AI: Bringing Mining Companies Closer to Their Data

E&MJ *explores the advantages that AI is instilling across mining value chains*

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If there's one technology (or group of technologies) that holds the potential to redefine mining processes and operations over the coming decades, that technology would be artificial intelligence (AI).

From supporting the discovery of new mineral resources and improving safety and productivity through remote and autonomous operations, to predicting machine maintenance requirements and ensuring the most efficient usage of natural resources… The potential that AI holds for an industry that's constantly squeezed to 'do more with less' is seemingly endless.

While mining companies are no strangers to the benefits that AI offers, with some having leveraged autonomous vehicles and equipment since the 1990s, many are just dipping their toes into the advanced capabilities that techniques like machine learning (ML) and deep learning (DL) can offer.

The team at S&P Global hit the nail on the head in a February 2025 article when they wrote: "With the rapid acceleration of AI adoption and continued use of automation across various mining activities, it is now nearly impossible to envision a significant-scale mining operation that does not incorporate technology at some stage of the mining value chain."

The more recent advent of foundation models and widespread access to generative AI (Gen AI) with the launch of tools, such as ChatGPT, DALL.E, Microsoft Co-Pilot and more, opens a further world of possibilities for miners. These tools not only hold the potential to revolutionize the way that mining operations and their supply chains are designed, built and run, but their multi-modal capabilities (speech to text, text to image etc.) also allow people to apply data-led insights more fully in their day-to-day decision making and workflows.

Rio Tinto's AutoHaul AI-controlled trains have travelled more than 7 million kilometers since their introduction in 2019. (Photo: Rio Tinto)

This democratization of AI is already bringing the mining and metals workforce closer to data which, in turn, is helping organizations to extract greater value from their operations. The following article examines examples of where and how AI is adding value across mining businesses today, as well as potential future applications.

Enhancing Mineral Exploration

AI is *the* current buzz-topic in mineral exploration. As the team at Deloitte noted in the 2025 edition of their annual *Tracking the Trends* report: "When treated as part of a systematic approach to mineral exploration, precompetitive geoscience data on properties and deposits can be leveraged by geologists [alongside AI] to better inform their exploration programs. This, in turn, can generate cost and time savings... It can also speed the identification of potential drill targets and help companies better understand mineralization systems that could lead to subsequent discoveries."

Specifically, AI enhances speed and precision in exploration by using algorithms to identify patterns in vast datasets which could indicate the presence of valuable mineralization. This information helps to hone drill programs, saving companies time and money by eliminating targets that have a low probability of returns.

There are multiple examples of miners, explorers and technology companies that are working collaboratively to harness AI as part of today's exploration programs (read more in *E&MJ* February 2025 *Discovering new opportunities in mineral exploration*). One of the most prominent proponents is BHP.

"Over the years, AI has helped BHP unlock potential value through multiple innovations, including predictive maintenance, energy optimization, autonomous vehicle and machinery operation, data-driven decision making and real-time

monitoring and reporting," the company explained in a recent online article.

"For BHP, ML, coupled with human ingenuity, has recently allowed us to discover new copper deposits in Australia and the USA. Cutting-edge work continues within our business as teams shift their focus to muon tomography."

One of BHP's alliance partners, Ivanhoe Electric, is also using ML to accurately detect the presence of sulphide minerals containing copper, nickel, gold, and silver at depths of over 1.5 km. Ivanhoe Electric's proprietary electrical geophysical surveying transmitter, named Typhoon, offers high precision at deep depth while minimizing land disturbance and preserving surrounding ecosystems.

Enabling Autonomous and Remote Operations

In its 2024 annual report, Rio Tinto mentioned that, through 2025 it plans to "invest in new partnerships with Chinese suppliers to trial new construction methods, innovations and technologies — including AI — to develop orebodies faster and reduce our capital intensity."

This is unsurprising as the company was one of the earliest miners to adopt AI through its autonomous rail and truck haulage systems which operate in Western Australia's Pilbara region. Rio Tinto's AutoHaul long-distance trains have travelled more than 7 million km since their introduction in 2019. Also, part of Rio Tinto's iron-ore operations is a fleet of 130+ autonomous trucks which are operated by a supervisory system and a central controller, rather than drivers. Each haul truck has more than 45 electronic tags which send data every few seconds, providing Rio Tinto with over 30 million geo positions every single day.

The autonomous haulage system (AHS) behind these trucks uses pre-defined GPS courses to help them automatically navigate haul roads and intersections and pinpoint actual locations, speeds and directions of all vehicles at all times. Rio Tinto estimates that, on average, during 2018, each of its autonomous trucks operated 700 hours more than conventional haul trucks would, with 15% lower costs, delivering clear productivity benefits. It noted that these systems also take truck operators out of harm's way, reducing the risks associated with working around heavy machinery.

The Hive — FMG's remote control center — oversees the operation of over 200 haul trucks, 4,000 ore cars and six hematite processing plants as well as FMG's magnetite mine at Iron Bridge. (Photo: FMG)

Underpinning this capability is Rio Tinto's Mine Automation System (MAS). This acts like a network server application, pulling together data at 98% of the company's sites, and 'mining' it for information. The MAS provides this information in a common format using sophisticated algorithms, and the results are displayed visually using Rio Tinto Visualization (a 3D visualization tool based on a gaming engine which allows 1,700 people across Rio Tinto's mines to 'see' inside of its operations) or through conventional dashboards with graphs, charts and tables.

"Because our autonomous equipment is made differently by manufacturers, MAS also enables these different systems to work together," Rio Tinto explained. "We then use AI to make the best use of our systems. We can automatically generate orebody models, organize equipment dispatch, and predict and control blasts. We have even optimized the speed and reduced queuing of our autonomous trucks — these small improvements have produced significant gains in productivity."

The company has built computer systems which analyze its operational data and make decisions in microseconds allowing, for example, an ore crusher at an iron-ore processing plant to 'talk' to the haul trucks and let them know when it needs more ore. Any new software features are rolled out to sites around the world in a matter of hours, capturing synergies across the business.

"At our bauxite mine in Weipa, special mathematical software helps our port schedulers manage hundreds of ships a year. Using data in these ways helps us minimize downtime, reduce energy use and cut operating costs," Rio Tinto added. "Every day our automated drills, trucks, shovels, conveyors, trains and ships produce huge amounts of valuable data. By combining this data with clever analytics, AI, ML and automation, we are making our business safer and more productive."

Realizing Pit-to-port Efficiencies

BHP also credits AI as a key factor in making its Western Australia Iron Ore (WAIO) business one of the lowest-cost major iron ore producers for the past four years.

It explained: "WAIO is an enormously complex operation with many mines and mine hubs in the Pilbara all connected to a railway and port, with conveyors, loaders, and trains. These touchpoints are all controlled through a remote operations center… As you can imagine, humans can't optimize all the decisions made throughout the operation, so we use AI as a decision support system. Our team members make the ultimate decision, but this is supported by the power of AI systems and their computer crunching ability."

BHP has eight automated ship loaders at its Port Hedland export facility. Operated remotely from its Integrated Remote Operations Centre in Perth, these are responsible for loading 1,500 bulk ore carriers annually, exporting approximately 280 million metric tons (mt) of iron ore to global customers in 2021. The company has calculated that automating its ship loader facilities has increased production by more than 1 million mt/y, through greater precision, reduced spillage, faster load times, and equipment optimization.

BHP is also using digital twins combined with Gen AI to simulate the outcomes of different strategic decisions and test their potential impacts across

complex operations and supply chains before they are made in real life.

"We are using digital twins at BMA, Copper South Australia and Escondida to predict future production outcomes and identify key performance drivers, risks and opportunities," said BHP. "Through these digital twins, we have found new opportunities including to optimize mine haulage, address ore fragmentation and material handling challenges, and debottleneck surface operations.

The BMA Autonomous Haulage Excellence Program has developed proprietary tools and in-house capabilities that use AI, advanced analytics and digital twin modelling to predict operational performance. This allows the team to act early before a problem arises. In a recent example, this capability facilitated an increase in productive movement by 10% per annum at one of BMA's autonomous operations.

Australian iron-ore producer, Fortescue Metals Group (FMG), has also strategically integrated AI across its operations to enhance efficiency, safety and sustainability. Central to this initiative is The Hive, a state-of-the-art control center in Perth that remotely manages FMG's integrated supply chain which runs from pit to port.

The Hive oversees autonomous mining equipment, including more than 200 haul trucks, 4,000 ore cars and six hematite processing plants as well as FMG's magnetite mine at Iron Bridge. Train controls, technical services, scheduling, planning, and energy operations are also handled by The Hive team. In 2024, The Hive oversaw the movement of over 4 billion mt of iron ore autonomously.

"AI is becoming increasingly valuable to Fortescue's operations, unlocking significant time and cost savings," said the company on its website. "By automating routine tasks and removing manual processes, AI empowers our teams to focus on higher-level problem-solving and decision-making. Tools, such as schedule optimization software, chatbots, and AI-driven product design are examples of how this technology is used to enhance operational efficiency."

At the Hive, advanced AI functions are integrated into Fortescue's process control systems to continuously monitor hazards and take corrective actions when necessary. Additionally, these systems optimize the scheduling of critical tasks, such as in-loading operations by synchronizing train control and scheduling decisions. This ensures that the right resources are deployed at the right time, improving operational efficiency and safety.

Making Maintenance Smarter

Maintenance for mobile and fixed plant equipment is one of the biggest drivers of operating costs for mines around the globe, representing around 30%-50% of their operating expenditure on average. Implementing predictive and prescriptive maintenance approaches using AI and ML algorithms can help miners to take a proactive stance on the maintenance of vehicles and machinery, lowering the cost of materials, parts and labor and reducing the likelihood of equipment failures.

BHP has calculated that automating its ship loader facilities at Port Hedland in Australia has increased its production by more than 1 million mt/y. (Photo: BHP)

For years, Teck relied on traditional maintenance methods like vibration, thermography and oil checks to assess the health of the fleet at its Trail Operations in British Columbia. In 2011, the team began to look at a new maintenance approach to reduce downtime, boost production and minimize risks while ensuring a stable and safe process.

With the availability of data, Teck wanted to leverage digital signals to predict equipment failures and mitigate risks to production, the company explained in a recent case study. Teck's reliability team selected Mtell, AspenTech's data-driven, predictive and prescriptive maintenance solution.

"Mtell has comprehensive predictive capabilities that integrate with our computerized maintenance management systems and is used by our digitization teams," said Gordon Kavaloff, asset performance specialist at Trail Operations.

Mtell has a broad set of monitoring technologies, including rules-based and condition-based monitoring, first principles modelling, AI, ML and custom models from data science teams.

"In addition to rules-based agents, Mtell's ML has allowed us to predict equipment failures that are not obvious or are complex," said Kavaloff. "Once a failure abnormality is detected, an automated work order can be generated and notification made by email."

Teck engaged with its mill wrights from the beginning, tapping into their knowledge and securing buy in before implementing Mtell on three critical pieces of equipment. Within three to six months, the maintenance teams were able to proactively identify potential failures, and the solution was scaled to protect pipelines, pumps, boilers and bag houses.

Teck used signals, like vibration, pressure, flow, temperature and current, to build Mtell agents and identify and monitor real time changes, like differential pressures in bag houses; water flow and temperature in furnace cooling systems; heat exchanger temperature differentials and current for pumps.

"For calcine dust pumps, we shifted the run time-based maintenance," said Kavaloff. "In another instance, Mtell iden-

tified impeller clogging issues very early in a filter feed pump. And despite just having one signal from a thickener, Mtell identified an increase in current, resulting in a higher than expected specific gravity. This early detection enabled us to pull the equipment out of distress and maintain plant stability."

Mtell also supports Teck's critical reliability efforts by providing leading indicators which help the company ensure production continuity and efficient use of resources.

Through a partnership with Google Cloud and Pythian, Teck is now using the millions of data points generated by its mobile fleets across the globe to identify issues that it said were "previously unpredictable", such as electrical failures.

"We generate terabytes of data at each of our operations — data from both connected equipment and connected employees," the company explained on its website. "Analysis of this data, powered by ML and AI, is helping us to develop new ideas to improve safety, sustainability and productivity. Thanks to an innovative use of ML, Teck is using big data to predict the unpredictable and fix problems before they happen.

"We are also modelling and predicting the remaining life span of our trucks, determining wear and tear, identifying abnormal failures, and enhancing alarm and notification systems. ML for maintenance is helping to minimize unplanned maintenance, reduce overall maintenance costs and extend equipment life."

The company estimated that, at one site alone, there is the potential for more than $1 million in annual savings from implementing this program.

At Rio Tinto's Weipa bauxite mine, mathematical software helps the company's port schedulers to manage hundreds of ships every year. (Photo: Rio Tinto)

Optimizing Material Flow

Optimizing material flows in mines and processing plants is critical for achieving both productivity and sustainability targets. Digital twins can provide insights that enable better management of production despite variability in ore feed, processes and equipment. Metallurgical digital twins simulate either the entire mine-to-metal value chain or specific process stages. Their main goal is to align operating parameters — such as feed capacity, target grades and mineral recoveries — with varying ore characteristics and equipment availability.

In 2023, Newmont's Lihir gold plant in Papua New Guinea implemented Metso's Geminex metallurgical digital twin with the aim of optimizing its material flows, managing ore feed variability, and maximizing metallurgical processes. By combining physics-based models with AI-driven ML algorithms, Geminex continuously adapts to further optimize the plant's operational parameters.

In the case study, Metso explained that typically, metallurgical digital twins operate in tandem with advanced process control (APC) systems or process optimizers specific to each process area using real-time data to anticipate the effects of ore blending and setpoint adjustments. However, ML allows for automatic adaptation of the simulation models, thus maintaining accuracy and maximizing plant performance and productivity.

To address the challenge of time varying modelling accuracy due to changing ore types, Metso focused on the calibration of the Lihir simulation model to geometallurgical ore types. This ensured it would be capable of accurately predicting plant performance under different operational scenarios. By creating dynamic equipment modes specific to different ore types, Geminex can respond to changes in ore blends and plant conditions in real-time.

At Lihir, the digital twin runs as a cloud-based application on Microsoft Azure, interfacing with data through a secure data lake. Its simulation model is connected to critical plant data such as flow rates, slurry densities and reagent dosages. This integration enables automated adaptation.

Modelling Mine Design and Capital Projects

Canadian miner, Teck Resources, has been working with tech startup, Skycatch, to implement AI-powered digital twins based on NVIDIA's Omniverse technology at its project sites.

"Teck Resources has been using Skycatch's compute engine across all of our mine sites globally and is now expanding visualization and simulation capabilities with SkyVerse and our own digital twin strategy," said Preston Miller, technology and innovation lead at Teck Resources, in an NVIDIA case study. "Delivering near-real-time visual data will allow Teck teams to quickly contextualize mine sites and make faster operational decisions on mission-critical, time-sensitive projects."

In the future, Gen AI could also help to improve mine design by exploring many possible designs to find the most suitable match for a company's objectives. David Alonso, partner and AI leader, at Deloitte Australia, explained in *Tracking the Trends 2024*, that Gen AI not only augments and accelerates design in many fields, but has the potential to 'invent' designs or objects that humans may have otherwise missed.

"Today, engineers spend months, even years, optimizing the design and delivery of mine sites from different dimensions, not just spatially, but also from cost and sustainability perspectives," he said. "Once the design is locked in, it can take years to develop and commission the mine, by which time the technologies selected might have been superseded. The ability to generate and adopt new designs through Gen AI could be a game-changer."

Teck uses the millions of data points generated by its mobile fleets to identify issues, such as electrical failures, before they occur. (Image: Teck)

The integration of the digital twin into APC systems allows operators to manage the plant more efficiently. Metso said that although technical deployment of the Lihir digital twin is complete, full operational commissioning is still in progress. The next steps include completing auto integration of crusher feed characteristics to enable usage and testing of the stockpile model, confirming all equipment running tags are working correctly to ensure accurate reflection of the plant, reviewing the data supply process, as well as develop and test the auto-optimizing algorithm and recommended plant settings.

Planning for Variability

Another of BHP's strategic ambitions is to transform its mine planning capabilities using AI to create more robust, stable and achievable mine plans. By incorporating probabilistic methods and ranges into mine planning, the company hopes to better understand the impacts of value chain variability.

"To increase copper production at Escondida, we use advanced analytics to understand the impacts of different ore characteristics and granulometry on semi-autogenous grinding (SAG) mill performance," the company explained in an online article. "A digital twin of the Escondida value chain and Gen AI models inform ore blasting and blending strategies, identify mine areas with challenging ore characteristics, and support the implementation of SAG mill model predictive control. By mitigating the impacts of varying mineral characteristics, we have reduced monthly production losses due to granulometry by an average of 70%."

The same data-driven decision making capabilities are being rolled out across BHP's business to support copper production, including at Copper South Australia and Spence. The company said that integrating Gen AI with its digital twin models has also resulted in faster insights generation, uncovered better opportunities and democratized access, allowing non-technical users to design and perform scenario analysis in natural language for improved business decisions.

"We recently applied Gen AI to our digital twin at BMA," it explained. "Using natural language, the non-technical user can ask a variety of questions. For example, what are the realistic production ranges over the next five years? How does the value chain bottleneck shift and what are the key performance drivers causing the bottleneck? Through Gen AI, future performance can be predicted with ease and hidden performance improvement opportunities can be uncovered."

Scaling Insights and Value

While the value that AI can add at the operational or individual business level of an organization can be significant, many of these tools and technologies can also be scaled to provide insights and efficiencies at the enterprise level.

For example, in 2018, data engineers, metallurgists, and mining engineers from Freeport-McMoRan collaborated with McKinsey's data scientists and experts to improve operations at the Bagdad mine in Arizona. The goal was to create a digital solution that could improve every aspect of the operation and be easily scaled to all of Freeport's mines.

To support this transformation, Freeport built a central cloud-based data architecture. A key component of this was a data warehouse to store the data collected from sensors installed on the company's trucks, shovels and stationary machines, allowing Freeport to capture second-by-second performance readings. It used that data to train an AI model custom-designed and built by McKinsey to find operational improvements that could increase the mine's output at lower cost. For instance, instead of running the Bagdad plant at a single setting all day, Freeport was able adjust settings every hour to maximize production from a given type of ore. This quickly boosted production by 5%-10%.

"We put in the recommended AI engine and saw 10% improvement in production," said Cory Stevens, President, Mining Services at Freeport in the McKinsey case study. "And we thought, if we do the implementation at all seven of our sites right, it's almost like having a brand-new plant without having to go through permitting processes and disturbing a new area. It's in the billions of dollars that we're offsetting by going through the transformation."

Once the AI models were built in a modular way, Freeport was able to easily adapt and scale their use throughout its mines in the Americas. The company estimates that, as a result of the program, it was able to increase its annual copper production across all of its mines by 200 million pounds, realize a $350-$500 million uplift in EBITDA and saved $1.5-$2 billion by avoiding the building of a brand new processing facility.

Saving Water and Energy Costs

ML algorithms can also analyze operational data with the aim of improving the efficiency of energy and water usage and other environmental parameters. For example, BHP's Escondida mine in Chile has saved more than three gigalitres of water and 118 gigawatt hours of energy since 2022 thanks to AI technology. This enables operators to implement water optimization plans using real-time data analytics on large volumes of energy usage data to identify anomalies and automate corrective actions at the mine's concentrator and desalination plant.