barriers to overcome in terms of adoption

geographically, skill alignment, and standardization. The findings of this study indicate that most companies are aiming to develop single platforms with defined multiple capabilities, simplified processes, one-sourced data and informed decisions that could save time, efforts, and cost. The recommendations and findings of this white paper will be useful in developing a road map for Mining 4.0.



7. About the authors

Harish Yendamuri, *Senior Associate Consultant, Mining & Metals, Domain Consulting Group*

Email: harish.yendamuri@infosys.com

Joseph Michael, *Senior Consultant, Mining & Metals, Domain Consulting Group*

Email: joseph.michael@infosys.com

Dr. Indresh Rathore, *Principal Consultant, Mining & Metals, Domain Consulting Group*

Email: indresh.rathore@infosys.com

Avinash Kumar, *Director Global delivery - Process and Resources sector, Manufacturing group*

Email: avinash_kumar@infosys.com

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