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Automated management system of mining ore production

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Abstract: The mining industry is undergoing significant transformation due to technological advances, particularly in the field of automated control systems for ore production. This article explores the important role that automation plays in increasing efficiency, safety and productivity in mining operations. By integrating advanced technologies such as artificial intelligence, machine learning, and the Internet of Things, mining companies can optimize ore extraction processes, streamline operations, and reduce risks associated with human intervention in hazardous environments. This abstract provides an overview of key components of automated control systems in ore mining, including real-time monitoring, predictive maintenance, autonomous vehicles, and data analytics. In addition, it examines the impact of these technologies on workforce dynamics, highlighting the importance of upskilling and reskilling efforts to adapt to the evolving nature of mining. This article demonstrates the tangible benefits of implementing automation in the mining sector and highlights future prospects for future innovation in ore production management systems.

Keywords: Automation, Mining industry, Ore production, Automated control systems, Automation in mining industry, Mining technologies, Safety.

1. INTRODUCTİON

At the heart of the mining industry is a transformative evolution driven by the integration of state-of-the-art technologies into traditional ore production processes. As demand for raw materials continues to grow, mining companies are forced to seek innovative solutions to improve efficiency, ensure safety and optimize productivity. At the forefront of this technological revolution are automated control systems, a new era of intelligent mining operations. This article examines the profound impact of automation on the management of ore production in the mining sector. Using the power of artificial intelligence, machine learning and the Internet of Things (IoT), mining companies are revolutionizing their operations, from exploration to production, processing and transportation. The use of manual labor in hazardous environments is left behind. Instead, autonomous vehicles and robotic systems now navigate the complex maze of underground mines with precision and efficiency. From real-time monitoring and predictive maintenance to the deployment of autonomous vehicles and advanced data analytics, these technologies combine to optimize every aspect of ore production. In addition, we explore the transformative effects of automation on workforce dynamics, highlighting the importance of upskilling and reskilling initiatives to equip miners with the competencies required in this digitally driven landscape. Automation includes the collection, transmission, distribution, storage of information about the current state of objects using technical and software equipment, and management of technological objects to achieve the set goal. As an object of automation, procedures related to human activity, communication systems, designs, engineering, energy, transportation, oil and gas industries, metallurgy, etc. an example can be given.
The main goals of automation are:

• Partial or complete release of human labor in information and management processes. This goal is to ensure the safety and freedom of human labor from hard physical work.
• Ensuring that the ongoing processes are carried out in a predetermined and required direction.
• Coordinating the work of objects performing a common function
• Improvement of facilities management features
• Prevention of unwanted external and internal excitatory effects during the processes taking place in the facilities

In modern production, technical means of automation are widely used to ease human labor. The main purpose of automation is to simplify processes, improve efficiency and reduce errors by using machines, software and other technologies. Automation is based on different technologies depending on the task at hand. This may include robotics, artificial intelligence (AI), machine learning, sensors, actuators and control systems. To automate a task, you need to program machines or software to do it.

In general, automation offers great opportunities to improve productivity, quality and competitiveness in various industries. By understanding the basics of automation and using the right technologies, organizations can unlock new levels of efficiency and innovation in their operations.

2. EXPERİMENTAL DETAİL

2.1 Mining industry

The mining industry involves the discovery and extraction of naturally occurring minerals from the earth. Since the dawn of civilization, clay, stone, and metals found close to the earth's surface have been used to make tools, weapons, utensils, and goods for wealth and trade. Today, this industry provides many raw materials for the equipment we use every day, from aluminum cans to the electronic chips of cell phones and computers. Although there are still major environmental concerns about the mining industry, the mining industry has become more efficient with the development of technology that allows miners to extract maximum ore at greater depths underground. The mining experience can be summarized in several steps, such as obtaining a license, mining the ore, selling the metal, and once the mined mine runs out of raw materials, start mining elsewhere. Mining is one of the human activities with the most extensive environmental and social impacts. Mining is the process of extracting minerals from the earth. Coal, metals, oil shale, precious stones, rock salt, potash, limestone, clay, chalk, stone and gravel are all extracted in mining. The mining industry involves exploration, planning and permitting of a mine, extraction, processing, transfer of raw materials by surface and underground mining methods, and restoration and reclamation when the economic life of the mine ends. Reclamation is a system of economic and technical measures to improve natural conditions that are not suitable for minerals. The mining industry also involves the extraction of non-renewable resources such as natural gas, oil, and water, but these resources are not considered part of the mining industry [1].

2.2 Life cycle of processes in the mining industry

The life cycle of a mine includes various stages starting from exploration, continuing to production and ending with reclamation. Exploration and discovery – mine exploration is carried out using a number of tools and techniques. Some of them are mentioned below.

• Metal detecting - mainly used to detect gold, nickel, cobalt or other ferromagnetic materials one meter below the earth's surface.

• Exploratory drilling - used to collect samples of rocks and minerals for further analysis. Sometimes, magnets help find small amounts of ferromagnetic ores like nickel, cobalt, and iron.

• Electromagnetic prospecting – airborne gravimeters and magnetometers are deployed to identify minerals several kilometers below the earth's surface. These waves react differently to different materials and provide 3D images of underground structures.

• Geochemical prospecting – this method involves the collection and testing of various materials, including gases, waters, rocks, plants, and animals [2].

Fig. 1. Explorer taking water samples.

Ore Reserve Estimation – Once an ore deposit is identified, precise mathematical estimates are made to determine its size and grade. These assessments are critical for measuring the economic benefit and viability of ore extraction. At this stage, project managers carefully evaluate the elements of risk to determine whether the investment of additional time and resources into the project is justified.

Determining economic efficiency - at this stage, the mining company evaluates the economic efficiency of continuing the development of the mine or stopping the project. Several factors influence this decision:

• Evaluation of the commercially viable segment of the mineral deposit

• Evaluation of mineral extraction, processing and treatment procedures

• Analysis of market demand for the mineral and potential return on investment

• Engineering problems and implications

• Calculation of costs related to basic infrastructure

• Provision of financial resources and determination of required capital

• Developing strategies for land reclamation and related costs

• Identifying and mitigating other financial uncertainties and risks

Mining development – after confirming the economic viability of the ore body, the mining company proceeds with the purchase of basic mining equipment, as well as the construction of mining plants and other necessary infrastructure. A development phase begins, marking the start of mining operations that continue until the mine ceases to be economically viable [2]. Removal of overburden - mining activity begins at this stage, the main focus is on the extraction of valuable minerals. To access the ore deposit, the layer of rock and soil covering the ore deposit is excavated. Load management strategies that include surface storage and the potential use for backfilling depleted mines after ore mining is complete are critical. Effective planning for cargo removal and storage is essential to minimize environmental impact and ensure operational efficiency.

Fig. 2. Overload removal.

Waste management – a significant part of the materials extracted from mines consists of waste. Waste management plays a major role in the planning of mining operations. The waste may be sterile or toxic and requires careful handling and storage. Waste is stored in closed systems such as engineered ponds built in valleys or along rivers using dams to confine the materials. However, these systems are not without risk, as dams can fail and toxic waste can be released into rivers. Especially in developing countries, waste is dumped directly into the ocean, which further exacerbates environmental problems. Such spills pose a serious threat to both humans and ecosystems, and have a serious impact on the environment.

Mineral processing - alternatively referred to as mineral dressing, mineral processing involves a series of procedures that involve crushing, grinding, washing and separating valuable minerals from extraneous materials. These minerals are then converted into commercially viable metallic forms through processes such as smelting or electrolytic reduction.

Reclamation is the final stage of the life cycle of the mine. After the cessation of economic efficiency, the process of land reclamation begins. Former mining areas have been successfully converted into agricultural land, forests and public amenities. Reclamation is important in the modern mining industry and is an integral part of mine planning. In the US, mining companies are not allowed unless they have a reclamation plan. Cultural impacts on society must also be considered.

Fig 3. Reclamation of surface mine.

2.3 Methods used in the mining industry

The mining industry involves two main methods: surface and underground mining. Surface mining has advantages over underground mining due to its wide distribution and application possibilities. Surface mining methods are carried out on the surface of the earth and the overburden above the ground is lifted to extract the ores. Underground mining methods involve digging and blasting tunnels and shafts into the earth's crust to access buried ore deposits. These sediments, together with waste, are transported to the surface of the earth for processing in processing plants.

Figure 4. Surface mining.

Artisanal mining – another important sector of mining includes artisanal miners or small-scale miners. These miners use traditional hand tools. Artisanal miners predominate in rural areas of developing countries, but they also make up more than 90% of the world's mining workforce. Many artisanal miners have little economic opportunity and turn to mining to support their families.

Figure 5. Underground mine.

2.4 Safety of the mining industry

Safety concerns are paramount in the mining industry due to large-scale operations, complex mining machinery, exposure to harmful substances and the risk of seismic events. Although mining accidents continue, important steps have been taken to improve safety standards over the years.

In the United States, the National Occupational Research Agenda (NORA) has selected the mining industry as a top priority for research efforts aimed at developing intervention strategies to improve miners' well-being and protect the environment.

In addition, the creation of the Mine Safety and Health Administration (MSHA) in 1978 underscores the commitment to strengthen miners' workplace health and safety. Miners are encouraged to report any unsafe conditions to MSHA for immediate action.[1]

Common hazards in the mining industry include:

• Exposure to toxic rock dust
• Exposure to harmful gases
• Exposure to excessive heat
• Hearing impairment due to loud equipment
• Rocks and caves

To reduce these risks, miners are provided with personal protective equipment:

• Air breathing systems
• Hearing protection equipment
• Safety goggles
• Gas detection solutions
• Protective headgear equipped with cover lights
• Fall protection device
• Reflective clothing
• Two-way communication tools
• Personal emergency breathing equipment
• Extra batteries

In addition, underground mines are equipped with shelter cells that can shelter miners for up to eight days in case of dangerous exposure. These rooms are equipped with supplies such as food and water to sustain the miners in case of emergency.

2.5 Automation in the mining industry

Ongoing digital industrialization and increasing automation in industrial environments are poised to transform the role of human resources. The four industrial revolutions reshaped the dynamics between people and industrial activity over time. It is very important to distinguish between partial or complete removal of human resources in industrial facilities. Removing people from industrial systems has a significant impact on the design and implementation of automation strategies. The integration of automated processes alongside human-driven processes within industrial systems is fundamentally changing workflow designs. As the trajectory of industrial activity evolves, its dependence on automated processes increases. Nevertheless, many workplaces will continue to depend on human participation and thus form social socio-technical systems [3].

2.6 Technical aspects of automation and its interface

In today's industrial environments, autonomous machines play an important role in reducing workload, increasing speed and increasing operational efficiency to achieve accurate, efficient v3434 reliable results with reduced variability. Intelligent, autonomous vehicles have significantly increased convenience, safety, reliability and operational efficiency. However, due to the existence of many unknown, unpredictable and uncertain situations in industrial and mining operations in the present era, human qualities such as judgment, logic and foresight are indispensable in any complex system. Given that human involvement is integral to the design, construction, installation, and operation of partially or fully automated systems, these automated systems may not completely replace human roles in the near future. Although the power of automated systems lies in their ability to reduce operator workload and increase operational efficiency, the transition to autonomous systems must be gradual and purposeful to provide users with design input, and only trained personnel must interact with them, monitor them, and most importantly, prevent tampering and manipulation. they should do. The tragic Lion Air crash in Indonesia on October 29, 2018 is a stark reminder of the consequences of entrusting autonomous systems without fully understanding their characteristics, capabilities, and most importantly, their limitations. Given the partially accepted role of humans in autonomous systems, the evolving role of humans as automation and its applications evolve remains a hotly debated topic. As reported in a Wall Street Journal article by the FAA in 2013, pilots have found it increasingly difficult to successfully perform intermittent landings compared to the past [3]. While automation holds promise in reducing significant workloads, mitigating high risks, and simplifying repetitive manual tasks, poorly conceived automation can produce unfavorable results. These consequences include automation bias, complacency, surprises, and obstacles. Due to the inherent performance limitations of humans, errors are inevitable, often resulting from inadequate automation system design and inadequate human operator input and training. Thus, understanding the differences and interplay between automation design and human input is critical to understanding adaptive interactions, allocation of functions, and degree of automation appropriate to a dynamically evolving environment to obtain optimal benefits [4]. The benefits most commonly attributed to automation include higher efficiency, higher production rates, improved use of materials and energy, superior product quality, enhanced safety, shortened work weeks, and reduced lead time. Automated systems perform designated operations with greater efficiency and reduced variation, resulting in product consistency and improved quality control. Also, automation can lead to reduced waste. Another potential advantage of automation is changing weekly working hours. In the early 1900s, the standard work week stretched to 70 hours. Currently, the average work week is around 40-45 hours. Automation has contributed significantly to this decline. Moreover, as a result of automation, the time required to complete a typical production product is reduced [5].

However, a significant potential drawback of automation is the prospect of employee layoffs. A report released in November 2018 stated that hundreds of workers were laid off as General Motors (GM) closed five assembly plants in North America. In 1983, it was documented that automation would create more jobs in the future, not fewer. This idea was originally articulated in 1983 by British researcher Lisanne Bainbridge, who observed the irony of automation contrasting with expected job losses. Although low-level and repetitive manual tasks will decrease over time, tasks requiring higher-level mental skills are expected to increase as the demand for programming, operating, and maintaining automated control systems increases. However, the development dynamics of changing or redistributing jobs remains uncertain for the coming years [6].

Employees may experience fatigue, distraction, or even overload due to increased activity or task-oriented input demands. In 2015, an Amtrak train derailed in Philadelphia, and the engineer reversed course, causing the train to travel more than twice the posted speed limit [10]. As a result of the derailment, 8 people died and more than 200 people were injured. To reduce such incidents from overloaded systems, it is important that humans consistently monitor automated processes and that the automated system monitor human activity. When a product or product quality defect is discovered, people must be able to intervene to correct the problem and ensure that the necessary adjustments are made to achieve the correct result. However, they need feedback from the control system to detect such abnormal conditions. Sometimes 20-30 or more human intervention is required per shift to maintain system operation and product quality and quantity. Conversely, an automated system should be able to detect when a human operator is tired, distracted, overwhelmed, or unable to perform their role. Subsequently, the control system must take over control of the task. An illustration of this scenario can be seen in the aforementioned Amtrak high-speed commuter train, which is equipped to recognize that the train has exceeded the speed limit for its current location. It sounds an alarm to signal a speed limit violation, and if the distracted operator does not react within a predetermined time frame, the automated control system regains control of the train and reduces the speed to the required speed limit [7].

Another major disadvantage of automation is the capital investment required to conceptualize, build, deploy, and run an automated system. In addition to capital costs, maintenance costs also increase because automated systems require a higher level of maintenance than manually operated machines. In addition, automated systems may exhibit a lower degree of adaptation in the range of products produced and the tasks performed compared to manual systems [8].

Industrial and mining jobs often require navigating difficult terrain, delicate maneuvering of heavy equipment, and making decisions in situations with limited information, among other challenges. These situations require people skills, cognitive flexibility, and innovative problem-solving abilities. Automation increases the complexity and sensitivity of the overall system, as seemingly small and insignificant events can have far-reaching repercussions for the entire organization. Moreover, all automated systems, regardless of scale, require maintenance. People must periodically inspect systems, replace, repair, or overhaul faulty machine components as necessary [11]. Regular maintenance of the automated system software is also important to ensure that the programming codes remain current and that the quality and quantity of the output is maintained. Maintenance of control systems' communication infrastructure, operational communication protocols, and decision-making human communication behavior is necessary to maintain reliable operation [9].

2.7 Special applications of automation in mining and mineral processing

Despite rapid population growth and increasing demand thanks to successive industrial revolutions, the proportion of the labor force in sectors such as agriculture, textiles and mining has been steadily declining. Mining as a percentage of total employment in the US declined from 4.1% to 0.5% between 1910 and 2015. Each revolution has had its impact on the reduction of labor required, and the latest industrial revolution, Industry 4.0, has reinvigorated automation and robotics in the mining industry. The history of automation in mining operations and facilities dates back to the 1960s. [12]. At the mineral processing plant of the Kloof and East Driefontein gold mines, tasks were simplified and machines were controlled remotely [13]. In 1973, automatic control of free acid during leaching at a uranium refinery was another notable example from South Africa. Automation provided opportunities to maintain continuous production in the 1970s and 1980s, but a decade later, the approach incorporated goals aimed at improving performance and efficiency through the use of advanced process control. The United States Department of Energy has made significant investments in the research and development of automation in mining systems to prevent mining productivity declines. Expert control systems, fuzzy logic, and artificial neural networks were among the tools used in column flotation in the 1990s. A roadmap for automating ore characterization and mineralogy laboratories was outlined in a recent study that predicted an estimated 92% annual internal rate of return on investment in modern mineralogy. The integration of automation into mineral processing plants is advancing rapidly along with advances in other phases of mining. Automation initiatives in the mining industry have long been an industry focus. However, the lack of a comprehensive approach to the development of industry standards in automation, change management, and fragmented efforts among different groups have hindered the industrial success of automation. Nor is there a comprehensive assessment of automation in mining to reassess the state of the industry [14].

Advanced Process Control (APC) represents a category of automation technologies that go beyond basic level control. Although the main control technologies are usually implemented in a distributed control system (Distributed Control System - DCS), APC applications are usually located on separate servers and work in direct connection with the DCS. While most DCS systems are highly customizable and provide the user with ample opportunity to develop complex, customized control logic, DCS is generally reserved for fundamental regulatory control. It is preferable for the DCS system to be relatively isolated from external networks, so communication between the DCS and other servers should be sufficiently limited and provided with a robust firewall to ensure that the essential functionality required to ensure plant operations and safety remains uncompromised. Although achieving this secure and robust operation involves complex coding and some advanced management software, these do not always qualify as APC. APC typically functions as a control system aimed at increasing process performance without being essential to critical tasks. In the event that an APC application encounters a compromise or critical failure, the DCS must have its own protocols to terminate communication with the APC server or identify erroneous information. It should then be able to operate independently, ensuring continued plant operations and safety, although temporarily deprived of the benefits of improved operation that APC would otherwise offer [15].

The most common APC approach is model predictive control (MPC). MPC is an advanced control technology that uses a dynamic model of a process to predict future, transient process behavior based on known process inputs. When these inputs affect the process but cannot be changed by the control application, they are called disturbance variables (DV). Often, these variables can be detected or estimated by sensors, in which case they can be integrated into the model to improve predictive accuracy. These detected disturbance variables can also be labeled as feedforward variables (FFV) [16]. This form of information typically improves the accuracy of the model and allows the plant to react when measured external factors directly affect plant performance. Variables that can be changed or manipulated are called Manipulated Variables (MV). MPC uses MVs as degrees of freedom in the optimization problem. Using a process model, MVs can be tuned using rigorous mathematical algorithms, such as linear or nonlinear programming, until an optimal solution is achieved [17].

MPC offers numerous advantages over traditional control methods. In addition to using a model to predict and optimize future plant performance, MPC is highly adaptable to multivariable control. Unlike many fundamental control schemes in DCS, MPC considers the interaction of multiple variables simultaneously and avoids negative interactions of individual process variables. MPC is capable of handling both continuous and discrete variables, allowing for efficient modeling and integration of binary decisions about equipment such as switches, on/off pumps, and on/off valves into the optimization process. Incorporating both continuous and discrete variables into MPC is called hybrid MPC [18].

Grinding/Milling is perhaps the most common area for MPC application in mineral processing. Advanced monitoring has obvious advantages if implemented effectively [19] demonstrated the potential of MPC to increase throughput by up to 10% and reduce variability by up to 66%. The performance of MPC is compared with other APC techniques such as non-MPC multivariable control, expert system-based control, and fuzzy logic control. In general, each control approach is effective in its own way, and advanced control enhances processing operations based on the analyzed metrics. Expert control systems tend to institutionalize suboptimal operating practices. They respond inadequately to unmeasured disturbances and are difficult to calibrate. MPC, on the other hand, is simpler to calibrate, better at handling disturbances, and less sensitive to modeling inaccuracies. MPC formulations are also applied to semi-autogenous grinding (SAG) mills [20].

In addition to reduced variability, optimization in MPC and grinding schemes can produce many other benefits. This approach has been shown in research studies to result in a 66% reduction in power and a 40% reduction in load deflection for a fully autogenous mill. This control strategy provides optimization and MPC application with greater adaptability to ensure optimal operating conditions based on the fact that the mill operates on a variable speed drive. As an added benefit of this study, it was also found that application resulted in a 0.32% increase in recovery due to improved mineral release. MPC has been applied in many cases for semi autogenous mills [21].

An MPC application was developed using fresh ore feed, fresh water feed and mill rotation speed as MV while trying to control energy consumption, volumetric filling level and size reduction percentage. Their application resulted in perfect control of the mill's power draw, even with changing targets, ensuring constant mill fill and size reduction. A program like this can be a great tool to help reduce demand costs on a facility's electric bill.

An MPC application was designed using fresh ore input, fresh water input and mill rotation speed as manipulated variables (MVs) to adjust energy consumption, volumetric filling level and percentage of particle size reduction. Their implementation provided effective regulation of mill energy consumption even when faced with changing targets, while consistently reducing mill fill levels and particle size. An application like this can serve as a valuable tool to help a facility reduce peak demand costs on its electricity bill [22].

2.8 Mining Operations. Autonomous Equipment

The usage of the term automation in mining has changed over time. A few decades ago, only remotely controlled machines were classified as automated. Currently, automated equipment can be remotely controlled, semi-automated or fully automated. The field of self-driving mining machines has been extensively researched, but very few companies are putting these technologies into practice. Automation is well suited for repetitive activities. These tasks occur many times throughout the day; therefore, they are identified as focal points of mechanization. In the early 1990s, special attention was paid to the automation of drilling. The concepts and methodologies of this research have been commercialized and widely used in industry. The next area for targeted automation research was underground mining. Specifically, load-haul-dump (LHD) equipment is used in underground work [23].

Common positioning mechanisms such as GPS do not work underground because signals cannot penetrate the ground. This fundamental limitation has been an important catalyst for exploration in this area. As a result, considerable effort has been devoted to the navigation and guidance of mining machines. In the late 1990s, a test initiative was initiated at the Mount Isa Lead Mine to evaluate the performance of sensors for guidance reliability for mining machinery. A study of this period shows that the 30 t LHD used 2D laser scanners with no localization infrastructure, using reactive navigation for the autonomous navigation system. In 2008, a combination of a navigation system and a laser scanner was used for experimental research. In addition, autonomous positioning and navigation systems for underground tunnels have been implemented using laser scanners, bar code theory and markers to guide the LHD and Scraper.

Surface loading operations have made minimal progress in automation. The help of global navigation satellite system (GNSS) was used in 2001 to map and control the bucket wheel excavator. Another example involved wheel loader automation and, more recently, route optimization for a wheel loader. In addition, research has been conducted on the automation of large trucks. In one case, more than 250,000 tons of material were transported autonomously. Historically, advances in technology as well as automation efforts in mining have been supported by equipment manufacturers and suppliers. In recent years, the focus has been on trucks in surface mining automation. The scarcity and high costs of operators in remote locations and the aging workforce in Western Australia have played a significant role in driving these developments. Major equipment manufacturers have partnered with iron ore producers to develop and test the technology. Numerous applications have proven successful, and these companies have reported significant increases in truck efficiency at various mining sites, resulting in operating costs of $0.50 to $0.62 per ton. Fortescue Metals Group (FMG) partnered with Caterpillar in 2012 for a fully autonomous mine at its Solomon Iron ore mine in Western Australia. FMG has transported more than 400 million tons of material with its autonomous trucks and recently purchased 60 autonomous trucks for this mine. Another comprehensive automation initiative is the Mine of the Future program launched by Rio Tinto in 2008. This program includes an operations center where mines, ports and rail systems can be controlled from one place, an autonomous transport system, and since 2008 an automatic drilling system (ADS) that allows the operator to control remotely from a single console, and control multiple drilling machines for automated train transport. make; There are a number of commercially available products for automating mining equipment, including bulldozers, loaders, excavators, graders, light vehicles and water trucks. In a recent industry example, automation played an important role in the cleanup after the Manefay landslide at the Bingham Canyon mine. Remote control is integrated into 32 pieces of equipment from different manufacturers, including bulldozers, excavators, shovels, transporters and loaders. Two exercises have been upgraded to full autonomy. These machines were used to improve unstable and dangerous slopes reaching 180 m in height after the largest mining landslide in history [24].

Underground automation efforts began decades before surface operational attempts at automation. The evolution of automation solutions has focused on technology and infrastructure development. Currently, the development of teleoperated, semi-automated and fully automated mining equipment is significantly advanced and more feasible than ever. This is due to the fact that in some countries the costs of automated solutions can be lower than traditional approaches. However, widespread adoption of fully autonomous solutions capable of providing comprehensive ore production capabilities is still not widespread in the industry. Other autonomous initiatives may have different or individual rationales. In some mines, the main objective was to replace operators, while in others the focus was on using teleoperation to reduce safety problems in hazardous areas. As a result, most operations automate fleets of dedicated equipment or individual machines for use in designated or isolated regions. Despite the availability of technology, such projects lack a comprehensive approach, where process changes and operating system re-engineering are not carried out [25].

2.9 Communication

Device-to-device communication is the cornerstone for automation and remote control. Automation has increased the amount and variety of data required to be captured from machines at increasing frequencies compared to traditional equipment positioning and tracking. Accuracy and positioning of mechanisms and reduced latency are critical for devices controlled by human operators or algorithms from a central control center. The current communication infrastructure has undergone significant advances in recent decades. However, given the multitude of connected devices, their locations, and other data points frequently collected across large mining operations, throughput and quality of service have become more important than ever for communications. In 2019, autonomous vehicles were involved in two incidents at large iron ore mines in Western Australia. Companies cited Wi-Fi outages and heavy rainfall as the main reasons for the crashes. Thankfully, there were no casualties as a result of these events. Nevertheless, the technology and system will be subject to scrutiny. As reported, preliminary inquiries have pointed to the failure of the communication infrastructure as the main cause of the incidents. Technology providers will have to overcome this hurdle by using upcoming technologies.

The next generation wireless system is expected to be 5th generation or 5G. This new technology is predicted to advance factory automation and the Internet of Things (IoT). In fact, Swedish miner Boliden has partnered with Ericsson on a research project to evaluate 5G at its Aitik mine, one of Europe's largest open-pit mines. The new technology has been used for mobile communication of drilling and blasting equipment with remarkable cost savings. The mining company intends to expand this capacity to carry trucks, excavators and planning systems in the coming years. The next few years will demonstrate the capabilities of 5th generation wireless systems and their integration into the mining industry. The triumph of this new technology will also have a significant impact on fleet management systems that control and guide a significant number of autonomous mining equipment, which often require acquisition of positional data. Advances in improved device-to-device communication and battery technology will enable more inventive ways to deploy automation in mining processes. The use of UAVs with various forms of remote sensing will enhance exploration and even rehabilitation of mining processes [26]. Mineral exploration and remote sensing Semi-automated reconnaissance and remotely piloted robots were originally developed by NASA for the Apollo program. As the technological capabilities of NASA and other space programs have advanced, remote sensing, mineral exploration, and robotic management of categories have evolved to meet new demands, enabling exploration of the Moon, Mars, and nearby celestial bodies. Like numerous other NASA and space research and development efforts, the use of these technologies on Earth will profoundly affect the future landscape of remote sensing for mineral exploration. The application of remote sensing for underground mining facilities has made significant progress over time. These improvements have also enhanced traditional surface remote sensing. An important area of focus in difficult conditions is the exploration of mineral deposits on the ocean floor. These programs have revolutionized the mineral sector, simplifying the ability to find and potentially exploit resources from the seabed. The mining industry's adoption of technology for both terrestrial and off-world mining will continue in parallel with NASA's research and development efforts and other space exploration programs. This technological advancement will expand the boundaries of the systems and human operators involved in the industrial process.

2.10 Planning of the automation system in the mining industry

The advent of automated manufacturing and robot-driven manufacturing has changed the way manufacturing is viewed. However, this has not made the human operator obsolete. The practical realities of production and mining often lead to situations that lack structure, predictability or clear definition. In industries such as aircraft, shipbuilding, or custom luxury car manufacturing, each vehicle is typically customized to unique specifications that require significant engineering involvement from human workers. Similarly, the mining environment can be variable. Automated control system algorithms cannot anticipate every event or demand faced by equipment or personnel. It is important to remember the frequency of unexpected problems - for example, a delay in the delivery of an engine part due to a shortage of raw materials or inadequately sized cable wires. Resolving unexpected events often requires human intervention, as unstructured and undefined processes such as management issues become difficult to automate [27]. Thus, direct human involvement in production and mining processes remains necessary, given the demands for skills such as flexibility, precision installation, and assembly orientation, which are inherently better suited to human capabilities. In addition, prohibitive costs act as a barrier to achieving fully automated production. These factors indicate that there are areas where human operators are important. Adaptive automation can adjust operator workload, improve performance, and maintain the benefits of automation. Defining roles and responsibilities for dynamically distributed control between human and automation is critical before the design phase. The concept of adaptive automation is exemplified in vehicles. In the early years of the twenty-first century, vehicles such as modern airplanes have reached a level of sophistication that can operate autonomously for extended periods of time. Human pilots are only involved during takeoff and landing, while automation controls the aircraft for the rest of the flight. Experimental vehicles using machine vision can drive fully autonomously on public highways, deserts or urban environments within specific parameters. Thus, if a system has the flexibility to dynamically adjust automation levels, it can improve overall system security and performance. Determining when and where automation is important is critical. If a particular task or process can be performed efficiently by humans, investing in and implementing an automated system can be a waste of both time and resources. For example, in custom unit production scenarios, each product is customized to order, different from the others. In such environments, an automated system may offer limited assistance if it requires extensive setup for each batch of product or lacks flexibility. A thorough cost-benefit analysis is essential, including aspects such as cycle time and inventory costs. The scale of the project is also a key consideration when installing an automated system.[28]. Therefore, although the main purpose of automated systems is to simplify and improve operations while reducing risk, it is not intended to replace human labor. In practice, automation aims to improve and optimize the work environment for people, and only with their cooperation, input and control can the true benefits of automation be realized.

2.11 Mine planning with automation

The mining sector faces challenges from deeper excavations, declining ore quality and fluctuating commodity prices. Some mining executives see automation as a potential solution to reduce these pressures. In addition, the reduction in ore content makes surface mining more economically viable than underground mining. Nevertheless, in order to extract an equivalent amount of ore from low-grade surface mines, a larger volume of material must be mined and processed than in underground operations. To meet increasing production demands and combat low prices, the mining industry has used increasingly large-scale equipment over the years to reduce operating costs. Automation in the mining industry has demonstrated that autonomous solutions can match or even exceed the productivity of human operators. Recent applications have shown productivity increases of more than 30% in surface operations associated with improved equipment utilization due to reduced downtime for shift changes, meal breaks and other interruptions. In addition, driverless cars experience fewer breakdowns, which leads to lower maintenance costs and increased uptime. Given the availability and use of underground mining equipment, productivity growth in underground mining can easily double that observed in surface mining. Reorganization of the underground production sequence can be fundamentally changed by removing human operators from the operation of the equipment. This change in traditional workflows allows machines to access unsupported areas and skip certain steps, thereby increasing their utilization [28]. In addition to the increased productivity achieved through longer operating times, the elimination of human involvement in production opens up other possibilities in the new pit design, such as narrower fairways and steeper slopes. Changing existing road width standards and narrowing haul routes can result in significant ore savings in a redesigned pit. Similarly, adjusting the slope angle of the pit can significantly reduce the total volume of waste material to be excavated. These factors require re-evaluation of current pothole boundaries and roadway specifications. However, most automation initiatives have focused primarily on technical elements without taking a comprehensive approach. A comprehensive approach involves examining all other processes in the mining value chain, from exploration and planning to extraction and ore processing, for potential re-engineering or integration with autonomous solutions. In the mining industry, a fully autonomous solution can offer cost savings for mining companies. Lower operating costs resulting from reduced labor and maintenance are a viable solution for mining lower ore grades. However, despite advances in recent decades, there are currently no fully automated mining operations. Surface mines in Western Australia and deep underground mines in Canada have some of the most sophisticated automated operations. However, most automated solutions are operated with humans. Partial automation of mining operations presents some risks as well as cost reduction opportunities. Another risk of automation in the mining industry is its impact on employment. While potential positions could be created in maintenance and supervision, some jobs involving cyclical tasks would be eliminated. Therefore, it is crucial for mines to redesign the entire process, including workflows, roles, responsibilities and hierarchies.

2.12 Key human factors for automation in the mining industry

Automation is highly regarded as a solution to increase overall system performance, reduce operator involvement and workload levels, and make systems more reliable and less susceptible to human error. However, while the implementation of automation may be attractive in many contexts, there are hurdles to overcome before this goal can be successfully achieved. Unfortunately, the technology-centric perspective still dominates. However, by ignoring the complexities of socio-technical systems, it faces challenges and surprises that a human-centered approach anticipates or eliminates, or at least mitigates. Assistance and automation were considered different terms. Automation has changed the nature of work and human cognition. The main paradox is that automation is designed to improve safety and efficiency, but the advancement of automation presents us with pragmatic challenges that can significantly affect job satisfaction, efficiency, safety and security. When evaluating the impact of automation on system performance, one thing to consider is how the automation affects the person interacting with it. In order to use any automated system, the operator must have expectations of the automation. These expectations of automation are encapsulated in the mental model of automation. A mental model is an internal representation of the system's operation and automation in general. It is the result of existing knowledge about the system acquired through training or experience. Clearly, automation that does not match the operator's mental model (the sequence of steps required) as the task changes creates problems and requires the operator to adapt to the automation. When automation changes the work process or tasks, it requires adjusting the mental model of the operator as well as the socio-technical system in which the tasks are performed. One approach to avoid unnecessary mental model adoption and related problems is to simplify the automation by adapting it to the operator's mental model, not the other way around.Such approaches implement automation that matches the operator's preferences and expectations, making it easier to identify potential problems with automation. In addition, such an approach makes it easier for the operator to take control of the system if such a need arises due to automation disruption. Another approach that emphasizes the relevance of operators' expectations is that automation performs similar functions to human actors.

2.13 Problems in automation

Automation — task errors are a new class of errors introduced by automation. An example of this type of error is automated systems that eliminate some potential for operator error by automating certain aspects of a task. An example of this situation is when an operator was previously required to perform a manual control task, automation replaces that aspect of the task because the operator risks not understanding how to operate the system due to the lack of automation. As a result of the introduction of automation, new training and knowledge requirements arise, as the operator must better understand the capabilities of the system, which requires additional training. Fragile automation is the result of automation that completely fails due to simple type problems. An example is automation's dependence on correctly entered or formatted data. If the user makes data entry errors, it results in the automated system not working properly. Brittle failures cause sudden and dramatic reductions in automation. An alternative approach is to gracefully crash the system, meaning that the system continues to function after the initial problem [29]. Configuration errors are another class of automation-related problems. Because automated systems require many complex steps during the initial configuration process, it is likely that errors in the initial phase of configuration can have significant consequences later in the use of automation. In addition, because differences in configurations can be difficult to track and their impact may be remote from the location of the failure, it is often difficult to identify the contributors to an automation failure.

3. CONCLUSION

In conclusion, the concept of an automated management system for mining ore production is a significant step towards revolutionary changes in the industry. By harnessing the power of advanced technologies such as artificial intelligence, the Internet of Things, and robotics, mining operations can achieve unprecedented levels of efficiency, safety, and sustainability. As we've explored throughout this article, the benefits of automation in mining are multifaceted. From real-time monitoring and predictive analytics to improved security protocols and reduced environmental impact, the benefits are clear. Nevertheless, the implementation of such systems is not without problems. Issues such as initial investment costs, workforce training, and integration complexity must be addressed for successful adoption. Despite these challenges, the potential rewards of automated systems are enormous. The ability to optimize production, improve safety standards and minimize environmental impact makes the pursuit of automated control systems in mining a worthwhile endeavor. Data management (analytics, business intelligence, data mining, etc.) will be critical to the successful implementation and operation of automated systems. Data should be managed to provide feedback to decision makers, as well as provide structured data to feed supervised or unsupervised learning algorithms. These algorithms will provide critical operating parameters to the automated machines. It is important to integrate and consider these optimization algorithms with short-term planning and key mining sequence factors. Short-term planning will become a critical component to managing successful autonomous mining operations. The political and social risk associated with widespread automation is real and must be measured. Companies developing operations, particularly in developing countries, will need to consider approaches to developing shared value and social license to operate in an environment of declining employment opportunities in their mining systems. These changes can have a significant impact on the current tax and distribution policies of governing bodies and are fundamental to understanding the role of automation in the sustainable development of mineral resources. These research findings apply not only to mining, but also to other industries that have the potential to be significantly disrupted by automation. The future of work will see higher levels of automation and workforce disruption. Automation will have significant social, political, economic and technological impacts. Government agencies and industry leaders need to build greater consensus around approaches to maintaining the stability of governance and industry institutions.

REFERENCES

1. Mining and sustainable development https://onlinelibrary.wiley.com/doi/full/10.1002/fes3.109
2. What is the mining industry and why is it important? https://www.flyability.com/blog/mining-industry
3. Jämsä-Jounela S-LJCEP, Current status and future trends in mineral and metal processing automation. Control Eng Pract 9(9):1021–1035, 2001.
4. Haight JM, Cole DG, Sejdic E. Optimized design and use of automated control systems. Proceedings of the 9th International Current Meeting on Nuclear Plant Instrumentation, Control and Human Machine Interface Technologies. American Nuclear Society? 2015.
5. D.B. Kaber, Wright MC, Prinzel LJ III, Clamann MP, Adaptive automation of human-machine information processing functions. Hum Factors 47(4):730–741, 2005.
6. L.Carver, M.Turoff, Human-computer interaction: the human and computer as a team in emergency management information systems. Commun ACM 50(3):33–38, 2007.
7. T.Inagaki, H.Furukawa, Computer simulation for the design of powers in adaptive cruise control systems under the possibility of driver overreliance on automation. Systems, Man and Cybernetics, 2004 IEEE International Conference on. IEEE, pp. 3932–3937, 2004.
8. Advantages and disadvantages of automation. https://www.britannica.com/technology/automation/Advantages-and-disadvantages-of-automation
9. D.Hounshell, From the American system to mass production. Development of Manufacturing Technology in the United States, Vol.4. JHU Press, pp. 1800–1932, 1985.
10. E.G.Fitzsimmons, J.Keller, Why an Amtrak train derailed in Philadelphia. New York Times, 17 May 2016.
11. F.Flemiš, J.Kelsch, C.Löper, A.Schieben, J.Schindler, Automation spectrum, internal/external fit, and other potentially useful human factors concepts for assistance and automation. Human factors for assistance and automation, pp.1-16, 2008.
12. Employment by industry, 1910 and 2015. (2016). https://www.bls.gov/opub/ted/2016/employment-by-industry-1910and-2015.htm. Accessed April 14 2019
13. H.E.Cross, Metallurgical considerations in the automation of gold mines. J South Afr Inst Min Metall 9:300–306, 1973.
14. G.Sommer, GTW Ormrod, R.P.Chaix, Recent developments in equipment and automation of uranium processing plants. J South Afr Inst Min Metall 73(12):413–420, 1973.
15. D.G.Almond, K.Becerra, D.Campain, Minerals plant of the future – using automation and an intelligent collaborative environment. J South Afr Inst Min Metall 113:273–283, 2013.
16. H.Chugh, H.E.Parkinson, Automation trends in continuous room and column mining systems in the United States. J South Afr Inst Min Metall 81(3):57-65, 2018.
17. L.Bergh, J.Yianatos, Flotation column automation: state of the art. Control Eng Pract 11(1):67–72, 2003.
18. W.Baum, Ore characterization, process mineralogy, and laboratory automation: a roadmap for future mining. Miner Eng 60:69–73, 2014
19. S.G.Bouffard, Advantages of process control systems in mineral processing grinding schemes. Miner Eng 79:139–142, 2015.
20. P.Karelovic, R.Razzetto, A.Cipriano, Evaluation of MPC strategies for mineral grinding. IFAC Proc Vol 46(16):230–235, 2013. https://doi.org/10.3182/20130825-4-US-2038.00066
21. A.Remes, J.Karesvuori, H.Pekkarinen, S.L. Jämsä-Jounela, An integrated approach to the monitoring and control of mineral grinding processes. IFAC Proc Vol 39(14):124–129, 2006. https://doi.org/10.3182/20060830-2-SF-4903.00022
22. YAW Shardt, K.Brooks, Automated system identification in mineral processing industries: a case study using a zinc flotation cell. IFAC-PapersOnLine 51(18):132–137, 2018. https://doi.org/10.1016/j.ifacol.2018.09.288
23. M.Scoble, J.Peck, C.Hendricks, A study of surface mine equipment monitoring. Int J Surf Min Reclam Environ 5(3):111– 116, 1991.
24. S.Scheding, G.Dissanayake, E.M.Nebot, H.Durrant-Whyte, An experiment in autonomous

navigation of an underground mining vehicle. IEEE Trans Robot Autom 15(1):85–95, 1999.
25. The future of the mining industry. (2018). https://www.riotinto.com/australia/pilbara/mine-of-the-future-9603.aspx
26. Case Study on Automation in Mining, Ericsson, 2018.
27. A.Bothma, Effects of adapting automated handling systems to a typical open pit mine, 2017. https://www.mining.com/
28. J.Parreira, Z.Mullard, J.Meech, M.G.Vásquez, How automation and key performance indicators (KPIs) contribute to sustainable development in the mining industry. Edumine, 2009.
29. H.Jenkins, Yakovleva NJJocp, Corporate social responsibility in the mining industry: Exploring trends in social and environmental disclosure. 14 (3–4):271–284, 2006.