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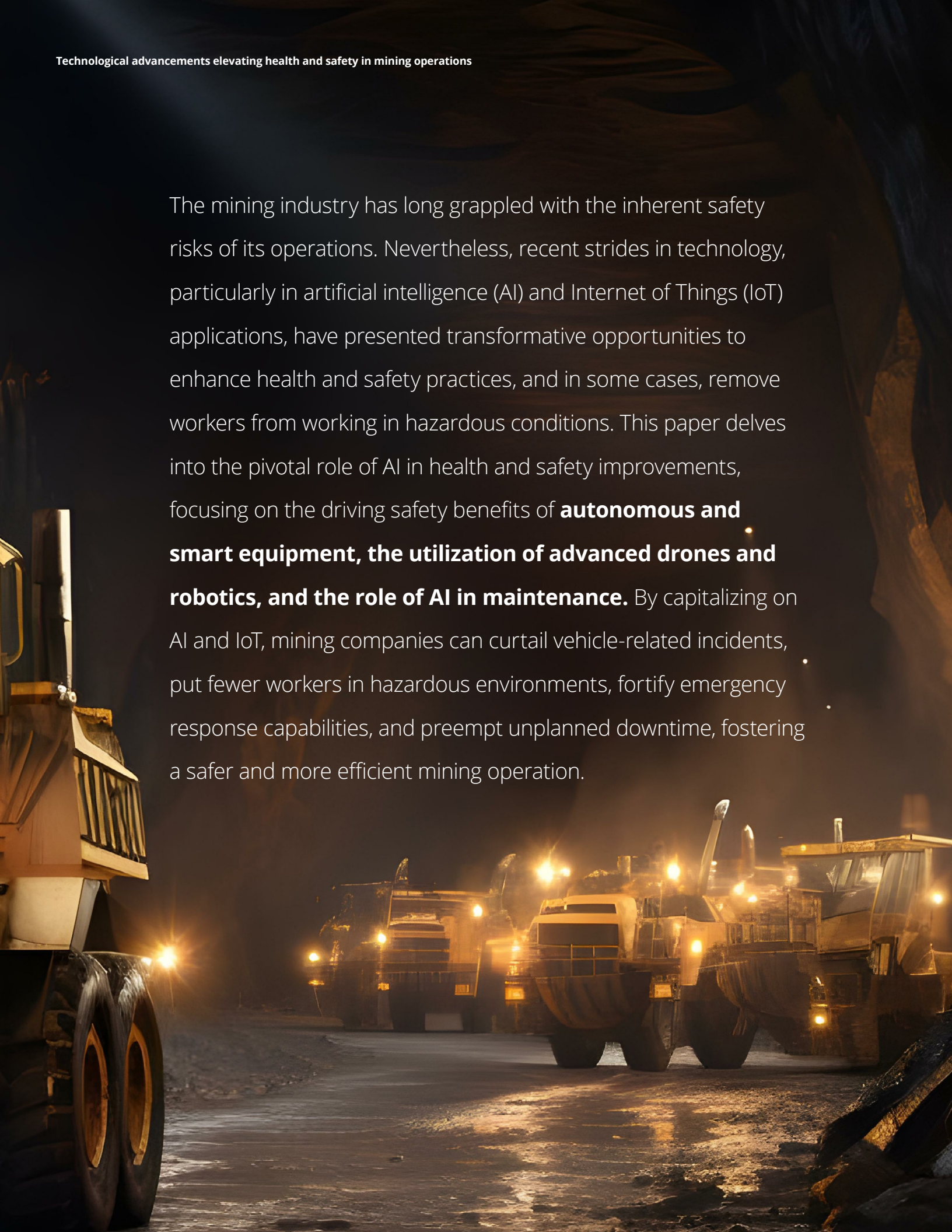
Technological advancements elevating health and safety in mining operations

The mining industry has long grappled with the inherent safety risks of its operations. Nevertheless, recent strides in technology, particularly in artificial intelligence (AI) and Internet of Things (IoT) applications, have presented transformative opportunities to enhance health and safety practices, and in some cases, remove workers from working in hazardous conditions. This paper delves into the pivotal role of AI in health and safety improvements, focusing on the driving safety benefits of **autonomous and smart equipment, the utilization of advanced drones and robotics, and the role of AI in maintenance.** By capitalizing on AI and IoT, mining companies can curtail vehicle-related incidents, put fewer workers in hazardous environments, fortify emergency response capabilities, and preempt unplanned downtime, fostering a safer and more efficient mining operation.



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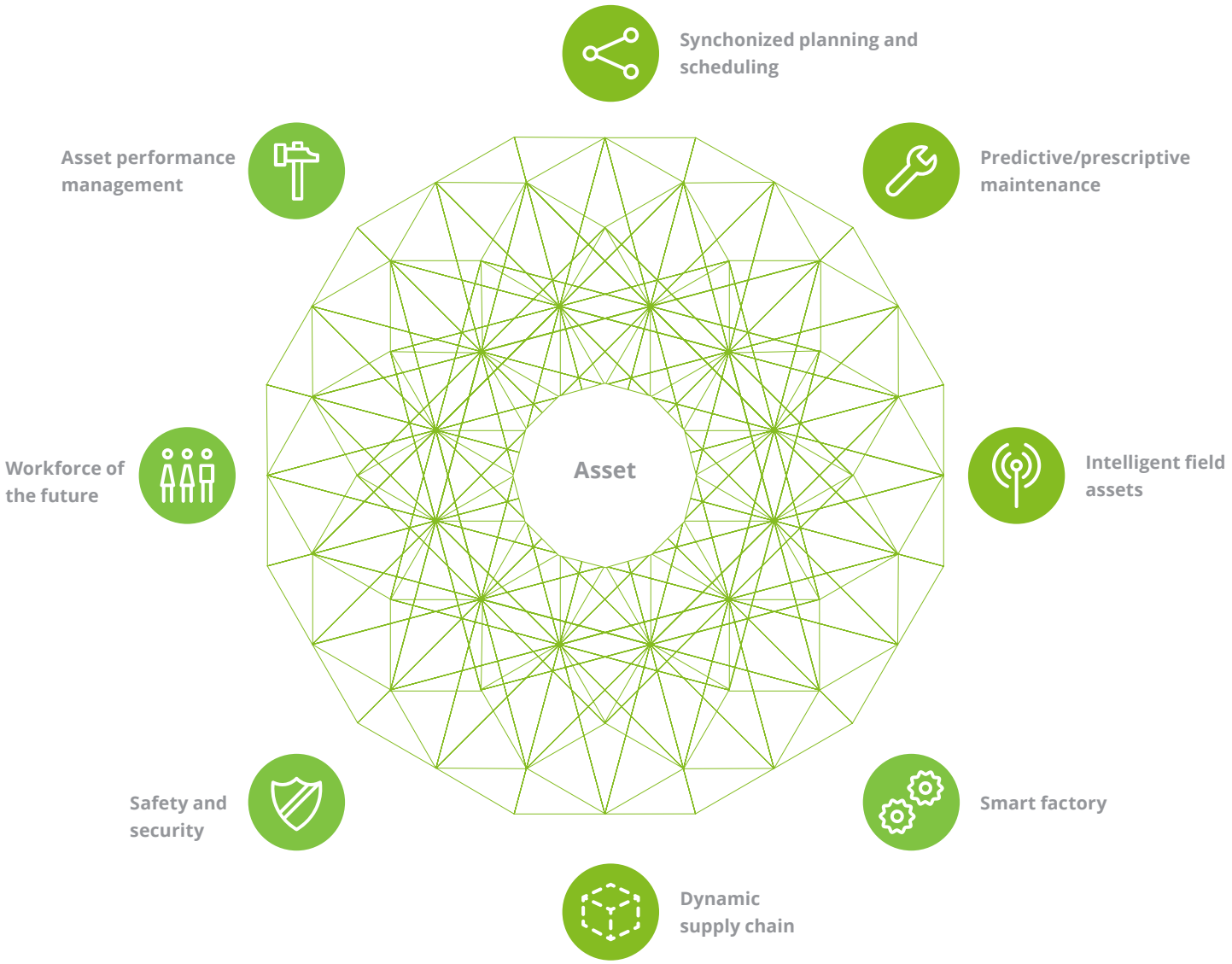
Introduction

The mining industry's operational environment has historically been fraught with safety challenges, necessitating continuous efforts to heighten safety standards and mitigate hazards. Mobile equipment and working conditions that are unsafe or hazardous are the main sources of health and safety risk at a mine.

These are challenges that have historically been very challenging for companies to address in the field. In recent years, the emergence of innovative technologies, particularly AI and IoT, has revolutionized health and safety in mining operations. This paper will explore the profound impact of AI-driven innovations across the problems related to mobile equipment and hazardous working conditions.



Mobile equipment

AI and automation

AI and autonomous mobile equipment (i.e., dozers, loaders, haul trucks) equipped with IoT sensors and connected in a smart environment represent AI's change in basic assumptions in mining operations. Empowered with sophisticated AI algorithms using millions of real-time calculations, equipment can be configured to operate autonomously. Without continuous onboard human operation, the mobile equipment instead relies on IoT sensors in their environment. This autonomous operation has the potential to mitigate accidents normally attributed to human error, and removes workers from a hazardous environment.

In the first half of 2021, nine miners were killed and 185 injured in accidents involving powered haulage equipment such as shuttle cars, scoops, locomotives, and front-end loaders. According to Mine Safety and Health Administration (MSHA) and Occupational Safety Health Administration (OSHA) data, this was the highest number of powered haulage fatalities since 2006.[1] As of September 2023, there were nine fatalities classified as "Power Haulage" by MSHA.[2] This trend underscores the urgency for innovative solutions to enhance safety, making autonomous mobile equipment an indispensable asset.

There is a strong interest in autonomous haul trucks within the mining industry. As of 2020, three companies in Australia (Rio Tinto, BHP, and Fortescue Metals) were operating fully or semi-autonomous haul trucks. In Canada, Suncor operated the world's largest autonomous haul truck and had planned to have a fleet of 150 autonomous haul trucks by 2022.[3]

Automated drilling

Drilling is inherently one of the most hazardous working conditions in any industry. Just a few of the many dangers include moving parts, high-pressure pneumatic or hydraulic systems, and falling objects. The application of IoT and AI to the drilling process can remove workers from the immediate area where many of these hazards exist, including both surface and underground applications. In Canada, ArcelorMittal has retrofitted its drilling equipment at its Mont Wright iron mine to all semi-autonomous equipment, as part of its innovation strategy. ArcelorMittal cited benefits including increased production, less maintenance, and better safety as operators can now simultaneously monitor multiple drilling operations remotely.[4]

Advanced collision avoidance systems

Current industry safety practices for mobile equipment include administrative controls, simple technologies such as seat belt interlocks, or more complex technologies such as collision avoidance and warning systems (CXS).[5] Moving a step beyond these practices, the fusion of AI and haul trucks yields remarkable safety dividends by exploiting real-time data from diverse sensors that enable dynamic adjustments in speed, direction, and braking, optimally navigating challenging terrains and circumventing rollover-prone scenarios. Like many automobiles on roads today, mining mobile equipment is being equipped with proactive recognition and preventive capabilities. These collision avoidance systems have the potential to apply braking to prevent collisions using radar, cameras, in some cases global positioning systems (GPS), and other technology to monitor surroundings.

One potential challenge that companies should monitor when implementing advanced collision avoidance technology is a lack of validation testing of collisions; AI-based collision avoidance systems have not yet been tested thoroughly in potentially fatal situations, thus they should be treated similarly to personal protective equipment (PPE) as a last line of defense rather than something to be relied upon to prevent incidents. Over time, software-guiding autonomy will improve as will the data from sensors and GPS. The long-term implications are a reduction in vehicle-to-vehicle collisions and improved safety performance.

Fatigue monitoring

Many incidents involving power haulage are a result of operator fatigue. A recent study by the National Institute of Occupational Safety and Health (NIOSH) identified that improved monitoring and reporting systems were identified as possible mitigating controls for over 48% of the haul-truck-related fatal accidents.[6] During a typical operator shift, which may range from 12–16 hours, the operator performs repetitive tasks: driving the haulage vehicle to be loaded, driving the load to the crusher, and repeating the process almost continuously. The travel path is typically consistent and there are several hazards along the path, such as other haulage vehicles, light-duty vehicles, changing berms, and other road obstacles that may be exacerbated by the limited visibility in the massive haul trucks. Throughout the day, the operator may become fatigued and suffer from periods of microsleep—a brief period (oftentimes only seconds) of sleep. This fatigue condition can happen without the operator's awareness and often goes unnoticed by anyone at the work site.

Equipment manufacturers and mining companies are solving this issue with advanced sensors and cameras inside the cabin. As operators run the equipment, advanced real-time software tracks eye movement and facial expressions. The software can alert the operator and/or management if fatigue occurs and let's the driver know if they are distracted. These systems, known as Fatigue Monitoring Systems (FMS) or Driver Safety Systems (DSS), can alert the operator through sounds, vibrations, and tightening of the restraint systems. Keeping the operator alert and focused with the application of technology can help to reduce mobile equipment-related incidents.

Amplified efficiency and productivity

Beyond safety gains, autonomous haul trucks enhance mining operations by determining continuous and streamlined transport without the constraints of human-driven shifts. Personnel monitoring haul trucks remotely can monitor up to eight vehicles at once, with this number predicted to increase as technology improves. This capability results in eight vehicles that do not have shift breaks, fatigue breaks, lunch breaks, or lapses in concentration. Their seamless integration maximizes efficiency, curtails idle periods, and results in substantial cost savings and enhanced production rates. Potentially, an autonomous haul truck's only downtime will be utilized for preventive maintenance.

Case study: Autonomous haul trucks

At its Bagdad, Arizona, copper mine, Freeport-McMoRan announced in late 2023 that, in collaboration with Caterpillar (Cat), it will be deploying 33 Cat 793 haul trucks at the mine site. The trucks will operate using Caterpillar's Cat® MineStar™ Command systems and hardware. Implementation of this technology will take three years of collaboration between Cat's teams and Freeport-McMoRan. Freeport-McMoRan acknowledges the safety improvements from this decision: "This project is expected to optimize our fleet, improve operating efficiency and contribute to safety by removing our people from this area of the operation."[7] Training of operators and site teams will be extensive, including train the trainer and increasing worker awareness of autonomous zones and red zones for equipment maintenance.

Hazardous working conditions

Drone data for emergency response

Drones have emerged as powerful instruments for mining with a variety of applications, many of which can improve health and safety outcomes. In underground environments, drones can be used to map areas that are difficult or impossible for humans to access. In recent years, the reliability and efficiency of drones has dramatically increased with IoT and will further accelerate with AI applications. IoT sensor application on drones has allowed for real-time data and improved obstacle avoidance, real-time flight path adjustment, and various other critical improvements to enable smart and connected environments not possible a few years ago.[8] One example is emergency response drones (ERDs). A drone can provide first responders with critical information to assess hazards and risks in a very timely way. In underground environments at Newmont, response drones are equipped with thermal imaging to aid recovery times. Other sensors such as methane or other gasses identify hazards in real time and share them with rescue teams. Newmont's emergency response specialist noted of ERDs, "They provided critical and practical operational information to our responders to ensure they can perform their activities without having to place themselves in harm's way."[9] Providing real-time data to rescue teams, drones enable informed decision-making and significantly augment the safety of search and rescue operations.

Drone mapping/3D modeling efficiency

Modern drones equipped with high-resolution cameras and advanced sensors, like such as Light Detection and Ranging (LiDAR), serve as indispensable tools for remote assessment. The application of AI allows these drones to make quick decisions independent of GPS and computer connectivity, which may not be available in underground environments.

In one example of drone mapping applications, Exyn Technologies recently teamed with Canada-based Dundee Previous Metals in its underground Chelopech gold-copper mine. Exyn uses LiDAR-based 3D mapping drones in the underground environment where there are no GPS signals to guide the drone. The technology greatly improved Dundee Precious Metals' safety and efficiency of the survey process by removing humans from the processes. After the initial project, the company incorporated the drone scanning technology into its underground processes and designed new areas and blasts to optimize drone performance. The two entities have entered into five-year partnership.[10]

IoT for environmental hazard scanning

IoT has demonstrated it can be a game changer when it comes to enhancing safety processes and monitoring environments. Smart sensors, and even wearable sensors, have become significantly cheaper and much more reliable over the past several years. The primary benefit of IoT sensors is that each sensor can transmit a signal to sensors around it, forming what is known as a "mesh network." The more sensors that are present in an area, the stronger the network becomes, as each sensor can also serve as a relay in the network. This is significant in underground environments where the ground itself may inhibit traditional signals. The application of IoT as wearable devices on hard hats and equipment for example allow the tracking of workers in underground environments. This could save lives by facilitating targeted rescue efforts in a ground-fall disaster event. Fixed IoT sensors in areas can continually monitor for environmental conditions that could be harmful to workers. Conditions that are typically monitored are air quality, temperature, radiation, and gas levels. Miners will receive timely warnings of potentially hazardous events, and mine managers can be notified simultaneously.

Blast monitoring

Drones bolster the mining industry's seismic monitoring capabilities, empowering early detection of potential ground instabilities. Timely identification of geotechnical hazards allows proactive intervention and the prevention of accidents, thus fortifying safety protocols. In 2018, Freeport-McMoRan was recognized by NIOSH for mine surveying of blasting and highwall monitoring, reducing the exposure of employees to traditional risks.[11] The use of aerial drones capturing footage of the blast pattern and resulting rock movement allows Freeport-McMoRan to better design future blasts and learn from flyrock instances. It also informs the crews of misfires that may occur and where they are located within the pattern.

Robotics for hazardous operations

The mining industry has long been an early adopter of robotics, particularly in underground environments where the application can increase workers' ease of travel underground and potentially remove them from harmful environments. Technological advancements in robotics and the application of both IoT sensors and artificial intelligence processing is effectively changing what's possible with robotics. One useful application of robotics is exploration or mapping of subterranean spaces that may have been considered a confined space or have other known hazards that prevent human interaction. Confined spaces, for example, present several challenges; sending robots into confined spaces, which may contain poor air quality, flooding, collapsing areas, poor visibility, and chemical/gas exposure, for exploration or mapping purposes could be very effective. Additionally, robots could be used for first response in rescue operations for which part of the risk is unknown hazards or conditions. Robots are capable of assessing structural conditions, mapping hazards, and delivering critical supplies including medical and oxygen. Rescue robots can be put to use rapidly after an incident, while response operations are planned, and can be equipped to perform rescue or triage operations and save lives with basic medical supplies and oxygen, thermal cameras, and environmental sensors.[12]

Case study: Advanced technology in underground mine areas

Metal miner Glencore, in its Kidd Creek Mine located in Canada, incorporated specialized drone autonomy technology by Emesent to map inaccessible underground areas and thereby remove personnel from areas at risk of ground falls. Rather than depending on mining engineers and surveyors to map unsupported voids, Emesent now deploys a drone system that uses LiDAR data and advanced algorithms. The drone and mapping technology generate specific 3D point clouds of the scanned environment, capturing critical visuals in places such as stopes, drawpoints, orepasses, and drives, while keeping personnel away from unstable ground. Emesent was a 2022 recipient of the NIOSH Mine Safety and Health Technology Innovations Award for its work related to removing people from highly unpredictable and dangerous environments.[13] Additionally, Glencore uses Boston Dynamics' Spot® robot to perform underground surveys and prevent workers from entering potentially hazardous areas.[14]

Prescriptive maintenance

Predictive maintenance
AI-driven predictive maintenance constitutes a pivotal facet of mining safety, leveraging data from equipment sensors and historical maintenance records to preemptively detect machinery health deterioration. Current maintenance practices vary by mining company, from planned maintenance to "as needed" maintenance when problems arise. Unplanned maintenance may increase the risk of incidents due to the higher potential lack of planning and confirmation that critical controls are in place. Predictive maintenance utilizing AI can predict specialized maintenance needs for each piece of equipment using an array of data from historical maintenance records, mine operations data, equipment telemetry and computer readings, and overall trends for a given piece of equipment. This predictive maintenance reduces unplanned down time and unplanned failures that often result in increased injury rates.

Mitigating unplanned downtime
Unplanned equipment failures pose dual challenges of halting production and potentially compromising safety. Predictive maintenance powered by AI empowers early fault detection, averting unplanned downtime and facilitating sustained operations.

Proactive incident prevention via maintenance
AI-based predictive maintenance facilitates preemptive mitigation of safety incidents arising from equipment malfunction. There is a strong correlation between equipment malfunction and/or mechanical failures and subsequent increase in safety incidents. Data analytics suggests that engine fires, brake failures, exhaust, and fumes are examples of hazards related to poor maintenance that contribute to increased safety incidents. By working toward optimal equipment performance, mining companies circumvent potential hazards, thereby safeguarding personnel and operations.

Informing preventive measures through incident analysis
The amalgamation of AI and data analytics enables mining companies to extract insights from historical maintenance-related incidents. Root cause analysis related to maintenance and downtime drives proactive implementations of preventive measures, allows meaningful shifts in maintenance behaviors, and can effectively reduce the recurrence of safety incidents.

Case study: AI predictive maintenance

Gold miner Newmont announced in 2020 a global collaboration with Australia-based Dingo, a global leader in advanced predictive maintenance software. In 2019, Dingo unveiled Trakka® Predictive Maintenance, a new software using machine learning models to predict impending equipment failures. "Trakka will enable our people to tap into the power of data to drive continuous improvements," said Newmont's Senior Director of Operations Support Hubs Jason Hill. "The common platform allows us to identify best practices and detect emerging issues. Taking the appropriate action, in either case, is critical to continuously improving our business."[15] Newmont plans to integrate its global predictive maintenance platform with existing enterprise resource planning systems to modernize supply chain and maintenance programs while reducing inventory costs. This proactive maintenance strategy will reduce injuries related to equipment failures—because there will be less failures.[16]

Conclusion

The convergence of AI and IoT technologies presents a major development in enhancing health and safety across mining operations. Through the strategic deployment of autonomous haul trucks, AI-based drone surveillance, and a predictive maintenance approach, mining companies can achieve tangible reductions in vehicle-related incidents, fortified emergency response capabilities, and optimized operational uptime by removing humans from hazardous working environments and predicting potential causes of incidents before they occur. As the mining industry continues to adopt and leverage emerging technologies in operational areas, there is increased potential to create a safer working environment for its workforce, as well as sustainable operational excellence. The speed at which mining companies are adopting some of these new technologies is increasing, with a particular emphasis on areas where health and safety overlaps with improved efficiency in operations or recovery.

The mining industry is currently undertaking a dramatic digital transformation incorporating advanced technology and data into processes to enhance safety, decision-making, and operational efficiency. Through data, mine operators have become more aware of correlations between operational efficiency and safety. As improved data quantity and quality from IoT and AI begins to affect decision-making, there will be an industry shift as operators begin to better understand correlations. Safer production environments contribute to the bottom line and improve profitability.[17] Safe production is efficient production.

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