Mining Process Systems in the Industry 4.0 Mandate Towards the Plant of Future

Mohammed Yaqot and Brenno C. Menezes
Division of Engineering Management & Decision Sciences, College of Science and Engineering
Hamad Bin Khalifa University, Doha, Qatar Foundation, Qatar
myaqot@hbku.edu.qa, bmenezes@hbku.edu.qa

Abstract

The interplaying of advanced technologies of the Industry 4.0 (I4) mandate towards the mines of the future creates a smart connected mining industry that transforms vast amounts of data into predictive and fully integrated intelligent systems. Thus, additional safety, stability, and predictability can be achieved to maximize efficiency while minimizing operating and capital costs. In addition, the road to overcoming mining challenges is fundamentally human-centered and has inclusive socio-economic development or what is known as sustainable development (SD) at its core. Throughout the production value chain, the mining sector faces various economic, geopolitical, social, and technological hurdles. Innovative manufacturing methods are required to introduce the next digital generation into the raw material area all the way to the tailings area. In the realm of increasing process automation, I4 applications are currently trending in the mining industry. This paper explores and debates process systems and automation outlook focusing on future automation systems in the context of minerals engineering, where mines can be categorized into human-governed, semi-self-governed, self-governed, and virtual mines. The paper discusses mining field challenges and opportunities and concludes with a discussion and future research paths in process system engineering prompted by I4 innovative system architecture.

Keywords
Automation, Industry 4.0, Process, Mines of the future, Human-centered, Sustainable development

1. Introduction
The increased demand for metals (particularly copper), harsh landscapes of mines, and environmental volatility coupled with an unstable workforce and a lack of insight into the benefits of a digitized plant are barring the mining industry from what lies beyond the fourth Industrial Revolution (I4). Overcoming these challenges is vital in future-proofing mining plants and propping up existing legacy systems. The productivity in the mining sector has been questioned by industry giants looking for solutions to achieve not only upward scalability but also efficiency and insights to look for future sustainability relevance or known as sustainable development (Rodrigues and Mendes 2018). Adopting artificial intelligence (AI) technology is a key to unlocking game-changing advantages in the mining industry. Creating a safer environment for the mining workforce is also another key to unlocking the next level of efficiency and productivity. Compared to legacy systems, predictive maintenance facilitated by the internet of things (IoT) provides a comprehensive overview of mining plants and machinery working conditions even in the most rugged landscapes. Human operators are at the heart of implementing an interoperable digital solutions, protecting each worker from potential incidents through real-time monitoring and comprehensive reporting of every single corner of the mining ecosystem (Horberry et al. 2018). Investment in technology and innovation sounds expensive and is considered a barrier but smart mining solutions will eventually overlay any legacy system. The promising synchronization of digital transformation shall deploy agile solutions that monitor energy and CO_2 emissions, workers' safety, possible anomalies, and mining wastage in real-time. In other words, employing productive analysis that drives evidence-based strategy and implementation is feasible and mining plants as such would have the potential to become an industry example and a pivotal driver of economic growth and stability (Mateus et al. 2019).

Automation and mechatronics or robotics are common parlance terms describing methods of separating people from technological machines. Robotics refers to the design, development, and deployment of autonomous vehicles, whereas automation refers to the operating condition of existing apparatus and unsupervised processes without human intervention. The real application of automation techniques focuses on the processing stages, which have been employed for years by automation systems. Automation or self-governance technological solutions are actively exploited in the haulage processes. For example, autonomous trucks are primarily used in surface mines, where consistent and long-lasting haul roads and simple deployment of information and communication technologies (ICT) infrastructures, i.e., GPS or LTE allow for effective implementation of automation. However, ore and waste loading on autonomous equipment are not yet fully automated (Jämsä-Jounela and Sirkka-Liisa 2019). The lack of automated loading techniques is most likely owing to the fact that rock characteristics, material placements, and mine's setup layout at specific mine sites change often, necessitating real-time data and analysis.

The most frequently cited technology having an influence on the mining business industries is automation (Barnewold 2020). As a fundamental element of the digital network control system (robotics, AI, machine learning (ML), 3D printing, etc.), automation is linked or influenced by a range of other cutting-edge technologies, making it a central pillar in the contemporary digital transformation discourse in the mining industry. As a result, it is the most important technology in the mining sector, and it is frequently seen as the digital transformation's ultimate vision. One of the most key technical catalysts for digital transformation in the mining sector has been autonomous vehicles in which heavy types of machinery are heavily used, and it must be characterized by reliability and function-ability. Sensors and IoT applications facilitate to make human operator an expert by giving maintenance data and analytical insights through cloud-computing platform's edge, allowing for greater consistency on operations. Additionally, actuators and AI will dramatically boost safe and healthy working conditions by alerting workers to dangerous places, for example. As the technology becomes more widely available, mining firms will be able to explore setting up mine operating centers to remotely monitor their mines, autonomous vehicles, and performance. Industrial internet of things (IIoT) platforms will provide excellent opportunities to construct these centers employing cutting-edge technologies.

The Internet of Things is a concept in which physical items are intimately connected and capable of communicating their status over the internet and being managed remotely from any location. In mining, IoT is utilized mainly to process inspection and monitoring status, which aids in the coordination of autonomous apparatus. There are also measures in place to trace human operators in case of an emergency or risk situation. IoT monitoring devices are also used in underground mines to monitor mineral production stability, machinery movements, and personnel positioning. IoT, in particular, facilitates inexpensive sensors to communicate with a central server and work as a cross-platform system to capture, share, and exchange data. The IoT and IIoT are both based on the same basic concepts, with the IIoT being specifically tailored for industrial applications (Molaei et al. 2020).

Big data analytics (BDA) is a terminology that refers to large amounts of data that are inaccessible to human capabilities or traditional data processing approaches. Real-time data refers to the pace, timeliness, and responsiveness with which the data is captured, shared, and exchanged with users instantly. Employing BDA in real-time in the mining sector can be highly beneficial to predictive maintenance of conveyors belts and dump trucks. For example, relying on real-time BDA infrastructure allows for improved optimization and forecasting of mining processes, mechanical conditions, machinery, and personnel performance tracking. Two more conceivable applications are mass and quality flow modeling and optimization of block caving activities to assess and monitor the real mining void (Qi and Chong-chong 2020). By utilizing BDA from aerial and ground vehicles and equipment tracking, it is possible to pinpoint the exact location of any vehicle or equipment inside the mine. As a secondary application, automatic resource hours are calculated, vehicles' speed is monitored in real-time, and equipment can be searched from any online platform such as web or mobile app. The highly accurate signalization module plays a key role in improving traffic efficiency and load management inside mines. The end result illustrates secured traffic with a hundred percent collision avoidance, reduced radio communication as vehicles can follow the signals rather than waiting for traffic clearance over the radio. IoT sensors systems also monitor and analyze environmental parameters in real-time such as temperature, humidity, pressure, presence of certain gases, water, electricity, etc. (McNinch 2019).

2. Process Automation System Architecture

For years, the automation industry has focused on a five-layer hierarchical architecture; a prominent architectural model is the five-level Purdue Reference Model, which eventually became the foundation for the ISA-95 standard (Seyedamir et al. 2018). The model is commonly represented as a series of hierarchical levels, from top to bottom; enterprise-level, e.g., enterprise resource planning (ERP), manufacturing and operation level, e.g., manufacturing execution systems (MES), monitoring and supervision level, e.g., supervisory control and data acquisition (SCADA), control level, e.g., programmable logic controller (PLC), and production processes or field level, e.g., sensors and signals. In which different levels are concerned with different managing time frames ranging from months to microseconds. Many industries including mining have reached an end at structuring automation level with respect to the traditional automation pyramid.

The IIoT is the extension and use of the internet of things in industrial sectors and applications with a stronger focus on machine-to-machine communication processes capitalizing on smart equipment and internet-based cloud computing technology. System integration connects sensors and actuators with controllers and robots through computational capabilities facilitated by data analytics and machine learning. To handle dynamic engineering processes, current factory automation systems must be connected to ERP and MES through an IoT infrastructure. The main challenge derives from the industry's wide range of proprietary (customized) control systems. There are different attempts to standardize integration, but there is no record of standardization use yet (Molaei 2020). The RAMI 4.0 (Reference Architectural Model for Industry 4.0) is a three-dimensional industry 4.0 model. The "*layers*" axis represents the breakdown of production objects into their constituent parts in six layers: business, functional, information, communication, integration, and asset. It plays a key role in representing the combination of the real production object and its virtual image (Bastos et al. 2021). The traditional automation pyramid has been supplemented by the levels of product, field device, control device, station, work centers, enterprise, and connected world. The "*Life Cycle & Value Stream*" axis, which is based on IEC 62890 standards and depicts the product life cycle from conception to depletion. The "*Hierarchy Levels*" axis illustrates the various capabilities inside factories and employs IEC 62264/IEC 61512 standard hierarchies.

The Industrial Internet Consortium (IIC), the United States' version of Industry 4.0, has published a standard architecture known as the Industrial Internet Reference Architecture (IIRA). IIRA is an open architecture for the industrial internet of things systems that are based on industry standards. It offers a framework for designing industrial internet networks without restrictions or providing explicit suggestions for any standards or technology that form these networks. The diverse technological and operational perspectives provided as viewpoints to identify and address architectural challenges are central to IIRA. The IIC's Industrial Internet Connectivity Framework (IICF) expands on the IIRA by mapping industrial internet of things connectivity. It establishes an open connectivity reference architecture that explains IIoT connectivity with a new stack model and assists practitioners in categorizing, evaluating, and determining the applicability of connectivity technologies for the IIoT system at hand. The purpose of such IIRA and RAMI4.0 models' development is the convergence of information and operational technologies (Pivoto et al. 2021).

3. Mining Challenges and Opportunities

The changing global context of mining and the increasing complexity can be categorized into economic, technical, geopolitical, and socio-ecological dimensions. More explanation is provided as follows.

A. Economic influences and market factors

The demand for metals is driven by a combination of factors, including population increases, economic growth, and technological factors. The economics of supply and demand for metals are complex and dynamic. Notwithstanding the continually increasing global demand for most metals, markets have tended to be cyclical as new production is added and mining companies compete to be low-cost producers. The first decade of the 21st century witnessed a significant expansion in mining activity in many countries, primarily driven by demand for commodities linked to rapid economic growth in China and other developing countries. While the sustained super-cycle that some in the industry predicted did not eventuate and prices fell back to lower levels, it is worth noting that overall production levels have continued to increase. Additionally, the expanded production capacity for many commodities developed due to these predictions.

Most countries in the world have a mining industry in some form. The most common metal elements in the Earth's crust are aluminium (8.2%) and iron (5.6%) (Venditti and LePan 2022). Therefore, it is quite common for these metals to find ore deposits of sufficient concentration to be mined economically. Other metals that make up a much lower percentage of the Earth's crust need a correspondingly higher concentration factor to be mined. The distribution of mined production can therefore vary quite widely. For example, although it has a very low crustal abundance at 0.0000004%, gold is mined in a relatively large number of countries. In 2015 China was responsible for 14.6% of global gold production, with Australia, the second-largest producer at 9.0%. A total of 18 countries were responsible for 80% of global gold production. In contrast, approximately 60% of the world's cobalt production came from the Democratic Republic of Congo in the same year (Garside 2022). This was almost ten times the amount mined by China, the second-highest producer at 6.04%, with the top six producing countries responsible for over 80% of global production. In addition to the physical distribution of ore deposits, other economic factors that influence where minerals are produced include location and the presence of infrastructure, local policies, regulatory frameworks for mineral extraction, the social and environmental context of the deposit, the physical characteristics of the orebody, and proximity to markets.

B. Technological challenges

The mining sector is also facing several more traditional and technical challenges regarding operational issues. It is becoming harder to find economically feasible processes in mining for lower-grade orebodies availability. In turn, the lower grades involved lead to larger volumes of waste material, including tailings, and increased demand for energy and water. For many metals, the average *head grade*, i.e., the grade of the ore delivered to the concentrator, has seen a gradual decline. For copper, the average has dropped from a stable period of just under 1% in the 1990s to just over 0.6% today. Another analysis highlighted the average grade of projects under development or in the advanced feasibility stage at 0.39% (Rötzer 2018). Moreover, an increasing number of deeper mines are being developed as existing operations pursue deeper reserves, and new technological exploration techniques help target and discover previously hidden orebodies. Continuing with the example of copper, the combination of depth and lower grade has led to the *block cave* mining method becoming the most common extraction method for new large-scale mines. For example, the Oyu Tolgoi mine in Mongolia and the Resolution Project in the USA. The latter, which is still in the project evaluation and permitting stage, targets an orebody over two kilometres below the surface. Technical challenges at these depths include managing high stresses around underground openings and higher rock temperatures, among others. The caving method also requires sophisticated smart management to minimize the effect of ore dilution within the caved material with waste material (Newell 2020).

According to Barnewold et al. (2020) the mining industry still faces challenges in adopting digital technology. Adoption tends to be influenced by independent variables such as mining operations' production scale, current infrastructure, skilled personnel availability, research and development capabilities, and an enterprise's vision to engage in technological diffusion. Regardless, their research findings revealed an apparent gap in technology dispersal across smaller operations. These elements combine to provide a final economic consideration that has a substantial impact on digital technology investments, particularly among small mining enterprises. Moreover, one of the most technical challenges in mining sites can be represented as the lack of information unity, in which there are several independent pieces of equipment, machinery, systems, and subsystems, and each has its own information and interfaces. Thus, decision-makers have fragmented pieces of asynchronous information and a lack of comprehensive overview referred to as "*islands of automation*". The lack of unity and integration imposes difficulties in performing proper decisions in a timely manner.

C. Geopolitical influences

A dynamic global geopolitical context, with current trends toward nationalism in many countries, is impacting many aspects of the global trade system. Questions of resource security, the ability to source critical commodities that underpin key industries and supply chains, are amplified by the effects of countries' determination to get the most out of their own mineral endowments for their own people. In most countries worldwide, the legal and constitutional frameworks allocate the ownership of mineral resources to its state. Therefore, governments are responsible for establishing policies that maximize the benefits of mining operations to their own populations at local and national levels while encouraging an active and sustainable mining sector. The term *Resource nationalism* has been used in recent years to describe more aggressive strategies that governments use to assert control over their resource industries and to maximize economic benefits for the host state. The primary mechanism for exercising this control is through selective and discretionary national policies. Governments typically pursue resource nationalism via a combination of three main policy avenues (1) imposing rules that target resource industry ownership, such as demanding local or state ownership; (2) imposing restrictions on resource corporations' activities, such as encouraging businesses to invest in local industries via industrial policy criteria; and (3) via resource taxation and other fiscal collection systems, capturing economic rents from resource enterprises (OECD 2017).

D. Socio-ecological influences

Mining operations can offer local communities some positive benefits, for example, through employment opportunities and other forms of local economic engagement. They can bring infrastructure to isolated regions. However, they can also negatively affect local communities through disruption to traditional economies and livelihoods, competition for resources such as water, and environmental impacts (Poudyal 2019). Access to land is critical for the sector - it is impossible to move an orebody to a more favourable location - and therefore, questions of property rights and Indigenous lands are prominent. As a more public discussion about the sector has developed in parallel with the emergence of the sustainable development framework, a wide range of stakeholder groups have engaged in the debate (Saenz 2019). Many proposals for new operations in many mining locations worldwide are met with public opposition demonstrations, with groups focusing on local and more global issues, e.g., climate change (Conde 2017).

4. Mining Outlook

Decarbonization, digitization, and diversification are disrupting mining models and creating new opportunities where sustainability, safety, and efficient productivity are the main beneficial gains and goals from emerging digital transformation in mining industries. Technological investments in mining operations (e.g., unmanned aerial and ground vehicles) have lately received great interest from mining companies. Increased automation deployment adds a new level of safety and efficiency measures to mine processes. Ground and underground autonomous vehicles provide a risk-free working environment where human involvement in mining systems can be described as human in-, on-, or out of the loop of CPS. Mining operators may operate and monitor the autonomous fleet movements in safer, quicker, narrowed dusty tunnels that human operators have great trouble navigating. Improvements in information and communication technology enable the mining sector to pursue more creative prospects, such as smart wearable technologies powered by immersive technologies (augmented, virtual, and mixed reality). Mine management can use connected mobility applications to acquire data in real-time and provide seamless communication, remote expert support, diagnostics, and real-time assistance or accessibility to service instructions.

The road to overcome mining challenges is fundamentally human-centred and has inclusive socio-economic development or what is known as sustainable development at its core (Carvalho 2017). As a key strategic priority for the next generation of mines, digital transformation aims to create an enabling environment for industry-wide change bringing us a step closer towards the mine of future. The roadmap can be classified into four phases (Figure 1) starting from current mine's terminology. With increased amount of data to gain more insights, higher automation levels are required to integrate mining systems and optimize decision-making. A consequent result can be observed as lowest level of human risks with high exponential level of efficiency.

A: Human-governed mines

Currently the majority of mining operations are controlled by people and software. Mining is a complex process and to manually schedule a mine plant is a very difficult task. Mine planning mainly depends on software at this stage to optimize a mine plan and satisfy short-, mid-, and long-term business goals based on the lifetime of the mine. Most of the digital solutions available in the markets address stress points in one silo of the mine and deliver point digital solutions. These solutions help to overcome either load, halt, mine, processing, logistics, or expiration related challenges. Only a few integrated digital solutions are currently available and are suboptimal. Decision-making is mainly done by humans and/or software.

B: Semi-self-governed mines

Top tier mining companies are driving concepts of autonomy in their minds by using autonomous fleets. As consequence, these activities help to reduce human involvement in mining operations. A few mining companies are working towards enabling truck to truck communication in their mines, where most of the decisions are made by autonomous machinery such as rocks, drills, drones, and machines with the help of humans and software. Third-party mining solutions providers will support this stage by developing integrated digital solutions. For example, Rio Tinto mining company a leader in automation and innovation started to use autonomous technology in the Pilbara in 2008 and currently they have at least 575 trucks operating in Australia across its mines (Mining-Technology 2022).

C: Self-governed mines

After the boom in autonomous ecosystems and AI matures, most mines in self-governing state could be seen where all decisions will be made by autonomous machines with less human interaction. Most solutions will become plug-and-play which means generic digital solutions that are not customized to a particular mind type, mining company, or commodity could be achieved.

D: Virtual mines

At this stage, humans would achieve singularity in AI when machines surpass human intelligence. This will impact the mining industry since in the virtual mines the decisions are made by AI. Humans' involvement would be only owning the mine where almost all human risk-activities will be carried out by robots in daily mining activities and operations. A very limited few miners might work at mine sites for only physical sense monitoring and most operations will be controlled virtually from the mining company's headquarters.

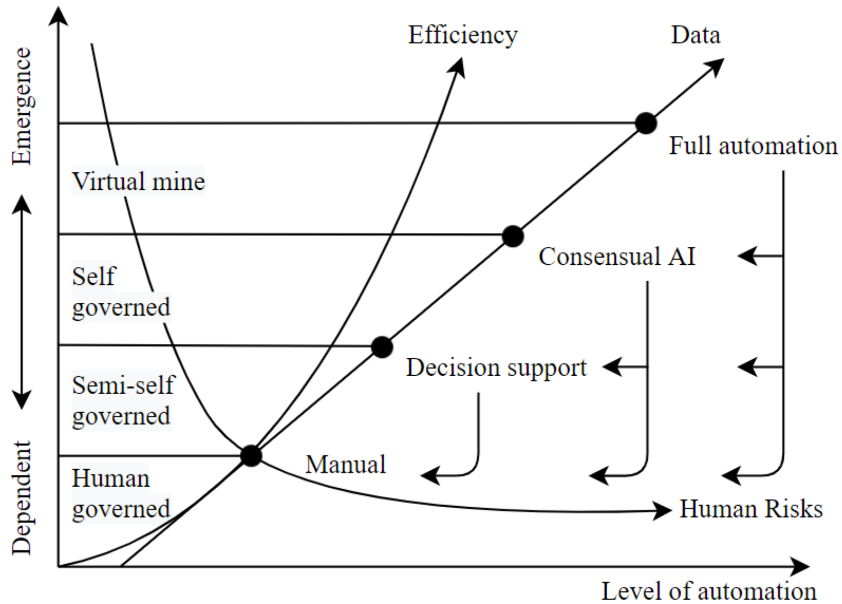

Figure 1. Mining outlook with automation levels

Complementary to the I4 move in organizations, concerns in resource utilization, conversation and recycling aligned with environmental issues worldwide have transformed the old-fashion profitability objective to be maximized in the short-term horizon to the sustainable economic growth targeting a long-term prospectus. With the support of the I4 technologies, the sustainable deployment or what is known circular economy (CE) in mining systems and supply chains will imply efficient use of natural resources, reduced energy and water consumptions, and generation of wastes as well as high-performance production, logistics and services. Therefore, the identification and design of opportunities for the resource-process-product within the I4-CE adoption will increase (Song and Wand 2018). Modern ICT is transforming production and service operations models, reducing consumptions of energy and natural resources, and optimizing material flows and inventories. The consequence of such transformations is the reduction of wastes and greenhouse gases (GHG) emissions. Such evidence of the GHG reducing by the virtue of the capabilities of the information age in transportation, logistics, smart cities, efficient buildings, and facilities, etc., demonstrate more sustainable environment while offering economic benefits.

Numerical and comparative assessment

An integrated mine type and key performance indicators (KPIs), sensitivity performance analysis against the proposed outlook (Figure 1), has been evaluated based on subjective ratings for mine-to-mill main processes (transport ore from mine, crushing, stockpiling, and milling) and summarized in Table 1. The aim is to have a sense of comparative evaluation of the emerging dependency on AI and the level of automation towards virtual mines. As discussed earlier, the type of mine environment is speculated and categorized into human-governed, semi-self-governed, self-governed, and virtual mines. In the comparative assessment methodology, every step of the mine-to-mill processes associated with each mine type, is subjectively evaluated using main KPIs (efficiency level, amount of big data to process, and the inherent risks involved). Then, the mine-KPI impact on the level of automation is identified, whereby human involvement can be described as human-in, -on, and -out of the loop of cyber-physical systems. The operational-performance matrix methodology quantifies the possible performance level of each mining environment under the defined KPIs considering impact performance values of 0.1, 0.3, and 0.6 for low, medium, and high, respectively.
Pooling the performance ratings in this context, we use the notation n for the number of processes, x denotes the KPI (efficiency, data, risk), P refers to the process itself. In the sensitivity analysis, the performance sum (Eq.1), its average (Eq.2) and the performance pooling (Eq.3) are defined to evaluate the KPIs effect within the level of automation in the mine-to-mill processes.

$$\sum_{i=1}^{n} P_i^x \quad (1), \quad \frac{\sum_{i=1}^{n} P_i^x}{n} \quad (2), \quad \sum_{i=1}^{x} \frac{\sum_{i=1}^{n} P_i^x}{n} \quad (3)$$

The summation and averages of performances for each KPI (efficiency level, amount of big data to process, and the inherent risks involved) for the main mine-to-mill processes are calculated and then pooled. Results show that the virtual mine performance pool value is the highest at 1.8, which is at the hypothetical maximum performance pooled value. Human-governed mines score 0.3 and semi-self-governed mines 0.5, both around the hypothetical minimum performance pooled value. Self-governed mines yield 1.5 in the direction of the hypothetical high-performance pooled value. The hypothetical minimum, medium, and maximum performance pooled values are 0.3, 0.9, and 1.8, respectively.

Table 1. Summary results.

Mine	Human-governed			Semi-self-governed			Self-governed			Virtual		
KPIs	Efficiency	Data	Risk	Efficiency	Data	Risk	Efficiency	Data	Risk	Efficiency	Data	Risk
Performance sum	0.4	0.4	0.4	0.6	1.0	0.4	2.4	2.4	1.2	2.4	2.4	2,4
Average	0.1	0.1	0.1	0.15	0.25	0.1	0.6	0.6	0.3	0.6	0.6	0.6
Risk pool	0.3			0.5			1.5			1.8		

The results in Table 1 show that the higher adoption of automation level toward virtual mines promotes the most efficient utilization of resources, the highest capability in handling and processing big data to make timely (real-time) informed decisions, and grants the lowest risks inherent in such working environment since mine-to-mill processes and subprocesses shall be re-executed allowing optimum performance to be reached. However, the effects on manpower would result in a total replacement.

5. Discussion and Conclusion

Employing integrated advanced technologies into the mining industry unveils competitive advantages. Such as, first, greater accuracy and fast decision-making at which mining operations involve extensive processing of real-time data to share instant directives to the control units. Integrating BDA and ML can help mining companies collect data and deliver insightful on-site decisions to streamline processes by reducing the chances of errors. Second, health and safety where better and faster decision-making is a key factor in improving the health and safety of mineworkers as AI help them by reducing their exposure to dangerous situations in mining. Therefore, shifting the industry from a people-oriented to a process-oriented. Third, efficiency-boosting by deriving patterns from previously accumulated huge data sets can drive efficiency by increasing processes' consistency and quality and reducing the chances of human errors. Forth, reducing environment footprints by embedding AI and ML into the previously existing systems can help the mining industry to reduce energy demand by reducing the environmental footprints.

Smart manufacturing is transforming industrial processes and communities into the so-called society 5.0, enabling the emergence of a new industry-society-environment nexus. Integrating sensing, calculating, and actuating innovative technologies enables data-driven setups and automated decision-making executions. In the meantime, humans operate mining operations substantially with the assistance of software to make decisions. However, in this field, the expanding use of autonomous robots is critical for dealing with risks and extreme conditions as no or little labour is required. Therefore, creative production systems require information and communication technology, advanced modelling and solving algorithms, and auxiliary mechatronics. Mining's changing progressive evolution and rising complexity can be divided into four main categories: economic effects with macroeconomic variables, technological obstacles, geopolitical impacts, and socio-ecological influences. The direction to overcoming mining difficulties is primarily human-centered, with comprehensive socioeconomic development, often known as sustainable development. Digital transformation, as an enabler solution for the next generation of mines, strives to provide a supportive environment for industry-wide transformation, bringing us closer to the mine of the future. Starting with existing mines nomenclature, the roadmap can be illustrated in four phases, including human-governed, semi-self-governed, self-governed, and virtual mines.

The purpose of the integrated mining process systems and real-time site management solutions using cutting-edge technologies will sustainably maximize net mineral production and generate a positive effect on mining processes and operations regarding the status of safety with risk-free facilities, operational excellence, productivity, increase resource efficiency, minimize waste, and maximize short-term profitability. Thus, the current and future research paths in the mining process systems concentrate on improving efficiency and productivity as one of the crucial aspects of the mining industry that can lead to sustainable development where industry-leading players are heading to create intelligent mining operations.

Acknowledgments

The authors are grateful to Hamad Bin Khalifa University, Doha, Qatar, for supporting this research.

References

Rodrigues, M. and Mendes, L., Mapping of the literature on social responsibility in the mining industry: A systematic literature review, *Journal of cleaner production* 181: 88-101,2018

Horberry, T., Burgess-Limerick, R. and Steiner, L., Human-centered design for mining equipment and new technology, *CRC Press*, pp. 1–9, 2018

Mateus, A. and Martins, L., Challenges and opportunities for a successful mining industry in the future, *Boletín Geológico Min* vol. 130, pp. 99-121, 2019

Jämsä-Jounela, SL., Future automation systems in context of process systems and minerals engineering, *IFAC-PapersOnLine,* vol. 52, no. 25, pp. 403-408, 2019

Barnewold, L. and Lottermoser, B., "Identification of digital technologies and digitalisation trends in the mining industry." *International Journal of Mining Science and Technology,* vol. 30, no. 6, pp. 747-757, 2020

Molaei, F., Rahimi, E., Siavoshi, H., Afrouz, S. G. andTenorio, V., A comprehensive review on internet of things (IoT) and its implications in the mining industry, *American Journal of Engineering and Applied Sciences,* vol. 13, no. 3, pp. 499-515, 2020

Qi, C. "Big data management in the mining industry." *International Journal of Minerals, Metallurgy and Materials,* vol. 7, no. 2, pp. 131-139, 2020

McNinch, M., Parks, D., Jacksha, R., & Miller, A., Leveraging IIoT to improve machine safety in the mining industry, *Mining, metallurgy & exploration,* vol. 36, no. 4, pp. 675-681., 2019

Seyedamir, A., Ferrer, BR., Jose L. and Lastra, M., An ISA-95 based ontology for manufacturing systems knowledge description extended with semantic rules, *IEEE 16th International Conference on Industrial Informatics (INDIN)*, pp. 374-380, 2018

Bastos, A., De Andrade, M. L. S. C., Yoshino, R. T., and Santos, M., Industry 4.0 Readiness Assessment Method Based on RAMI 4.0 Standards, *IEEE Access*, vol. 9, pp. 119778-119799, 2021

Pivoto, D., de-Almeida, L., Rosa Righi, R., Rodrigues, J. J., Lugli, A. B., and Alberti, A. M., Cyber-physical systems architectures for industrial internet of things applications in Industry 4.0: A literature review, *Journal of manufacturing systems*, vol. 58, pp. 176-192, 2021

Venditti, B. and LePan, N., Visualizing the abundance of elements in the Earth's crust, *World Economic Forum*, 2021, Available: https://www.weforum.org/agenda/2021/12/abundance-elements-earth-crust/ , April, 2022

Garside, M., Gold production in world 2005-2020, Statista, Available: https://www.statista.com/statistics/238414/global-gold-production-since-2005/ , April, 2022)

Rötzer, N., and Schmidt, M., Decreasing metal ore grades—Is the fear of resource depletion justified?, *Resources*, vol. *7,* no. 4, pp. 88., 2018

Newell, E., Resolution Copper Project and Land Exchange Environmental Impact Statement, *USDA Forest Service Tonto National Forest*, Arizona, 2020

OECD, Mining regions and their cities: Scoping paper to inform the first OECD meeting on Mining Regions, pp. 1–38, 2017

Poudyal, N., Gyawali, B. and Simon, M., Local residents' views of surface mining: Perceived impacts, subjective well-being, and support for regulations in southern Appalachia, *Journal of Cleaner Production*, vol. 217, pp. 530-540, 2019

Saenz, C., A social conflict diagnostic tool for application in the mining industry: A case study in Peru, *Corporate Social Responsibility and Environmental Management*, vol. *26, no.* 3, pp. 690-700, 2019

Conde, M., Resistance to mining. A review, *Ecological Economics*, vol. 132, pp. 80-90, 2017

Carvalho, F., Mining industry and sustainable development: time for change, *Food and Energy Security*, vol. 6, no.

2, pp. 61-77, 2017
Mining-Technology, Australia leads the way in autonomous truck use, Avaliable: https://www.mining-technology.com/features/australia-leads-the-way-in-autonomous-truck-use/ , April, 2022
Song, M., and Wang, S,, Market competition, green technology progress and comparative advantages in China, *Management Decision*, vol. 56, no. 1, pp. 188–203, 2018
Ubiquity, C., Pitch, M., Yafee, P., Stuckey, J., Andersen, E. and Saha, G., The impact of information technology on energy consumption and carbon emissions., *Ubiquity*, pp. 1–15, 2015

Biographies

Mohammed Yaqot is a Ph.D. candidate in logistics and supply chain management at Hamad Bin Khalifa University, collage of science and engineering, division of engineering management and decision sciences (Qatar). He earned his bachelor and master's degrees in industrial & system engineering and engineering management, both obtained from King Fahad University of Petroleum and Minerals (KFUPM), Saudi Arabia. His research interests mainly concern supply chain management, digital transformation, circular economy, control systems, and production and operation management.

Brenno C. Menezes is an Assistant Professor at Hamad Bin Khalifa University, college of science and engineering, division of engineering management and decision sciences (Qatar). He holds a BSc and an MSc in Process Engineering from Federal University of Rio de Janeiro, Brazil. He has more than fifteen years of international experience as a process engineer and researcher in Smart Manufacturing and Engineering Management. Dr. Menezes has published many papers in top academic international journals, such as Computers and Chemical Engineering, Industrial Engineering Chemistry Research, and Computer Aided Process Engineering, among many others. His current fields of research include the areas of simulation and optimization, LNG value chain, precision agriculture, and machine learning.