Crisil Intelligence

FICCI



Intelligent Mines & Metal Plants

Automation, Digitalization & Technology Integration in Mining & Metals Industries

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by S&P Global

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FICCI would also like to thank CRISIL for preparing the report in consultation with the industry and other stakeholders in the sector. The CRISIL team conducted a detailed and comprehensive study to develop a holistic perspective on the key challenges & opportunities for technology integration into the mining & metals sector.

The report attempts to comprehensively cover the trends & developments, opportunities, challenges, and recommendations pertaining to the emerging technologies in the mining and metals sector, which will help in optimizing production processes, reduce operational costs, enhance safety and increase the industrial competitiveness.

FICCI further appreciates the valuable contributions of various organisations, associations and individual experts in the sector for sharing their insights and contributing to the report. Their views have contributed immensely to finalising the report.

FICCI expresses its gratitude to everyone whose efforts were essential to the creation of this report.

Message from FICCI



India's mining and metals industry stands at a pivotal moment. To strengthen competitiveness, enhance sustainability, and drive growth, the sector must accelerate the adoption of automation, digitalization, and advanced technologies—contributing meaningfully to the country's economic development.

The path forward involves leveraging cutting-edge & innovative technologies such as Artificial Intelligence, Internet of Things, robotics, digital twins, and advanced analytics, revolutionizing the mining operations and metals' production. By embracing these technologies, Indian mining and metals companies would be able to drive innovation and create a more sustainable & competitive industry. Technology integration with mining & metals operations would help in optimizing production processes, improving productivity, reducing operational costs and increasing competitiveness.

In this context, we are delighted to share FICCI's report on Automation, Digitalization & Technology Integration in Mining & Metals Industries jointly developed with CRISIL. The report provides a comprehensive overview of the current technological landscape in India's mining and metals sector. It identifies key opportunities & challenges facing the industry and presents a forward-looking roadmap for technology integration into the operations.

We hope you find the report insightful and a valuable resource for shaping the future of India's mining and metals sector.



Jyoti Vij
Director General
FICCI

Message from Crisil



The mining and metals industry in India has long been a cornerstone of the nation's economic growth, contributing significantly to employment, infrastructure, and industrial output. In recent years, the sector has witnessed a profound transformation, driven by the forces of **automation, digitalization, and technology integration**. As India strives to position itself as a global manufacturing and resource powerhouse, the adoption of cutting-edge technologies has become critical to enhancing productivity, efficiency, and sustainability.

This report, in collaboration with FICCI, delves into the emerging technologies reshaping the Indian mining and metals sector. From Industrial Internet of Things (IIoT) to advanced robotics and data analytics, the report highlights how these technologies are revolutionizing traditional practices. It also identifies the challenges in implementing these innovations, including skills gaps, infrastructure limitations, and resistance to change.

However, the true potential of these technologies can only be realized through effective integration of key enablers — people, processes, technology, and strategic partnerships. A collaborative ecosystem that fosters continuous learning, adaptability, and innovation will be essential for driving long-term success in this industry.

We hope this report serves as a useful resource for industry leaders and policymakers alike. By understanding the challenges, opportunities, and pathways forward, we can collectively contribute to a more resilient, competitive, and forward-thinking mining and metals sector, one that can compete on the global stage while driving sustainable growth in India.



Dr. Sanjeev Prasad
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Crisil Intelligence

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Executive summary

The Indian mining and metal sector is a key contributor to the country's economic growth and infrastructure development. As the sector navigates an increasingly complex landscape of rising demands, sustainability imperatives and intensifying global competition, the strategic integration of automation, digitalisation and technology has emerged as a key catalyst for transformation.

This report comprehensively examines the sector's current landscape, pinpointing critical challenges and opportunities and outlining a roadmap for growth and development. By identifying the essential enablers of digital transformation—including people, processes, and technology—this study provides an actionable framework for industry stakeholders to harness the potential of emerging technologies and drive sustainable competitiveness.

The Indian mining and metal sector holds significant strategic importance, making substantial contributions to the country's gross domestic product (GDP), employment and industrial development. This report delves into the key challenges and opportunities facing the mining and metal industry, including declining ore grades, escalating operational costs, workforce safety risks, market and price volatility and complex regulatory requirements. To overcome these challenges, the industry can leverage digitalisation and automation to transform business operations and realise growth potential. Emerging technologies such as AI, IIoT, automation, integrated platforms and robotics can enhance operational efficiency, reduce costs and build more resilient mining and metal enterprises.

However, the report also highlights several barriers to adoption, including high capital expenditure, shortage of digital skills among workers, inadequate infrastructure in remote areas and the lack of standardised digital frameworks across companies. To overcome these hurdles, the study emphasises the importance of focusing on three critical enablers of digital transformation: people, process and technology.

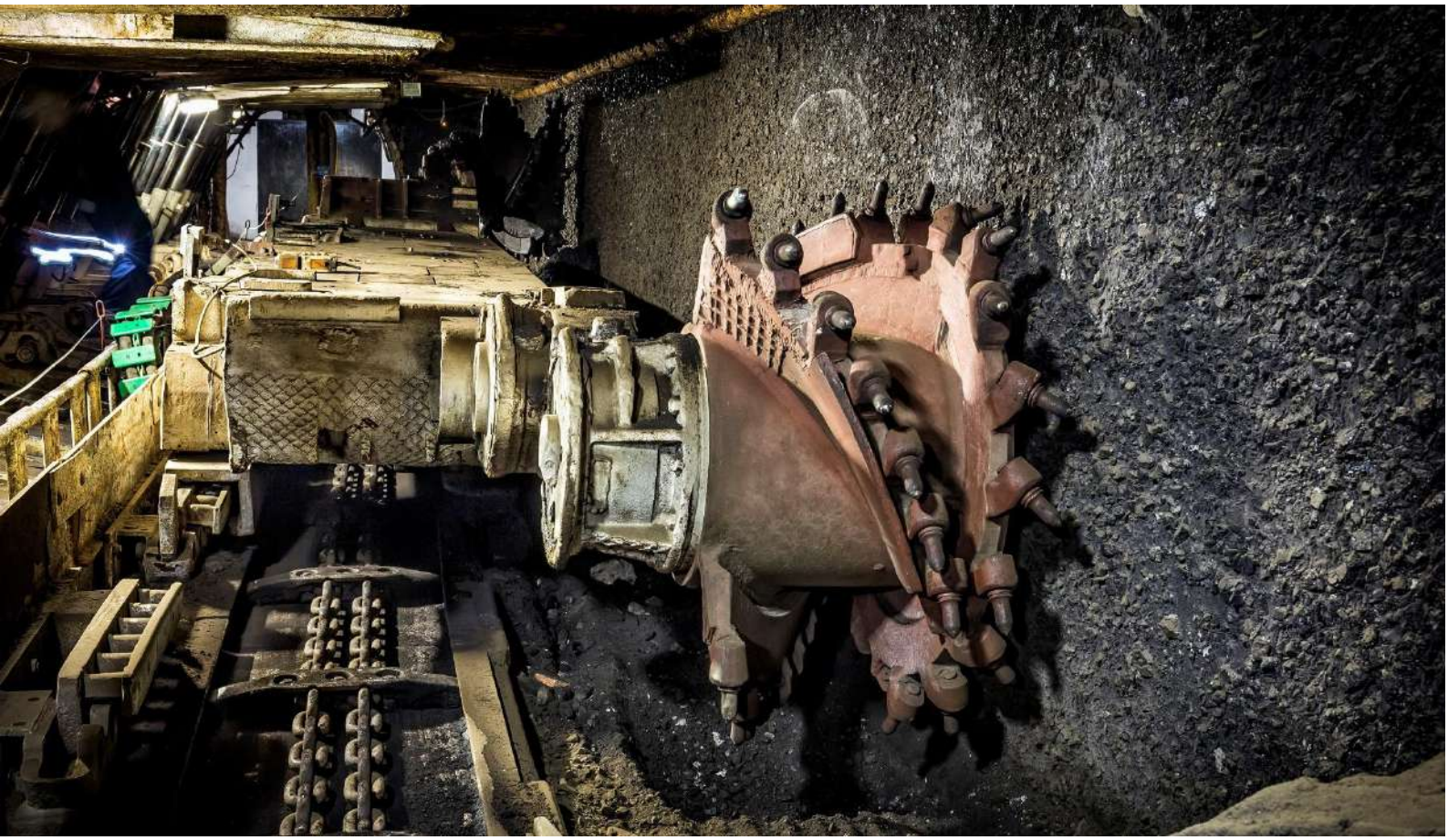
From a people perspective, developing a digitally skilled workforce is essential. This requires investing in training programmes, creating digital-first roles and fostering a culture that encourages innovation and experimentation.

In terms of processes, companies must redesign their workflows to support data-driven decision making, integrated planning, digital operations and predictive maintenance.

On the technology front, the emphasis should be on selecting scalable, secure and interoperable platforms that enable end-to-end digital integration, thereby unlocking the potential of digital transformation and driving business growth, competitiveness and sustainability.

The report also highlights that many companies will need to establish strategic collaborations with experts who combine domain depth with project management skills due to lack of in-house capability, experience or bandwidth to drive large-scale digital projects. This factor will often be the difference between a successful transformation and a stalled project.

We then propose a strategic roadmap for the Indian mining and metal sector, outlining key recommendations to drive growth and transformation. These include harnessing the power of data, bridging the digital skill gap, embracing sustainability and environmental, social and governance (ESG)-driven innovation and adopting scalable and customisable solutions. By embracing digital transformation proactively and responsibly, Indian mining can unlock unprecedented value while securing its place in the global value chain.



1. Mining and metals industry overview

India's emergence as the fourth-largest global economy is a testament to its diverse industrial base, burgeoning consumer market and strategic geopolitical position. It is the only growing major economy in the world, while others are either stagnant or into negatives. With a projected growth rate of 6-7%[1] in this decade, India will continue to remain a substantial contributor to the world's GDP.

The Indian metal and mining industry is experiencing a significant growth phase, driven by increasing domestic demand, policy reforms, technological advancements and increased investment. The mining and quarrying sector accounted for ~2%[2] of the gross value added (GVA) at constant prices in fiscal 2025. The growth in mining GVA was a healthy 2.7% in fiscal 2025[3], indicating a positive trend.

1.1. Macro-economic perspective

The mining and metals sector plays a vital role in the economy, extending beyond its function as a supplier of raw materials. It is a cornerstone of macroeconomic stability, industrialisation, and overall development, providing a foundation for economic growth, job creation, and government revenue. The sector's significance can be gauged from the following aspects:

a. ***Contribution to GDP***: The mining sector makes a substantial contribution to India's GDP, particularly given the country's rich mineral resources.

[1] *IMF – World Economic Outlook (April 2025)*

[2] https://mospi.gov.in/sites/default/files/press_release/NAD_PR_30may2025.pdf

[3] https://mospi.gov.in/sites/default/files/press_release/NAD_PR_30may2025.pdf

Furthermore, it has a strong multiplier effect on the economy, driving growth in other sectors such as power generation, infrastructure, construction, transportation and equipment manufacturing.

b. ***Attracting foreign direct investment***: The mining and metal industry has potential to attract foreign direct investment (FDI), which can have a positive impact on the country's development. As per the FDI policy effective from October 15, 2020, 100% FDI is allowed under the automatic route for the mining and exploration of metal and non-metal ores.

c. ***Infrastructure development***: Development of projects drives the construction of essential infrastructure such as roads, railways, power plants and ports, stimulating broader economic growth. The revenue the government generates from mining such as royalty, auction premiums, taxes and District Mineral Foundation Trust contributions is often utilised to finance public infrastructure and social services. The development of infrastructure drives demand for metal and minerals, while these resources, in turn, support the advancement of infrastructure.

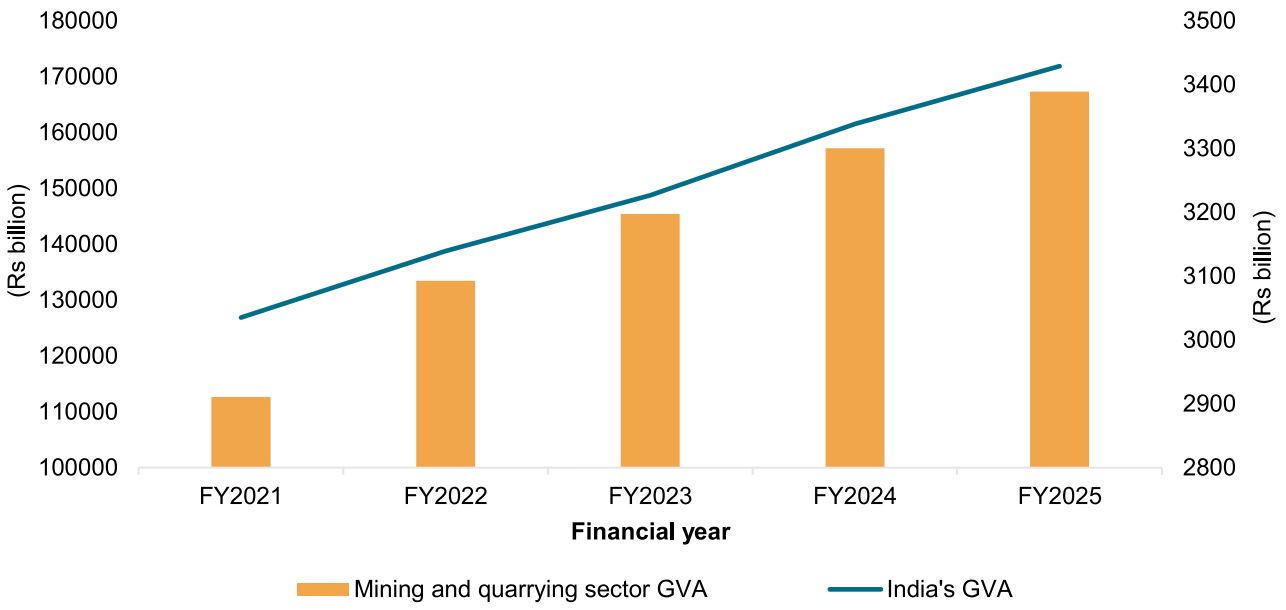
d. ***Industrialisation and supply chain integration***: Metals play a crucial role in the production of various goods, from automobiles and electronics to construction materials and defence equipment. A robust mining sector enables the country to achieve vertical integration, increasing value addition and reducing reliance on imports.

e. ***Energy reliability***: Coal plays a significant role in ensuring energy reliability for India, particularly in meeting base-load electricity demand and supporting industrial needs. Its abundance and relatively low cost compared with other energy sources make it a crucial component of the energy mix in the near future.

f. ***Strategic resource security***: Access to critical minerals such as lithium, cobalt and rare earth elements is becoming increasingly important for the development of emerging technologies, renewable energy and defence systems. As a result, development of mining assets is being prioritised to ensure a stable supply of these essential resources.

g. ***Environmental and social considerations***: The mining sector poses significant environmental and social risks, including pollution, deforestation and community displacement. Hence, innovative processes and emerging technologies need to be used to adopt sustainable mining practices and establish robust regulatory frameworks that prioritise environmental protection, social responsibility, and community engagement.

Table[4]: GVA of India and the mining and quarry sector at basic prices (base year FY 2012)



1.2. Current state

India is endowed with an abundance of mineral resources, producing 95 minerals[5], including fuel, metallic, non-metallic, atomic and minor minerals. Metallic minerals account for ~45% of the country's total value of mineral production. India's coal production has seen a quantum jump of 716 MT to 1048 MT[6] during past five years at annual growth rate of ~8%. The government has taken various initiatives to reduce dependence on imported coal such as auctioning of coal blocks for commercial mining, FDI under the automatic route, provision for sale of excess coal production in case of captive mines, expansion of existing mines, the opening of new mines under Coal India Limited and strengthening the evacuation infrastructure.

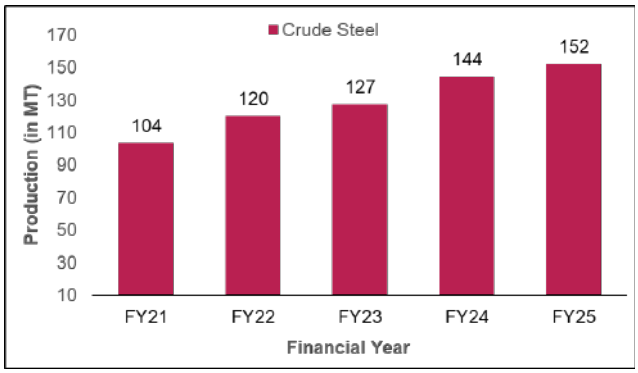
Iron ore is a crucial component, contributing ~36% to the total value of minerals mined in India and underpinning the country's economic framework. The steel industry, a critical component of sectors such as construction, infrastructure, automobiles, engineering and defence, has undergone significant transformations driven by policy initiatives such as the Production-Linked Incentive Scheme for Speciality Steel. India is the world's second-largest steel producer, with a production of 149.6 million ton in 2024, representing 6.3%[7] growth compared with 2023.

India is the second-largest producer of aluminium with an annual production of 3.99 MT [8]. Growth in infrastructure, automotive, renewables and greater dependence on strategic sectors such as defence and energy transition will increase aluminium consumption at more than 10% compound annual growth rate[9].

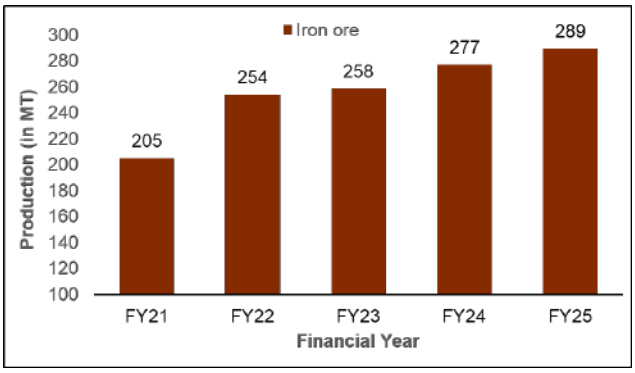
[4] https://mospi.gov.in/sites/default/files/press_release/NAD_PR_30may2025.pdf; https://www.mospi.gov.in/publication/national-accounts-statistics-2025
[5] https://mines.gov.in/webportal/nationalmineralscenario
[6] https://coal.gov.in/en/major-statistics/production-and-supplies
[7] https://steel.gov.in/sites/default/files/202504/Steel_English_AR_2024%20%281%29.pdf
[8] https://ibm.gov.in/writereaddata/files/1748864652683d8e8cdc8f1MSMP_MARCH25FINAL.pdf
[9] https://www.ibef.org/industry/metals-and-mining-presentation

Table[10]: *Crude* Steel, Iron Ore, Aluminium, Zinc-Lead and Coal Production in India

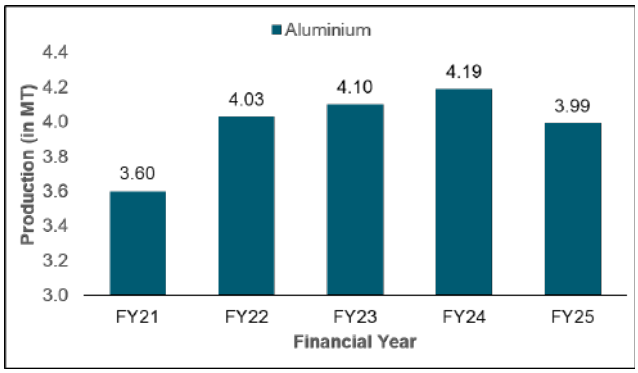
Crude Steel Production (MT)



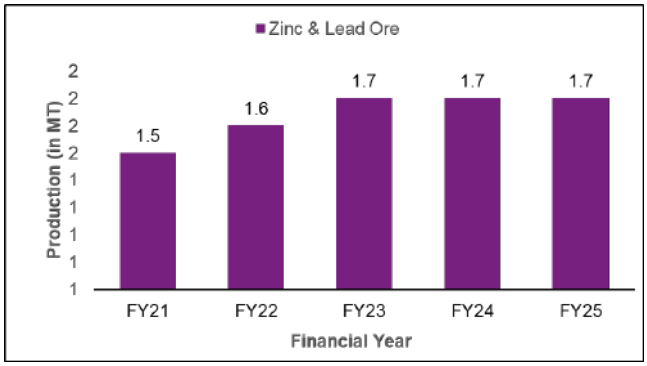
Iron Ore Production (MT)



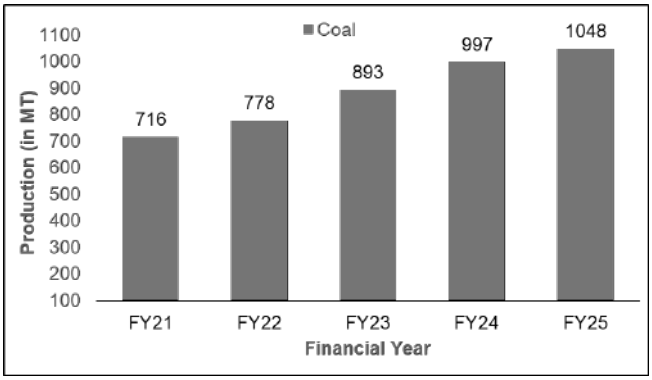
Aluminium Production (MT)



Zinc - Lead Production (MT)



Coal Production (MT)



[10] https://ibm.gov.in/writereaddata/files/1748864652683d8e8cdc8f1MSMP_MARCH25FINAL.pdf
https://steel.gov.in/sites/default/files/2025-04/Steel_English_AR_2024%20%281%29.pdf
https://mines.gov.in/admin/download/67b48dd05215b1739886032.pdf
https://coal.gov.in/sites/default/files/2021-01/productiondata_tenyear.pdf

Table: Annual production of major minerals (world vs India)

Major minerals	Resources		Position as per reserves*	Production in India (FY2025) (MT)#
	World (MT)*	India (MT)*		
Iron ore	2,00,000	5500	8th	289.39
Manganese ore	1,700	34	6th	3.80
Bauxite	29,000	650	9th	24.70
Copper content	980	2.2	15th	0.03
Chromite	1,200	79	4th	3.03
Coal^	10,74,108	1,11,052	5th	1047.69

*{Note: *Major minerals (excluding coal) – resources (world vs global)[11]*
#Major minerals (excluding coal) – domestic production[12]
^Coal – resources and annual domestic production}[13]

The government has introduced initiatives to drive growth in these sectors through sustainable policies, including the decarbonisation of the steel industry and the PM Gati Shakti National Master Plan, which aims to enhance multimodal connectivity through expanded railway lines, new inland waterways, roads and ports. The National Steel Policy, 2017 envisages a steel production capacity of 300 MT per annum by 2030, enhancing domestic per capita consumption to 160 kg by 2030. The government has also taken policy reforms in the mining sector such as transparent allocation of leases, 50-year long-duration mining leases, allowing captive mines owners to sell up to 50% of their annual production and international collaboration for strategic minerals.

Hence, the Indian mining and metals industry is poised for significant growth, driven by increasing domestic demand, policy reforms, technological advancements and increased investment. As the industry moves forward, it is imperative to adopt sustainable mining practices and establish robust regulatory frameworks that prioritise environmental protection, social responsibility and community engagement. In the emerging scenario, the mining and metals industry will embark on an accelerated digital transformation journey that can boost throughput, simplify processes, lower costs, improve metal recovery and yield and reduce supply chain complexity. Even regulators will adopt automation and digitalisation to ensure a hassle-free regulatory environment and address social and environmental effects. However, the industry, with its unique functional requirements, will need partners who understand both domain and digital to drive the implementation.

[11] *Mineral commodity summaries 2025, U.S. Geological Survey -https://pubs.usgs.gov/periodicals/mcs2025/mcs2025.pdf*
[12] *IBM monthly statistics of mineral production, March 2025 – https://ibm.gov.in/writereaddata/files/1748864652683d8e8cdc8f1MSMP_MARCH25FINAL.pdf*
[13] *BP statistical review of world energy, 2025 -https://www.energyinst.org/statistical-review; https://coal.gov.in/en/major- statistics/production-and-supplies*



2. Road ahead: Challenges and potential

India is undergoing an infrastructure development boom, driven by a record-breaking capital expenditure of Rs 11.21 lakh crore ($135+ billion) in the budget for fiscal 2026. The outlay represents a 10% increase over the previous year, accounting for ~3.3% of the country's GDP. The funds are being utilised to develop new highways, railways, ports, airports, urban metros, housing and logistics parks at an unprecedented pace. Flagship programmes such as the PM Gati Shakti National Master Plan and the National Infrastructure Pipeline (Rs 111 lakh crore) are gaining momentum, driving construction activity and demand for steel, cement, aluminum and copper. Increasing urbanization is also fuelling infrastructure growth as with expansion or creation of cities, demand for infrastructure like roads, buildings and utilities grows. Similarly, India's energy demand is surging in tandem with its economic growth and urbanisation. The country's electricity demand is rising rapidly, with a record peak power demand of 250 GW achieved in fiscal 2025, marking the highest ever without major outages. As a result, total power generation and coal burn increased significantly, with coal remaining the backbone of India's energy mix, providing ~74% of electricity.

Thus, the outlook for the mining and metals industry is promising, with steady growth anticipated in the coming years. Being an energy-hungry economy and with an expected growth in infrastructure, India will have a steady demand for coal, iron ore, bauxite and zinc. Minerals such as lithium, copper, cobalt and nickel are also in high demand due to their critical role in energy transition.

Despite the growth drivers, the industry faces obstacles, including the need to adopt environment-friendly and sustainable practices due to increasing environmental concerns and stricter regulations. The industry is also vulnerable to fluctuations in commodity prices, geopolitical uncertainties and supply chain disruptions, particularly for rare and critical minerals. Additionally, the depletion of resources, inferior quality ore and local resistance to mining activities in certain areas pose as further draggers to growth.

That said, the industry can capitalise on opportunities by leveraging digital technologies such as automation, AI and data analytics to enhance operational efficiency and minimise its environmental footprint. Furthermore, there is potential for metal recycling and the adoption of circular economy practices, which can help alleviate resource scarcity and environmental degradation. The exploration of new mineral deposits, particularly in previously underexplored areas, also offers a promising avenue for expansion.

Although the mining and metals industry is poised for growth owing to technological advancements and global demand, its success will hinge on the ability of companies to navigate environmental, economic and regulatory factors while effectively harnessing innovation and technology-driven opportunities.

2.1. Growth draggers

Challenges in the mining and metals industry can be categorised into three areas, i) Operational constraints impacting efficiency and safety, ii) Market challenges due to price and market volatility, and cost pressure; and iii) Regulatory framework due to environmental/ forest approvals, pollution norms, safety requirements and land acquisition.

Fig: Challenges constraining growth



Operational

- Technical
- Environmental
- Financial

Market competitiveness

- Cost competitiveness
- Price and market volatility

Regulatory framework

- Approvals
- Environmental compliances

Source: Crisil Intelligence Analysis

2.1.1. Operational constraints

The mining and metals industry is subject to a range of operational factors influencing overall efficiency, such as equipment utilisation, workforce productivity and material handling practices. These factors may be broadly classified into three key categories: Technical, environmental and financial.

Technical

- ***Ore characterisation:*** Inferior ore quality necessitates a lower yield of metal, as the extraction process (e.g. smelting, leaching) and mineral beneficiation process is less efficient and requires more consumption of energy and

chemicals, driving up costs and increasing waste disposal and higher emissions

- ***Geological factors:*** Deposits are getting deeper with difficult geological characteristics and thereby pose challenges in extraction of minerals as well as higher cost of raw materials for metal industry
- ***Equipment capabilities:*** Older or inefficient equipment impacts availability as well as operating costs, and higher emissions
- ***Infrastructure limitations:*** Inadequate access to essential resources due to transportation bottlenecks (e.g., congestion at ports or railways, non-availability of railway siding or sub-optimal weight- bearing capacity of road), inadequate communication, power and water severely impacts operations

Environmental

- ***Water scarcity:*** Many metal and mineral extraction operations often require significant amounts of water, especially in mineral floatation, cooling, washing operations and effluent treatment, which can be in short supply in arid or water-stressed regions
- ***Waste and tailings management:*** The disposal of tailings and waste rock requires advanced environmental safeguards and proactive compliance with evolving regulations, supported by scientific planning and sustainable management practices and aligned with global best practices
- ***Sustainability and emissions:*** The need to reduce greenhouse gas (GHG) emissions and achieve decarbonisation can limit operational flexibility, necessitate costly upgrades or require the adoption of new technologies and practices
- ***Land acquisition and community displacement:*** Requirement of land on a regular basis for mining operations and waste disposal often leads to community displacement and social disharmony

Financial:

- ***Increasing operational costs:*** Inferior ore quality, lower yield and rising expenses for energy, labour and consumables erode profit margins, making it essential to optimise operations and manage costs effectively
- ***Market uncertainty:*** Volatile commodity market may impact production schedule, result in cash flow uncertainty, delayed investments or even project cancellations, making it challenging to predict revenue and plan for future
- ***Limited access to funding:*** Restricted access to credit, investor caution or high financing costs can hinder expansion plans, modernisation efforts or even the ability to maintain existing operations, ultimately limiting growth and competitiveness

2.1.2. Market competitiveness

The mining and metals industry is highly commoditised, facing supply and demand pressure. On the supply side, the industry must consistently strive for cost competitiveness, while on the demand side, it must manage market volatility and fluctuating prices

Cost competitiveness

- ***Low production costs:*** Companies with older plant and equipment, poor access to infrastructure, and high raw material/labour/energy costs are less competitive
- ***Economies of scale:*** Larger operations or vertically integrated firms often benefit from lower per-unit costs
- ***Operational inefficiency:*** Lack of adoption of automation, AI and advanced processing technologies can lead to operational inefficiencies, reduced productivity and increased waste

Price and market volatility

- ***Commodity price cycles:*** Metal prices fluctuate based on global demand (e.g., infrastructure growth, electric vehicles or EVs) and supply trends that create uncertainty and limit a company's ability to predict revenue and plan for growth
- ***Uncertainty in demand:*** The challenge makes it difficult for companies to invest in new projects, expand existing operations and achieve sustainable growth

2.1.3. Regulatory framework

The industry operates within a comprehensive regulatory framework covering environmental/forest clearances, pollution control measures, safety standards and land acquisition processes—with

significant scope for further streamlining through digital tools, process innovation and coordinated facilitation across stakeholders. Companies must operationalise their assets, comply with environment regulation and manage the project affected community

Approvals

- ***Delayed approvals:*** The lengthy and complex process of obtaining multiple, sequential clearances, especially environmental/forest approvals is a major reason for project delays in the industry. *A 2024 report by the Comptroller and Auditor General of India showed that only 25-30% of mining blocks allocated through auction since 2015 were operational due to clearance delays*

Environmental compliances

- ***Rigorous environmental regulations:*** The industry is subject to rigorous environmental regulations, necessitating significant investments in pollution abatement, waste management, mine closure and ecosystem conservation measures to ensure adherence to stringent standards
- ***Decarbonisation:*** Policymakers are pushing decarbonisation strategies (e.g. green hydrogen steelmaking and net zero), while global mechanisms such as the European Union's Carbon Border Adjustment Mechanism threaten to penalise carbon-intensive exports such as Indian steel and aluminum
- ***Reporting requirements:*** The introduction of the Business Responsibility and Sustainability Report now binds only top-listed companies, but may soon extend to smaller and unlisted firms, increasing compliance complexity

2.2. Possible opportunities

The industry can use digitalisation and automation to transform its business operations and realise its growth potential. By deploying intelligent systems, real-time monitoring, robotics and data analytics, the industry is finding robust pathways to mitigate its pressing constraints. Emerging technologies will help improve productivity, manage environmental concerns and provide a safe working environment. These opportunities can be further accelerated by aligning with national initiatives such as the National Mineral Exploration Trust, PM Gati Shakti National Master Plan for logistics optimisation and the Make in India initiative for local manufacturing of advanced equipment

Fig: Possible opportunities



Productivity management

- Real time monitoring and data analytics
- Optimised resource extraction
- Energy use optimization

Environment management

- Smart monitoring and compliance tools
- Integrating renewables with smart grid
- Advanced monitoring and reporting

Safe working environment

- Wearables devices and AI
- Virtual Reality and Augmented Reality

Source: Crisil Intelligence Analysis

2.2.1. Productivity improvement

A perennial challenge in Indian industry is the fragmentation of data across disparate systems - equipment maintenance logs, material stock registers, surveys, environmental measurements and supply chain records often exist in silos. With a defined digital transformation strategy, the firms have potential to improve productivity of its men, machine and processes.

- ***Real-time monitoring and data analytics:*** Digital platforms that integrate various data streams such as IoT sensors, combined with cloud-based analytics, provide a unified, real-time view of operations.

  Embedded sensors in haul trucks/ ladle, conveyors, crushers and mineral processing/ metal extracting plants transmit continuous performance indicators such as location, speed, temperature, vibration, energy consumption and production throughput to central dashboards. Advanced analytics enable production forecast and support predictive maintenance to improve operations.

  Digital twins, virtual replicas of physical assets, allow engineers to simulate stress scenarios, optimising algorithms and scheduling changes before implementation in real time, thus enhancing efficiency and reducing risk

  Optimised resource extraction: Usage of robotics, autonomous equipment and remote-controlled machinery are being explored. For example, automated welding tools are being used in metal fabrication plants to ensure consistent quality, reduce human error and speed up production. Robotics are used for picking, sorting and placing heavy metal components.

  Deployment of autonomous haul trucks and loaders is also gaining traction. These vehicles can traverse predefined routes in rugged terrain, reducing operator fatigue and human error, enhancing safety. They are also useful for areas with extreme weather conditions or limited workforce availability.

  Remote operation centres allow centralised monitoring and control of multiple sites. This offers another layer of resilience: A sudden environmental hazard, extreme heat or labour unrest on site does not necessarily halt operations, since control can shift to distant operators.

- ***Energy consumption optimisation:*** Smart energy management systems, enabled by IoT sensors and analytics, track instantaneous energy consumption, enabling peak-load shaving, demand forecasting and dynamic tariff optimisation

2.2.2. Environment management

To successfully manage environmental concerns and achieve decarbonisation goals, the industry must adopt a multi-faceted approach, encompassing the adoption of cutting-edge technologies, innovative process improvements and a fundamental transformation of the entire value chain, including energy consumption, material management, logistics and supply chain operations.

- ***Smart monitoring and compliance tools:*** Operations must adhere to stricter norms on water usage, air pollution, land restoration and carbon emissions. Digital tools aid in achieving these commitments transparently, efficiently and cost effectively.

  Sensor networks monitor dust levels, particulate emissions, water discharge quality and noise in near real time, feeding environmental management systems whose dashboards alert management to variances beyond permissible thresholds.

  Moreover, digital platforms that track water usage throughout mineral processing/ metal extraction plants help in the implementation of zero discharge or recycling targets. Blockchain enabled traceability can log every drop of water consumed, recycled or discharged, ensuring auditability and sustainability reporting. Geospatial analytics, using drones and satellite imagery, informing land use changes, afforestation progress and tailings dam and waste disposal areas integrity, helps ensure legal compliance and community trust

- ***Integrating renewables with smart grid:*** Integrating renewable energy sources such as solar panels, wind turbines or even hydroelectric micro plants with battery storage allows mines to decrease reliance on fossil fuel generators. Digital controllers and micro grids manage the balance between generation, storage and consumption. In regions with grid unreliability, renewable plus

storage systems enhance uptime and reduce carbon footprints, aligning economic and environmental goals.

To reduce emissions and increase efficiency, transition to battery EVs or hydrogen fuel cell trucks are being explored, replacing traditional diesel-powered trucks, loaders and other mobile equipment. Electrified rail or conveyor belt systems for transporting ore over long distances are being evaluated to reduce reliance on fossil fuels

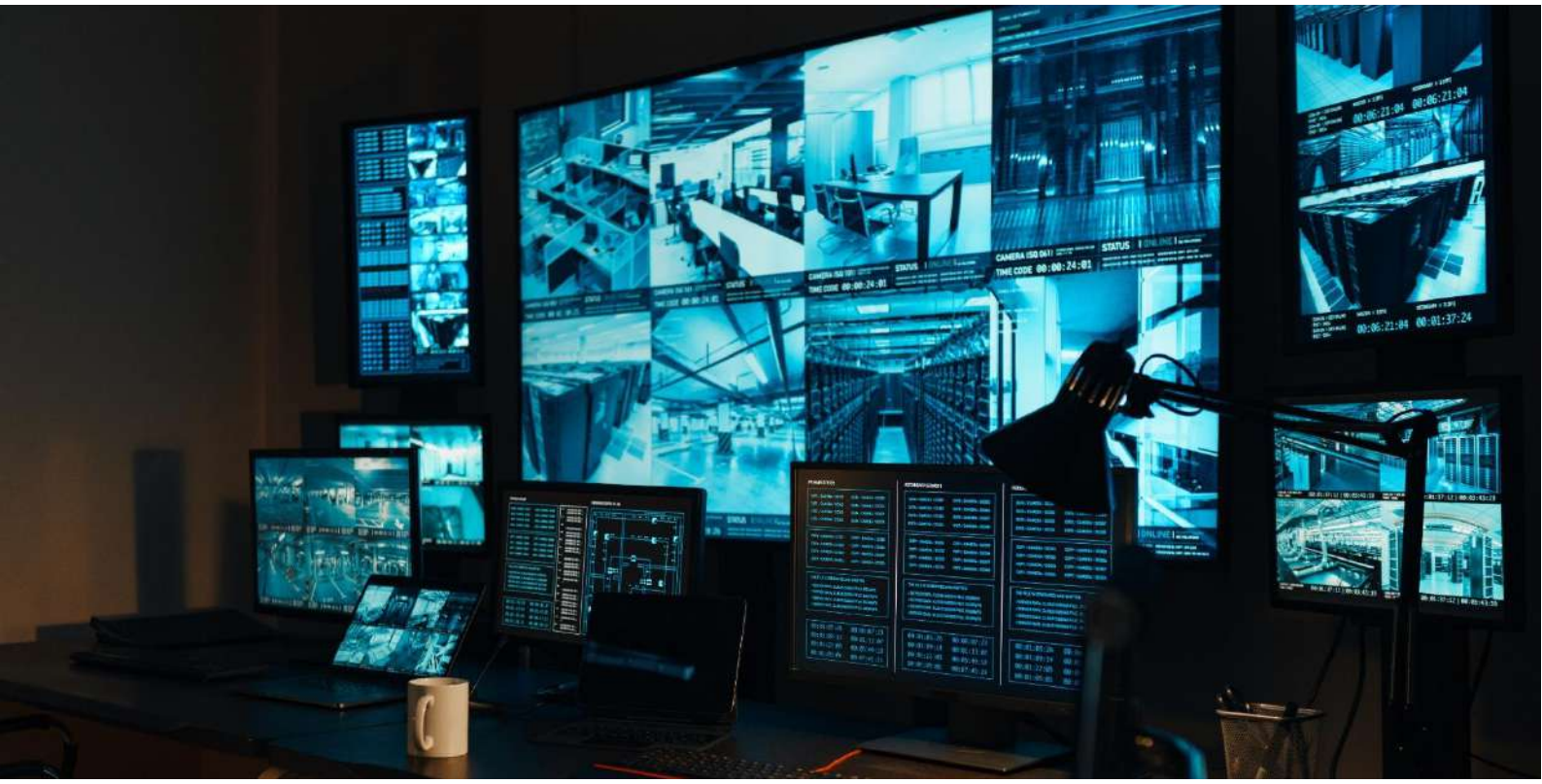
- ***Advanced monitoring and reporting:*** Real-time digital dashboards and automated reporting tools will help monitor and analyse GHG emissions. Similarly, blockchain technology or third-party verified systems will help accurately measure and report carbon footprints.

  Digital systems that tag and track scrap flows, integrate recycler data and analyse material yields enable better sorting, yield optimisation and compliance reporting. AI-powered sorting systems can identify metal grades in e-waste or industrial scrap with high accuracy, enabling more efficient downstream processing

2.2.3. Safe working environment

Creating a safe working environment is critical given the high-risk nature of operations—exposure to dust, heavy machinery, high temperature and chemical processes.

- ***Wearable devices and AI:*** Wearable devices such as smart helmets, vests and sensors can monitor workers' vital signs, location and proximity to hazardous zones. In case of abnormal readings such as elevated heart rate, oxygen deficiency or exposure to high levels of methane or carbon dioxide, alerts can be instantly issued to control rooms and supervisors. AI-driven algorithms assess patterns and predict unsafe behaviour, prompting pre-emptive interventions such as task rotations or rest breaks
- ***Virtual reality (VR) and augmented reality (AR):*** VR/AR training modules prepare staff to respond to emergencies, safely operate equipment and adopt best practices, particularly valuable in locations with high turnover or limited training infrastructure. Digital training platforms standardise competence and promote a safety-centric culture



3. Adoption of automation/ digitalisation / technology integration

There is a growing convergence of digital technologies, automation and technology integration, leading to a profound digital transformation across the global mining and metal industry to meets its urgent needs for sustainable and efficient operations. These technological advancements are no longer futuristic aspirations, but strategic imperatives that are reshaping operational practices, safety protocols, productivity benchmarks, customer experiences and environmental commitments. Businesses are increasingly integrating automation and digitalisation into their operations and integrating technologies to drive growth, improve profitability and achieve sustainable competitive advantage in an increasingly complex and rapidly evolving business landscape.

In India, where the sector remains a significant contributor to the GDP and employment, digital transformation is gradually finding its place in the traditional mining ecosystems and among metal producers. From resource exploration to mineral processing to downstream operations and from logistics to environmental monitoring, the technology is being woven into every segment of the value chain. The Government of India is also encouraging the adoption of Industry 4.0 in mining through policies promoting innovation, research and development collaborations and infrastructure development, creating an enabling ecosystem for digital transformation.

The following section outlines key emerging technologies and explores how they are being leveraged to enhance operational efficiency, reduce costs and build more resilient mining and metal enterprises.

3.1. Emerging technologies

1. ***Process automation**:* Automation refers to eliminating manual, non-value added, repetitive processes with hardware and/or software. A **hyper automation** approach refers to the advanced integration of technologies such as AI, robotic

process automation (RPA), machine learning (ML) and process mining to automate entire workflows, not just repetitive tasks. For instance, invoice processing can be automated by leveraging AI driven data recognition, RPA for task execution and optical character recognition technologies for document analysis.

Similarly, **intelligent process automation (IPA)** builds on the foundation of RPA, and incorporates AI, natural language processing and cognitive technologies to create a more sophisticated automation system. This enables the system to understand context, make informed decisions, and learn from experience over time, making it effective in domains such as customer service, human resource onboarding and regulatory compliance where a high degree of judgement and adaptability is required.

2. ***Industrial internet of things:*** IIoT involves connecting sensors and devices across various manufacturing and industrial systems, enabling the collection and analysis of data in real-time. This leads to numerous benefits, including predictive maintenance, energy optimisation, and real-time monitoring, ultimately resulting in increased efficiency and reduced downtime. For instance, drones equipped with cameras, light detection and ranging, thermal sensors or multispectral imaging tools are used for applicated such as mapping, inspection and surveying among others.

3. ***Robotics****:* Robotics refers to the use of robots, both physical and virtual, to automate and streamline processes that were previously done manually. This involves integrating robotics with other digital technologies. **AI-driven robotic control systems**, also called industrial robots, are powered by advanced technologies such as computer vision and reinforcement learning, allowing them to perform complex, non-repetitive tasks with ease. This is particularly useful in advanced operations, where adaptability and precision are crucial and not easy to access.

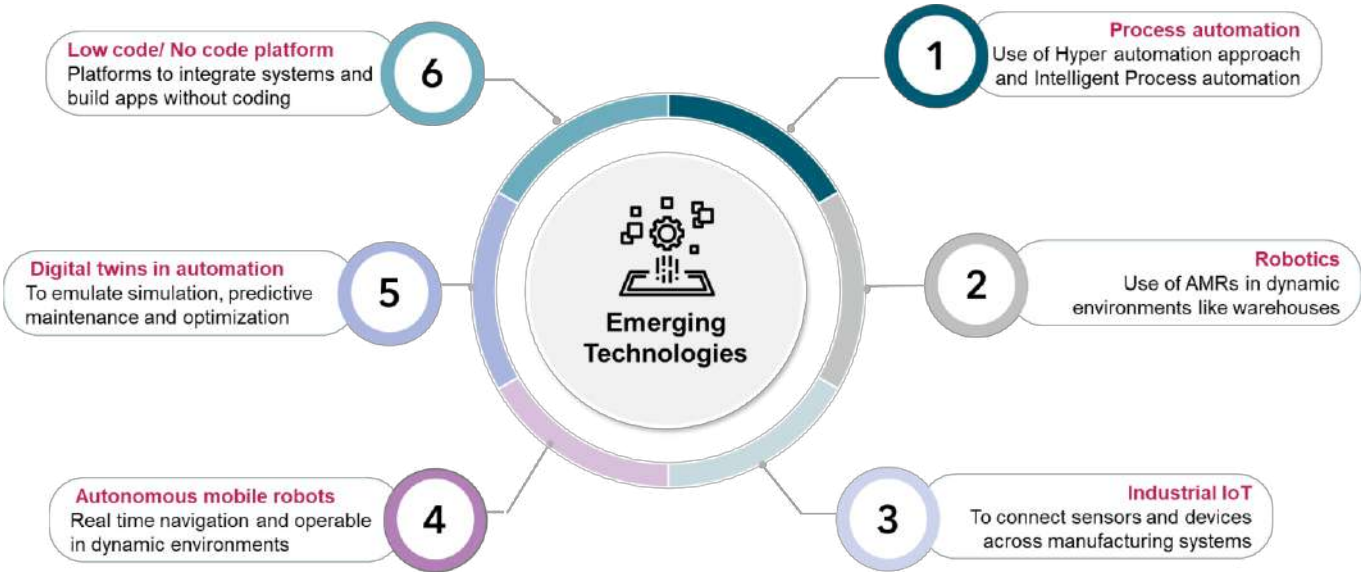
4. **Autonomous mobile robots** are equipped with real-time navigation and AI capabilities and are designed to operate in dynamic environments, such as stockyards, processing facilities and railway sidings.

5. ***Digital twins:*** By creating virtual models of physical assets, digital twins enable simulation, predictive maintenance and optimisation. Integrated with IoT sensors and AI, these virtual models provide real-time feedback, allowing efficient and effective management of physical assets and systems.

6. ***Low-code/no-code platforms:*** These platforms provide tools that allow users to integrate systems and build applications without requiring extensive coding knowledge. By democratising digital integration, low-code/no-code platforms speed up digital transformation, enabling businesses to respond quickly to changing market conditions and customer needs. This approach also helps bridge the gap between technical and non-technical teams, fostering collaboration and innovation.

Other key emerging technologies are i) Edge computing that allows processing data locally near source, ii) 5G technology that helps faster data transfer and reduced latency, iii) AI and ML that support pattern recognition, anomaly detection and predictive modelling, iv) Big data analytics and decision intelligence that help transform operational data into actionable intelligence, v) AR/VR that offers immersive experiences, vi) Digital thread that enables seamless data flow across a product's entire lifecycle, and vii) Blockchain that helps in supply chain transparency and compliance.

Fig: Key emerging technologies



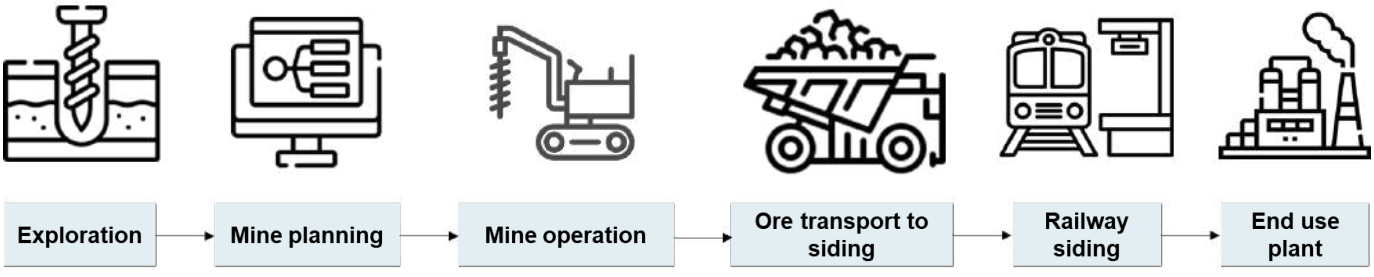
Source: Crisil Intelligence Analysis

3.2. Applicability for the mining and metals industry

3.2.1. Mining industry perspective

Emerging technologies in automation and digital integration are rapidly transforming the mining sector, enabling safer, efficient and sustainable operations.

Fig: Mining industry value chain



Source: Crisil Intelligence Analysis

1. ***Industrial IoT:*** IIoT is being used in mining to monitor equipment and personnel in real-time, tracking vibration, temperature and pressure in pumps, conveyors and crushers. This enables early fault detection, better resource allocation and increased equipment uptime, leading to improved productivity and reduced downtime. Air quality and gas concentration can be monitored in underground mines to enhance worker safety and ensure compliance with regulatory norms. Geotechnical stability may be assessed by monitoring structural health of mine shafts, tailing dams or blast zones.
2. ***GPS tracking of logistics movement:*** The use of GPS tracking is revolutionizing logistics both within and outside the mine. It enables real-time monitoring of assets, providing data on location, status and delays, which improves operational

efficiency. The system can also support with optimized route planning, identifying anomalies and monitoring performance of trucks and drivers.

3. ***Autonomous mining equipment:*** The use of autonomous haul trucks, drill rigs and loaders is revolutionising the mining industry. Companies are already leveraging this technology to operate 24/7 in remote and unsafe environments, reducing human error and lowering operating costs. Remote-controlled machinery in high-risk environments, such as deep underground mines or unstable blasting zones, reduces occupational hazards. Automated ore crushing, screening and beneficiation plants that operate with minimal manual input lead to more consistent output quality and reduced operational errors. Autonomous equipment also improves fuel efficiency and safety, making it a game-changer for the industry.

4. ***Drones and UAVs*:** Drones and unmanned aerial vehicles (UAVs) are being used in mining for aerial mapping and surveying of mine sites, monitoring blasting and ore movement, and inspecting assets and tailing dams. This technology enables faster, safer and more accurate data collection, reducing the need for manual fieldwork and improving overall efficiency.

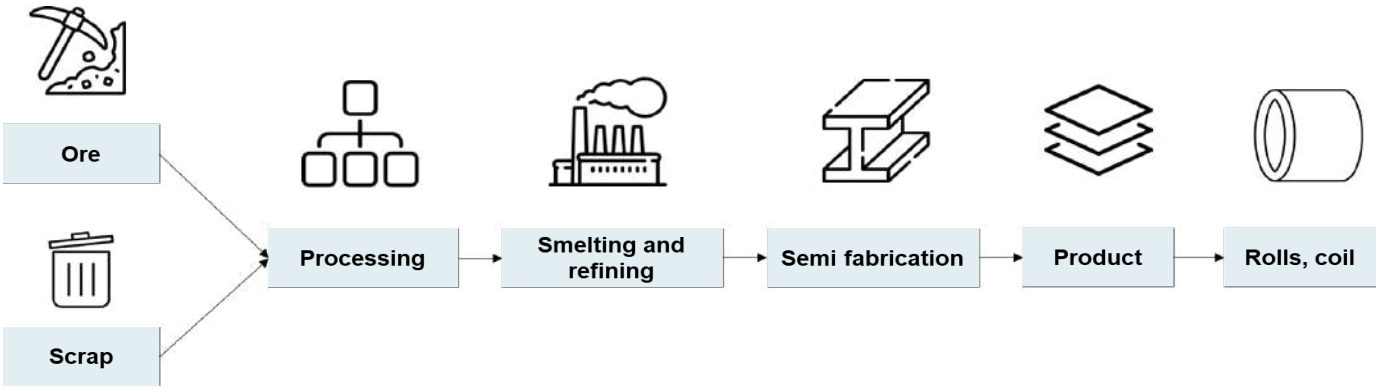
5. ***Digital twins:*** Digital twins are virtual models of mining operations and equipment, allowing for simulation of ore extraction, ventilation and equipment usage. This technology enables real-time operational optimisation, reducing downtime and operational costs and improving overall efficiency.

6. ***Remote operations and centralised control centres*:** The consolidation of operations into centralised, remotely operated control centres is another major shift enabled by digitalisation. These centres can manage and monitor multiple operations across geographies using integrated digital platforms. They help in the real-time remote monitoring of production, logistics, safety and environmental parameters across multiple sites. They are also used for remote control of autonomous or semi-autonomous machinery from a single location. Most importantly, they allow integrated planning and scheduling functions that synchronise mining, transportation and processing.

3.2.2. Metals industry perspective

Metals industry is using emerging technologies in automation and digital integration to embed intelligence, precision, and agility into operations.

Fig: Illustrative metals value chain



Source: Crisil Intelligence Analysis

1. ***Business process automation:*** Hyper-automation is being used in the metal industry to automate entire production workflows, such as ore-to-ingot or scrap-to-sheet processes. By reducing manual intervention in high-temperature or hazardous zones, hyper-automation improves productivity and consistency while enhancing worker safety.

Intelligent process automation (IPA) is being applied to drive quality control of metal surfaces using vision systems, automate scrap classification and make predictive alloy adjustments. This enables smarter decision-making in real-time, such as adjusting furnace parameters or cutting profiles, to optimise production and reduce waste.

2. ***Industrial IoT (IIoT)****:* IIoT is being used to monitor furnaces, mills, CNC machines and environmental controls in real-time. Real-time monitoring of equipment conditions such as temperature, vibration and pressure helps schedule predictive maintenance. This enables energy optimisation, early fault detection and improved maintenance scheduling, resulting in increased efficiency and reduced downtime. Radio frequency identification (RFID) tags and global positioning system-enabled sensors enable tracking and tracing of high value equipment or materials across sites or yards to reduce pilferage and improve supply chain transparency.

3. ***Robotic systems****:* Robotic systems are being used to automate tasks such as welding, cutting, grinding and packaging of heavy or repetitive metal components. AMRs are being used for internal logistics, moving materials between warehouses, furnaces and finishing stations. This improves safety, reduces downtime and addresses labour shortages.

4. ***Digital twins****:* Digital twins are being used to simulate casting, rolling or extrusion processes in real-time. This allows for the detection of process inefficiencies, prediction of equipment failures and minimisation of waste, resulting in improved productivity and reduced costs. Process simulation in plants helps to identify bottlenecks and test potential upgrades or modifications.

   Digital twins are also being used for virtual testing of environmental impact scenarios for waste management, water discharge and emissions control. Workers are trained using immersive simulation tools based on digital replicas of equipment and sites.

5. ***Digital thread****:* Digital thread is being used to link raw material data (chemical composition, origin) with final product specs and quality reports. This enhances traceability and compliance, particularly in higher quality grade metals, and enables the creation of a digital record of the product's entire lifecycle.

The mining and metals industry is adopting emerging technologies to drive tangible improvements in safety, efficiency, environmental stewardship and strategic agility. Some other use cases being deployed in the industry are: i) Low-code and no-code platforms to develop dashboards for performance and environmental KPIs, as well as rapid development of compliance tracking tools, ii) Edge computing to process seismic, geological, and equipment data on-site in mines, and to process high-frequency data from metal-cutting machines, forges and inspection systems on-premise in plants, iii) 5G connectivity to enable real-time coordination of automated cranes, mobile robots, remote machinery, safety systems across a plant or mining site, iv) AR/VR technology for training simulation, remote assistance, v) Blockchain for source traceability and smart contracts, vi) AI/ML for predictive maintenance and; vii) RPA to automate reporting, such as environmental compliance, and to streamline support processes such as procurement, invoice generation, bill payment and payroll.

3.3. Illustrative cases

Global context

- **ArcelorMittal Steel, Europe**[14]

  ArcelorMittal has implemented the "Smart Steel" strategy that drives digital transformation through an extensive digital effort at every production stage. AI-powered quality control system is implemented where the AI system uses machine learning algorithms to inspect steel coils for defects during production and automatically triggers corrective actions when defects are detected. Digital Twin technology is deployed that allows automated blast furnace operations optimization through improved output and lower carbon emissions.

[14] https://www.steel-technology.com/articles/top-6-steel-companies-adopting-ai

The European operations of ArcelorMittal have made Spain and France leading examples of smart sensor integration and process automation to achieve better decisions.

- **Rio Tinto – Gudai-Darri 'mine of the future', Australia**[15]

  The Gudai-Darri iron ore mine in western Australia's Pilbara region with a production capacity of 43 million tonne per annum (MTPA) has been developed as Rio Tinto's most technologically advanced operation. The mine operates a fleet of 26 autonomous haul trucks and five autonomous drills. These vehicles use real-time ore tracking and sensor data to optimise dig face progression and improve safety.

  All autonomous assets at Gudai-Darri, including trucks, drills, trains and water carts, are monitored and controlled from Rio Tinto's centralised remote operations centre in Perth, located over 1,500 Km away. The mine also has a full digital replica of its processing plant, known as a digital twin. AI-driven analytics and ML models are used to support predictive maintenance and performance optimisation. It also uses interactive 3D environments for virtual reality training.

- **Boliden Aitik mine, Sweden**[16]

  The Boliden Aitik mine, located near Gällivare in northern Sweden, is an open-pit copper mine. Boliden has deployed a private 5G-ready mobile network at the mine, supporting high-speed, low-latency communication essential for automation and remote operations.

  Aitik has pioneered electric autonomous blast hole drilling and uses real-time monitoring tools to track equipment and production. The mine uses an advanced process control system to manage its grinding circuit. This software uses a digital twin to simulate and optimise operations before real-world deployment.

Indian context

- **Tata Steel**[17]

  Tata Steel has developed digital twins of its operations, particularly at its Jamshedpur plant, to simulate, visualise and optimise production processes. These virtual replicas allow predictive analysis of yield, energy consumption, throughput, quality and productivity—collectively referred to as YET-QP.

  By analysing sensor data from machinery, AI models forecast potential failures and optimise maintenance schedules. AI is also used for process optimisation and quality control across mining and manufacturing operations. At various sites, drones and robotics are used for tracking warehouse conditions, surveying and inspection, while IoT sensors monitor equipment health, environmental conditions and operational metrics in real time.

  Tata Steel has also partnered with TEXMiN, the mining technology innovation hub at IIT (ISM) Dhanbad. This collaboration focuses on integrating advanced software, remote sensing and digital methodologies into exploration, mining and beneficiation processes. The alliance also supports skill development and creation of scalable, sustainable mining solutions.

- **Rampura Agucha underground mine, Hindustan Zinc Ltd**[18]

  The mine has a dedicated centre of excellence that supports the shift towards leveraging digitalisation by focusing on analytics, automation, asset management, energy, climate change, ore body knowledge and underground mining.

  RFID-enabled digital cap lamps are being used to track worker movements in real time. Biometric systems and automated fleet status reports are implemented to streamline shift transitions. Remote-controlled drilling is being deployed to mitigate geotechnical risks. VR-based simulators

[15] https://www.riotinto.com/en/news/releases/2022/rio-tinto-opens-gudai-darri-its-most-technologically-advanced-mine
[16] https://www.ericsson.com/en/blog/2022/3/private-networks-enable-automation-at-the-boliden-aitik-mine
[17] https://www.tatasteel.com/newsroom/press-releases/india/2024/tata-steel-and-texmin-forge-strategic-alliance-to-revolutionise-india-s-mining-sector/ https://consulting.tatasteel.com/blogs/what-are-the-latest-innovations-in-mining-technology/, https://www.cio.inc/tata-steel-mission-2025-lead-digital-steelmaking-a-19996
[18] *AUTOMATION IN INDIAN MINING INDUSTRIES by Indian Bureau of Mines)*

for winders and Low Profile Dump Truck (LPDT) operators provide immersive training.

- **Aditya limestone mines, UltraTech Cement Ltd[19]**

  The digital ecosystem includes hardware such as sensors, RFID tags, IoT devices, GSM infrastructure, drones, and embedded systems, alongside software such as cloud platforms, data analytics, imaging tools and specialised applications for drilling, blasting and data management. These components are integrated into a web-based mine digitalisation solution that spans multiple functional modules such as mine planning, drilling and blasting, operations control, maintenance and grade control. The solution helps optimise extraction planning, undertake predictive maintenance and analyse blast performance; it also provides a centralised dashboard for operations monitoring.

3.4. Implementation/ adoption challenges

The adoption of automation and digitalisation in the metal and mining sectors, while promising substantial benefits, faces several significant challenges that can impede implementation.

1. ***High capital investment:*** Advanced technologies such as autonomous vehicles, robotics, AI platforms and digital twins often involve substantial upfront costs for hardware, software and system integration. From deploying sensor networks in underground mines to implementing AI-driven predictive maintenance systems in metal plants, the costs can be excessive. Additionally, the return on investment (RoI) is not always immediate or guaranteed, making companies hesitant to commit large budgets, especially when operating under tight margins or fluctuating commodity prices. This can be especially burdensome for small and medium-sized enterprises working with limited resources.

2. ***Prevalence of legacy infrastructure***: Many existing plants and mining sites rely on outdated machinery or manual processes that are difficult to integrate with modern digital solutions. Upgrading these systems or retrofitting them with IoT sensors and connectivity features often proves complex and costly, limiting scalability and interoperability.

   Moreover, there is a strong cultural resistance to change. Many workers and mid-level managers are either unfamiliar with digital tools or skeptical of their utility, fearing job losses or increased workloads.

3. ***Workforce skill gaps:*** Automation and digital tools demand new competencies in data analytics, AI, IIoT, and cybersecurity. However, much of the existing workforce in these industries lacks formal training in such areas, creating a mismatch between available technologies and human capability. Thus, the lack of a digitally skilled workforce proves to be a hindrance. This often leads to resistance to change, driven by concerns over job displacement, uncertainty about new systems and a general reluctance to move away from established processes. The sector faces a dual challenge: upskilling the existing labour force while also attracting new talent with expertise in data analytics, automation and digital project management. With limited in-house capabilities, companies often depend on external vendors, further complicating the implementation and knowledge transfer.

4. ***Data quality and management****:* The success of automation and AI tools heavily depends on access to accurate, high-quality and real-time data. Many mining operations are located in remote or geographically challenging regions where internet connectivity is poor or unreliable. This makes it difficult to implement cloud-based systems, real-time monitoring, or remote operations. Inadequate data infrastructure also hampers the effective use of IoT devices, drones and digital twins, which rely heavily on seamless data flow. Moreover, fragmented systems and inconsistent data collection methods can undermine the effectiveness of these technologies.

[19] *AUTOMATION IN INDIAN MINING INDUSTRIES by Indian Bureau of Mines)*

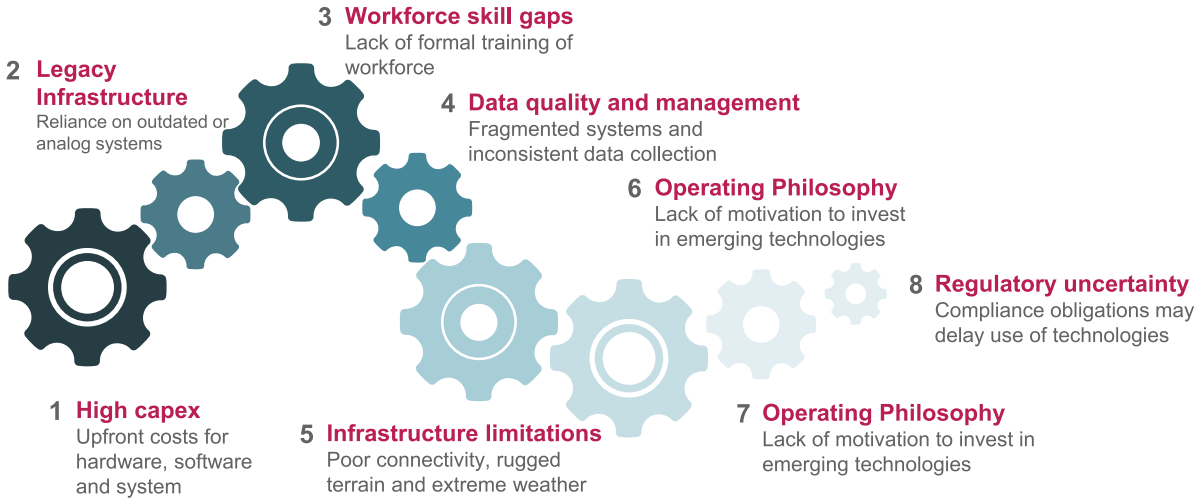
5. ***Technology Transfer:*** The adoption of digital technologies in the Indian mining and metal industry faces significant barriers, primarily due to the limited technology transfer from global companies. This transfer is often hindered by intellectual property concerns, lack of local customization and limited engagement with Indian stakeholders. Moreover, the existing solutions are not always adaptable to the unique challenges of the industry, making it crucial for the technology to be customizable.

6. ***Infrastructure limitations:*** Poor connectivity, extreme weather and rugged terrain can restrict the deployment of drones, autonomous equipment and real-time monitoring systems.

7. ***Operating philosophy:*** The practice of deploying mining contractors for operations sapped the motivation to invest in emerging technologies since there are no immediate financial benefits. Similarly, the mine owners also do not have the interest since the payout is fixed under the mining contract and is based on per tonne of production. Therefore, a mindset change is needed on the part of both the contractors and the mine owners.

8. ***Regulatory uncertainty* and compliance *obligations:*** These may delay or restrict the use of certain technologies, particularly those involving autonomous operations or drone surveillance, depending on jurisdictional laws.

Fig: Implementation/ adoption challenges



Source: Crisil Intelligence Analysis

In summary, while automation and digitalisation offer transformative potential for the metal and mining sectors, their successful implementation requires overcoming a combination of **technical, financial, cultural, and regulatory factors**. Addressing these barriers will demand a strategic approach that includes workforce development, infrastructure modernisation, risk management and strong leadership commitment to digital transformation.

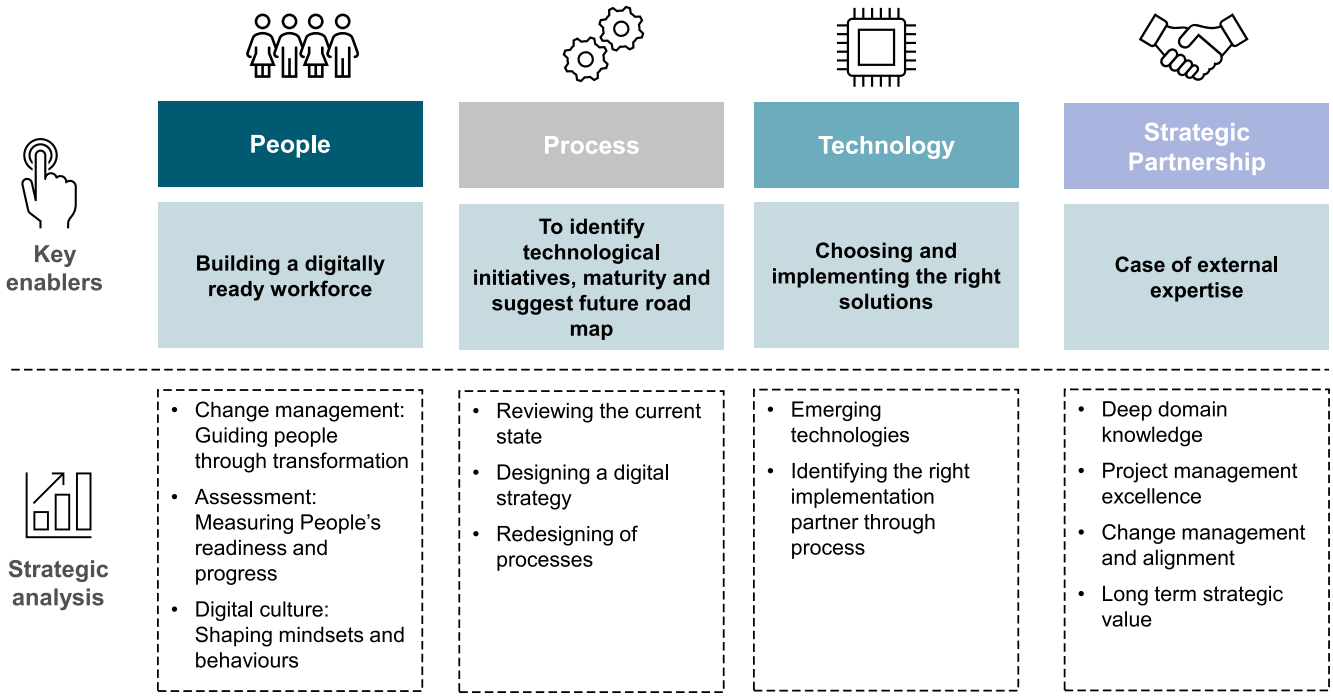
Indian mining and metal industry players—though at varying stages of technology maturity—are increasingly investing in and experimenting with these innovations. While projects often begin on a pilot basis, the broader trajectory is clear: digital transformation is essential for the industry to remain globally competitive, sustainable and responsible



4. Key enablers for digital transformation

The mining and metals industry is set to become future-ready, with enterprises embarking on a digital transformation journey. While emerging technologies such as AI, IIoT, automation, integrated platforms and robotics receive much of the spotlight, their successful implementation depends on a delicate interplay between people, processes and technology—the three foundational pillars of digital transformation. Equally critical is the role of external partners and consultants, who bring domain knowledge and structured project management expertise to help companies realise their digital ambitions. This section explores these enablers in detail, particularly in the Indian industrial context.

Fig: Digital transformation enablers



Source: Crisil Intelligence Analysis

4.1. People: Building a digitally ready workforce

While technology is the catalyst for digital transformation, it is ultimately the people within an organisation who are the adopters and sustainers of this change, leveraging technology to bring about meaningful and lasting impact. The Indian mining and metallurgical industry is traditionally labour-intensive, with a substantial workforce in remote and often hazardous environments. As digital tools reshape operations, the role of the workforce must evolve in tandem. Accordingly, people's role has to be understood from three lenses: *change management, digital culture and people's readiness.*

Change management: Guiding people through transformation

Change management plays a vital role in facilitating the successful transition of individuals, teams and organisations from their current state to a desired future state, with the goal of achieving digital transformation. This structured approach is essential, as a significant proportion of digital transformation initiatives falter because of employee resistance, rather than technical complexities.

Effective digitalisation begins at the top. Indian companies that have made significant strides in automation often cite committed leadership as a key enabler. Senior leaders must actively promote digital initiatives, set clear transformation goals and foster a culture that embraces change and innovation.

Key components of change management are listed below.

- ***Leadership engagement****:* Leaders must champion the change, clearly communicate the vision and demonstrate visible support. Employees take cues from the leadership and if leaders are not aligned, the transformation is likely to stall
- ***Clear communication:*** Employees need to understand the reasons for the transformation. Transparent and honest communication helps reduce fear, confusion and rumours, making it easier for employees to adapt to the change
- ***Resistance management:*** Identifying and addressing resistance early on is vital. People often resist change because of the fear of the unknown, job security concerns or lack of skills. Effective change management strategies can mitigate these concerns

- ***Supporting learning and development:*** Providing training, coaching and tools enables employees to adopt new technologies and workflows. For instance, introducing AI tools requires employees to be trained to understand and use them effectively
- ***Reinforcing new behaviours***: To ensure that change is sustainable, new behaviours must be reinforced through recognition, performance systems and leadership modelling. Rewarding digital experimentation and agility, for example, encourages employees to embrace the new ways of working.

Digital culture: Shaping mindsets and behaviours

A strong digital culture is essential for successful digital transformation since it promotes the necessary mindsets, behaviours and values that enable organisations to effectively adopt and integrate new technologies and work methods. By embracing a culture of openness, innovation and continuous learning, organisations can overcome barriers to change. Without such a culture, digital transformation efforts are likely to be hindered, leading to slow, expensive and incomplete outcomes.

To develop a robust digital culture, organisations must engage in deliberate planning and intentional actions. Key factors to consider when building a strong digital culture include:

- ***Leadership involvement:*** The organisation shall establish a well-defined digital strategy providing direction and clarity. Executives must lead by example, embracing digital tools and practices in their daily work, such as using digital communication platforms for company-wide announcements
- ***Employee engagement:*** Engaging all employees in digital transformation is crucial. This involves soliciting feedback, addressing concerns, fostering collaboration and involving employees in decision-making processes, such as beta testing new platforms
- ***Promoting inclusion***: A successful digital culture is inclusive, ensuring all employees, regardless of their digital literacy levels, are involved in the transformation process and have access to necessary education and training
- ***Cross-functional collaboration:*** Digital projects often cut across departments, from mining operations and metallurgy to the procurement, safety and environmental teams. Breaking down silos and promoting collaboration ensures digital tools are integrated into workflows rather than added on as afterthoughts
- ***Evaluation and recognition:*** Measuring the success of digital initiatives and acknowledging achievements, such as using analytics to track outcomes and celebrating success in adopting new digital methods, is essential to reinforcing a strong digital culture

Assessment: Measuring people's readiness and progress

Assessment is a crucial step in evaluating an organisation's current digital capabilities, skills, mindsets and overall readiness for transformation. It provides a clear understanding of where people and teams stand, ensuring digital transformation efforts are aligned and effective.

Several types of assessments can be used to evaluate an organisation's digital readiness, including:

- ***Digital maturity assessments***: Evaluate the organisation's level of digital advancement across people, processes and technology. For example, how well do employees use data in decision-making and how automated are their workflows
- ***Skill gap analysis:*** Identify the digital skills that are lacking, such as data literacy, cybersecurity awareness or agile practices. This helps prioritise training and reskilling efforts
- ***Readiness surveys:*** Measure how employees feel about upcoming changes, including their level of excitement, anxiety or confusion. These insights guide the change strategy and help ensure a smooth transition
- ***Continuous feedback:*** Implement regular pulse surveys, suggestion tools or town halls to listen to employees and adapt digital initiatives to real-world challenges

- ***KPIs and metrics:*** Track digital adoption, engagement, productivity and learning progression. Use these metrics to prove ROI and make informed adjustments to digital transformation strategies

4.2. Processes: Creating a foundation for scalable digitalisation

Technology can only deliver results if it is embedded into well-structured and standardised processes. In India's mining and metals industry, where legacy systems and manual operations are still common, rethinking processes is critical to unlocking digital value. It includes reviewing the current state, designing a digital strategy and selecting the right implementation partner.

Reviewing the current state

The organisation should carry out a thorough evaluation of current operations, systems and capabilities, which includes:

- Creating visual representations of existing workflows to identify inefficiencies and areas for improvement
- Conducting a gap analysis to compare the current performance with the desired outcomes or industry benchmarks
- Assessing digital, data and process maturity across departments to get a clear understanding of where transformation is needed and the baseline KPIs to measure improvement

Designing a digital strategy

The planning phase should be structured to ensure alignment with business goals. This includes:

- Utilising strategic frameworks such as TOGAF (The Open Group Architecture Framework), ITIL (Information Technology Infrastructure Library) or Business Model Canvas for comprehensive planning
- Applying prioritisation models to focus on high-impact initiatives, such as the MoSCoW method. The technique categorises priorities as must have (M), should have (S), could have (C) and won't have (W)
- Conducting structured workshops and interviews to ensure stakeholder alignment and a business-driven strategy. The result is a roadmap that aligns technology investments with business outcomes, along with defined metrics and a governance model

Re-designing processes

Some of the processes that will have to be redesigned are as follows:

- **Standardisation and integration:** Standard operating procedures must be defined and harmonised across sites to ensure consistency in data collection, system integration and performance monitoring. Integrated platforms that connect Enterprise Resource Planning system, manufacturing execution system and field-level automation help achieve a single source of truth for operations
- Without such alignment, companies risk creating data silos and inefficiencies that undercut the benefits of digital investment
- **Data governance and quality control:** The mining and metals industry produces massive amounts of data, from exploration and ore analysis to furnace performance and fleet tracking. However, poor data quality is a bottleneck. Establishing clear data ownership, validation mechanisms and access protocols ensure that data-driven tools such as AI and machine learning yield accurate, actionable insights.
- **Agility and continuous improvement:** Rigid operational models can hinder digital progress. Agile methodologies, pilot testing and iterative scaling should be encouraged, especially in early-stage digitalisation journeys. Continuous improvement frameworks such as Lean or Six Sigma, when combined with digital tools, can optimise efficiency and reduce waste.
- **Health, safety and environment (HSE) integration:** Digitalisation can significantly enhance safety and compliance, from smart Personal Protective Equipment (PPE) and real-time gas monitoring to drone-based inspections and automated emergency response systems.

However, these tools must be fully integrated into existing HSE protocols and compliance tracking systems to deliver tangible benefits.

4.3. Technology: Choosing and implementing the right solutions

Technology plays a crucial enabling role in digital transformation by helping organisations effectively identify, implement and scale the right solutions. While technology is the most visible part of digitalisation, its success will depend on how well it aligns with business goals and site-level realities.

Emerging technologies

Companies are deploying emerging technologies, such as business process management, IPA, RPA, IIoT, robotics and digital twins for the digital transformation of its operations.

- Digital tools being implemented have to be in alignment with the firm's overall digital strategy
- Clear identification of business requirements and the likely impact is needed so that the digital tool meets user expectations
- Infrastructure readiness and protection against cyber threats should be ensured, implying adequate investment in hardware, software and network components
- Integration with other applications and data capturing methods needs to be ascertained

Identifying the right implementation partner

An objective selection of the most suitable technology and consulting partners involves:

- Developing a well-defined request for proposal/ information process with clear evaluation criteria
- Using process-driven scoring models to reduce bias and focus on measurable outcomes
- Conducting structured pilots to test vendors before making a full commitment leads to a partnership with a best-fit vendor, reduced risk of project failure and strategic alignment

4.4. Strategic partnership: The case for external expertise

As Indian mining and metal companies navigate the complexities of digital transformation, one truth becomes evident. For many organisations, going it alone is not a viable option. This may be due to a lack of in-house capability, experience or bandwidth to drive large-scale digital projects. This is where external partners and consultants play an important role. External partners and consultants should bring the following capabilities:

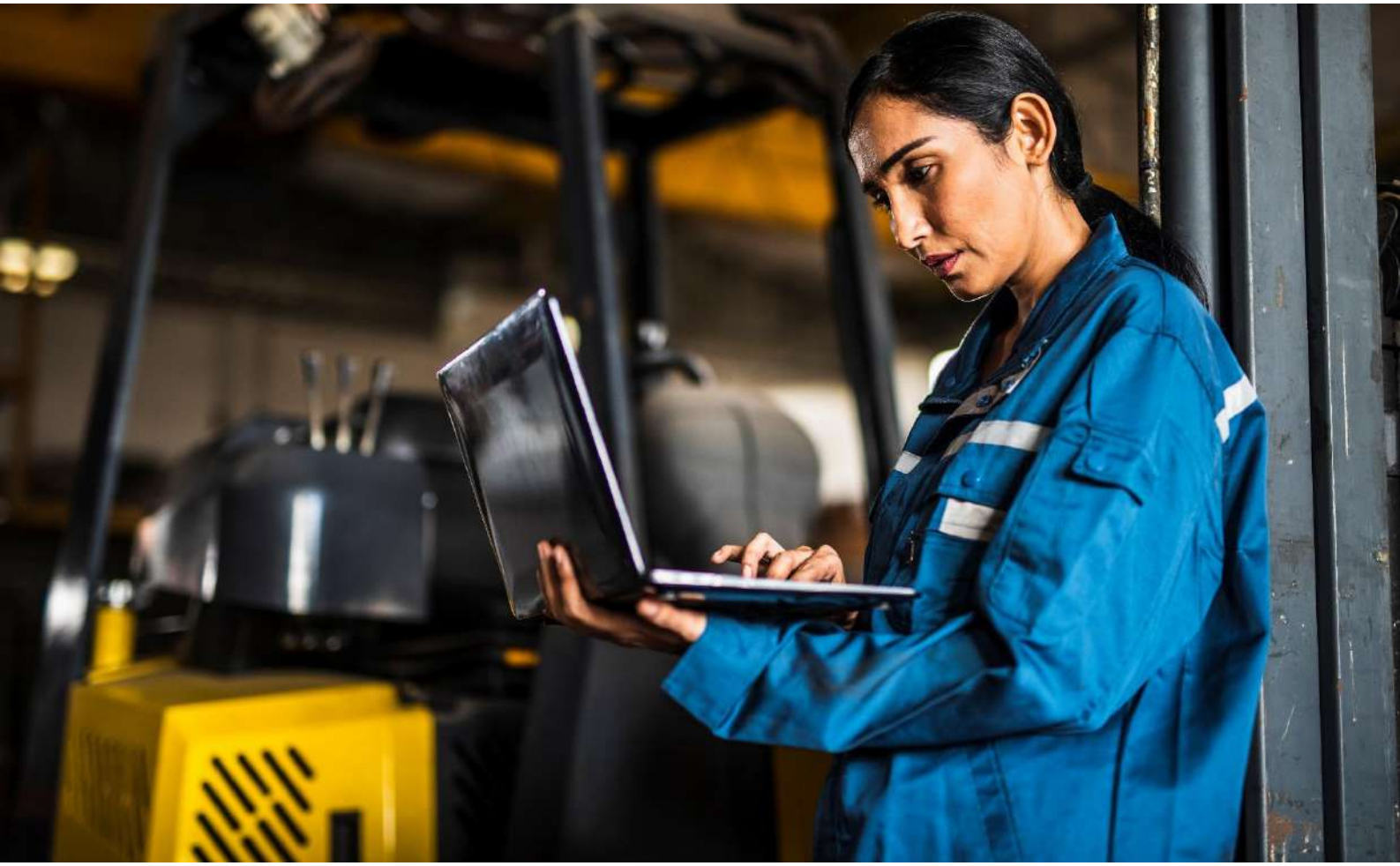
1. **Deep domain knowledge:** Unlike generalist IT firms, partners with deep mining and metallurgical experience bring invaluable insights. They understand the intricacies of open-cast versus underground mining, the nuances of beneficiation and smelting, and the unique environmental and regulatory landscape of India. This will help the company tailor digital solutions to suit specific operational and business contexts, ensuring practical and measurable outcomes

2. **Project management excellence:** Many digital initiatives fail not because of technical shortcomings, but owing to poor execution. Structured project management methodologies shall be brought to the table, from requirement gathering and stakeholder mapping to rollout planning and performance tracking. In Indian companies, where teams are often stretched thin, such partners can help maintain focus, drive accountability and ensure timelines are met

3. **Change management and alignment:** External consultants also serve as effective change agents. Their neutral perspective allows them to navigate internal resistance, align conflicting priorities and promote a transformation agenda across departments. By helping leadership define a digital vision and engage employees throughout the journey, they can build a stronger foundation for success

4. **Long-term strategic value:** The best partnerships go beyond short-term implementation. Many Indian firms are now working with consulting and technology partners to co-develop solutions, train internal teams and set up innovation centres. These strategic collaborations ensure the digital momentum is sustained and scaled across the enterprise

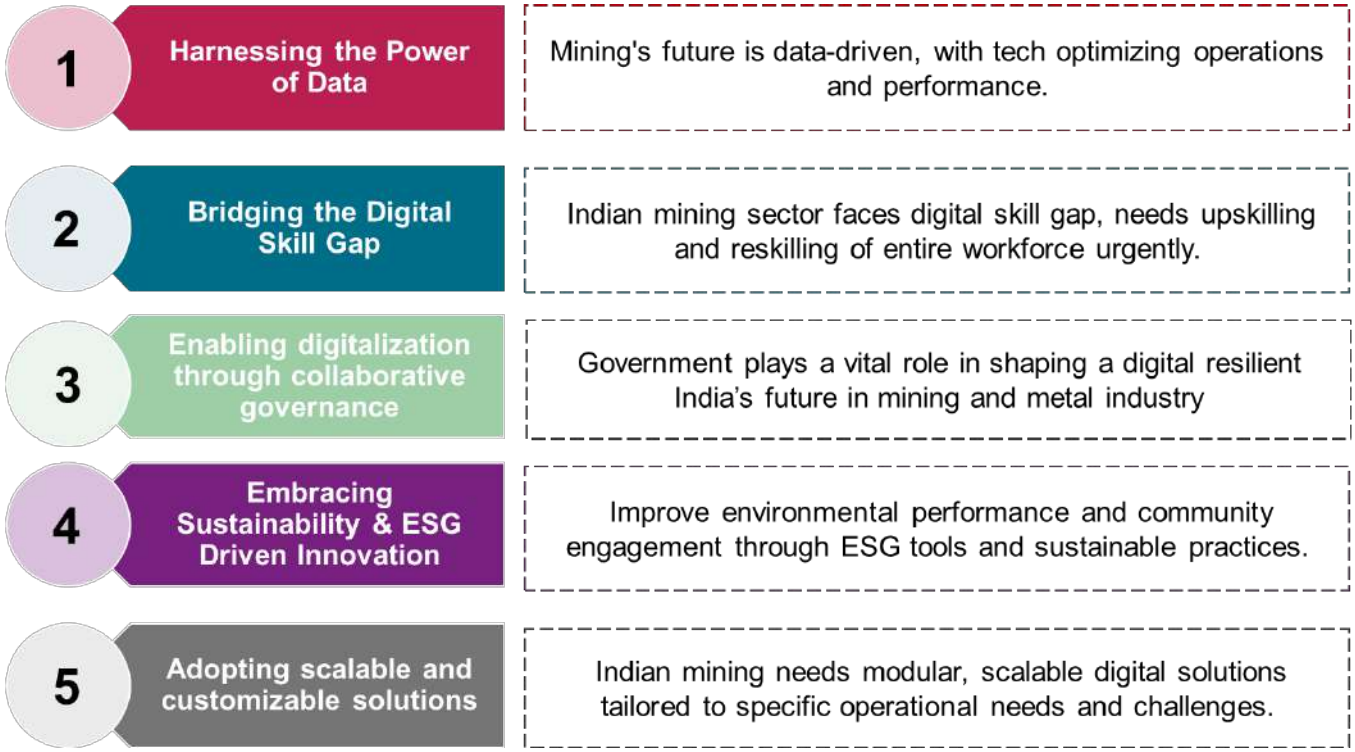
Organisations must take a holistic approach towards digital transformation. It is not enough to invest in technology. Companies must also equip their people, redesign their processes and choose the right partners to guide them through this journey. Strategic collaboration with experts who combine domain depth with execution rigour will often be the difference between a successful transformation and a stalled project.



5. The way forward

The Indian mining and metals industry stands at the cusp of a significant transformation. As digitalisation reshapes global industrial paradigms, the industry has begun embracing technology to meet the dual object v tives of operational efficiency and sustainable growth. While notable strides have already been made, the road ahead demands a more structured, collaborative and future-ready approach to fully realise the potential of automation, digitalisation and technology integration.

Fig: Focus areas



Source: Crisil Intelligence Analysis

Harnessing the power of data

The future of the mining and metals industry will be data-driven. Sensors, IIoT devices, drones and satellite imaging are already generating vast volumes of data. However, data remains underutilised in most Indian operations owing to the absence of integrated data platforms and advanced analytics capabilities.

- Building a unified digital ecosystem that connects exploration, production, logistics and supply chain functions is essential. Cloud computing, big data analytics and real-time dashboards can provide actionable insights, reduce downtime and optimise asset performance. Mobile solutions ensure seamless field connectivity, even in areas with limited internet access, allowing for offline operation and synchronisation when connectivity is restored
- Real-time process optimisation with the implementation of automation software, such as PLCs and distributed control systems, and creating digital twins i.e. virtual replicas of mining sites and plants to simulate scenarios, optimise resource allocation can enhance performance
- Deployment of AI and machine learning can help analyse data from various sources, identify areas for improvement and provide actionable insights to inform operational decisions. Predictive maintenance, for instance, can drastically reduce equipment failures and improve safety outcomes
- Data transparency and availability can enhance regulatory compliance and build trust with stakeholders. Open data platforms on mineral exploration, environmental monitoring and community impact can drive more informed decision-making and promote social licence to operate

Bridging the digital skill gap

Digital transformation cannot succeed without an equally robust transformation in the workforce. The mining industry continues to face a substantial digital skill gap as much of the workforce is either unaware of the latest technologies or lacks the training to leverage them effectively.

- Upskilling and reskilling of the existing workforce should be a priority. Mining companies must invest in digital literacy programmes, vocational training and partnerships with academic institutions. VR/AR-based simulations can be used for safe and immersive training experiences, particularly in hazardous operations
- Implementing a structured change management approach can facilitate a seamless transition to new technologies, minimising adoption barriers and maximising the benefits of digitalisation. The focus should be on leadership buy-in, transparent communication and employee engagement to overcome resistance and ensure alignment across the organisation. Celebrating quick wins, setting measurable KPIs and embedding digital thinking into day-to-day operations will foster a mindset of continuous innovation
- Attracting young, tech-savvy talent to the mining and metals industry is essential. It must be repositioned as a modern, innovation-driven industry offering exciting career opportunities in AI, data analytics, robotics and geospatial technologies

Enabling digitalization through collaborative governance

The Government of India plays a vital role in shaping a digitally resilient future for the mining and metal industry by fostering an ecosystem grounded in innovation, collaboration, and responsible governance. The government's role lies in continuing to act as a collaborative enabler—building policy frameworks, fostering innovation ecosystems, and aligning national missions to support a future-ready mining and metals industry. With initiatives like Digital India, Skill India, and Startup India, the groundwork has already been laid to support the sector's transition towards advanced technologies.

- A forward-looking regulatory framework, co-developed with industry stakeholders, can be a strong catalyst for digital transformation. By streamlining compliance processes through digital platforms and ensuring clarity in standards around data usage, automation, and remote operations, the government can facilitate smoother adoption of emerging technologies without compromising oversight or sustainability goals.
- Promoting public-private partnerships in digital research, pilot projects, and technology incubation centres can bridge existing capability gaps and encourage scalable innovation. The mining and metals sector, with its unique challenges, stands to benefit from cross-sectoral collaboration led by government-backed innovation hubs and accelerators.
- The alignment of skilling programmes under Skill India to the digital competencies required in mining—such as data analytics, remote sensing, and machine learning—will ensure the workforce is prepared for the industry's evolving needs.
- Leveraging Startup India to nurture tech-driven start-ups focused on industrial automation, safety solutions, and environmental monitoring can bring fresh energy and innovation to the sector.

Digitalization for embracing sustainability and ESG-driven innovation

As ESG imperatives become non-negotiable, digitalisation offers tools to improve environmental performance and community engagement. Technologies such as remote environmental monitoring, energy management systems and automated emission tracking help reduce the ecological footprint of the industrial activities.

- Digital platforms can also improve traceability across the metals supply chain, from mine to market, ensuring ethical sourcing and compliance with global sustainability standards. Blockchain, in particular, holds promise in enabling provenance tracking of critical minerals and reducing the risk of illegal mining
- Digital tools can be leveraged to monitor and manage energy consumption and implement automated environmental monitoring systems. This enables real-time tracking of environmental performance, supporting decarbonisation efforts and ensuring compliance with standards
- Sustainability analytics tools can aid companies measure and report their ESG performance accurately, while also identifying opportunities for circular economy initiatives, such as waste reuse and recycling and metal recovery

Adopting scalable and customisable solutions

One of the challenges in digital adoption is the 'one-size-fits-all' approach. Indian mining operations are diverse in terms of scale, geology and technological maturity. Therefore, solutions must be modular, scalable and adaptable to specific operational needs.

- Initiate digital transformation with targeted pilot projects and minimal viable products to test and validate new technologies and solutions. This approach enables the identification of potential challenges, refinement of solutions and progressive scaling up of successful initiatives across the value chain
- Replace legacy systems gradually with modular, open-standard automation and digital platforms, ensuring future scalability, flexibility and adaptability. This modernisation effort enables the integration of new technologies and improvement of the overall system performance
- Startups and tech innovators can play a crucial role in developing localised and cost-effective digital tools suited for small mines and complex terrains. Piloting and scaling up successful case studies across similar operations can further accelerate adoption
- Experts who bring deep domain knowledge and strong project management skills may be able to assist the industry in successful implementation of digital initiatives

The journey ahead for digital transformation

Digital transformation presents a transformative opportunity for the Indian mining and metals industry to become more efficient, sustainable and globally competitive. Digital transformation is not a destination but a journey, which requires more than just technology—it demands a holistic, collaborative and future-focused approach. By embracing digital transformation proactively and responsibly, the Indian mining and metal industry can unlock unprecedented value, while securing its place in the global value chain.

Abbreviations

Abbreviation	Full form
%	Percentage
~	Approximately
3D	Three dimensional
AI	Artificial Intelligence
AR	Augmented Reality
CAG	Comptroller and Auditor General
CAGR	Compound Annual Growth Rate
CNC	Computer Numerical Control
DMF	District Mineral Foundation
ESG	Environmental, Social and Governance
EU	European Union
EV	Electric Vehicle
FDI	Foreign Direct Investment
GDP	Gross Domestic Product
GHG	Green House Gas
GSM	Global System for Mobile Communication
GVA	Gross Value Added
GW	Giga Watt
HSE	Health, Safety and Environment
IPA	Intelligent Process Automation
IoT	Internet of Things
IT	Information Technology
IIoT	Industrial Internet of Things
ITIL	Information Technology Infrastructure Library
KPI	Key Performance Indicator
LPDT	Low Profile Dump Truck
ML	Machine Learning

Abbreviation	Full form
MT/ MTPA	Million tonnes/ Milltion tonne per annum
NMET	National Mineral Exploration Trust
NSP	National Steel Policy
PLC	Programmable Logic Controller
R&D	Research & Development
RFID	Radio Frequency Identification
RPA	Robotic Process Automation
TOGAF	The Open Group Architecture Framework
UAV	Unmanned Aerial Vehicle
USGS	United States Geological Survey
VR	Virtual Reality

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Established in 1927, Federation of Indian Chambers of Commerce and Industry (FICCI) is the largest and oldest apex business organisation in India. Mahatma Gandhi addressed FICCI's fourth AGM in 1931. Our 97th AGM was held in November 2024. With our rich legacy, FICCI would play an even greater role as India emergence as the third-largest economy.

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