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Artificial Intelligence, Machine Learning, and Autonomous Technologies in Mining Industry

Zeshan Hyder, Missouri University of Science and Technology, Rolla, USA
Keng Siau, Missouri University of Science and Technology, Rolla, USA
Fiona Nah, Missouri University of Science and Technology, Rolla, USA

ABSTRACT

The implementation of artificial intelligence (AI), machine learning, and autonomous technologies in the mining industry started about a decade ago with autonomous trucks. Artificial intelligence, machine learning, and autonomous technologies provide many economic benefits for the mining industry through cost reduction, efficiency, and improving productivity, reducing exposure of workers to hazardous conditions, continuous production, and improved safety. However, the implementation of these technologies has faced economic, financial, technological, workforce, and social challenges. This article discusses the current status of AI, machine learning, and autonomous technologies implementation in the mining industry and highlights potential areas of future application. The article presents the results of interviews with some of the stakeholders in the industry and what their perceptions are about the threats, challenges, benefits, and potential impacts of these advanced technologies. The article also presents their views on the future of these technologies and what are some of the steps needed for successful implementation of these technologies in this sector.

KEYWORDS

Artificial Intelligence, Autonomous Technology, Autonomous Trucks, Challenges of AI and Machine Learning, Machine Learning, Mining Industry

INTRODUCTION

Mining plays an important role in the world economy. In 2016, revenue from the world's leading mining companies was US$496 billion (Statista, 2018). The mining and extractions industry employed around 756,000 people in the US in 2016 (DOE, 2017). After being on the decline for the last few years, the mining industry is growing again and investment in the mining sector is increasing (Deloitte, 2017). One factor that can boost the growth of mining sector and make it more lucrative to investors is the application of Artificial Intelligence (AI), machine learning, and automation to improve the technological, economic, and environmental outlook of the industry.

AI and machine learning are two technologies that have the potential to change the technological framework of the future and both rely heavily on big data manipulation and analytics (Marr, 2016; Wang and Siau 2019). In 1956, John McCarthy defined artificial intelligence as the capacity of machines to behave intelligently. Machine learning is based on computational algorithms that are designed to emulate human intelligent by learning from the surrounding environment utilizing big data provided to them (El Naqa & Murphy, 2015). In this paper, we have discussed the use of AI, machine learning, and autonomous technologies in the mining industry and how it can help in a new mining revolution.

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CURRENT APPLICATIONS OF AI AND AUTONOMOUS TECHNOLOGY IN MINING INDUSTRY

The following are the sectors of the mining industry in general and mining operations in particular that are experiencing increased applications of AI and autonomous technologies. Figure 1 also shows some of the sectors where the implementation of these technologies is underway.

Prospecting and Exploration

Prospecting is the first stage of looking for an economic mineral deposit and evaluating this deposit in terms of current economic and market conditions to ascertain if further investment is viable for the given prospect or not. Prospecting involves reconnaissance of the area of interest, collection of geophysical, geological, and economic data. Exploration involves sampling, laboratory work, borehole logging, and further investigation of prospect (Böhmer & Kucera, 2013). Both these stages involve extensive collection and use of data, and with the use of traditional methods involving human labor, site visits of remote areas, manual sampling and assaying, and primitive techniques can last a period of two years to twenty years before the actual worth of the deposit is established (Böhmer & Kucera, 2013).

Prospecting generally starts with finding an anomaly in the structure, lithology, geological features, and plantation and plant growth patterns using maps, aerial photographs, satellite images, and other available data. AI systems and data analysis software can be fed with geological, topographical, mineralogical, and mapping data and can be used to pinpoint the anomalies and variances in the data and to locate areas of potential interests. Some research in this field is already underway and one such system is being utilized on an experimental basis by Goldspot Discoveries Incorporated for gold discovery. Similarly, Goldcorp and IBM Watson are working together to sift through large geological data to improve the accuracy of targeting mineable prospects (Walker, 2017).

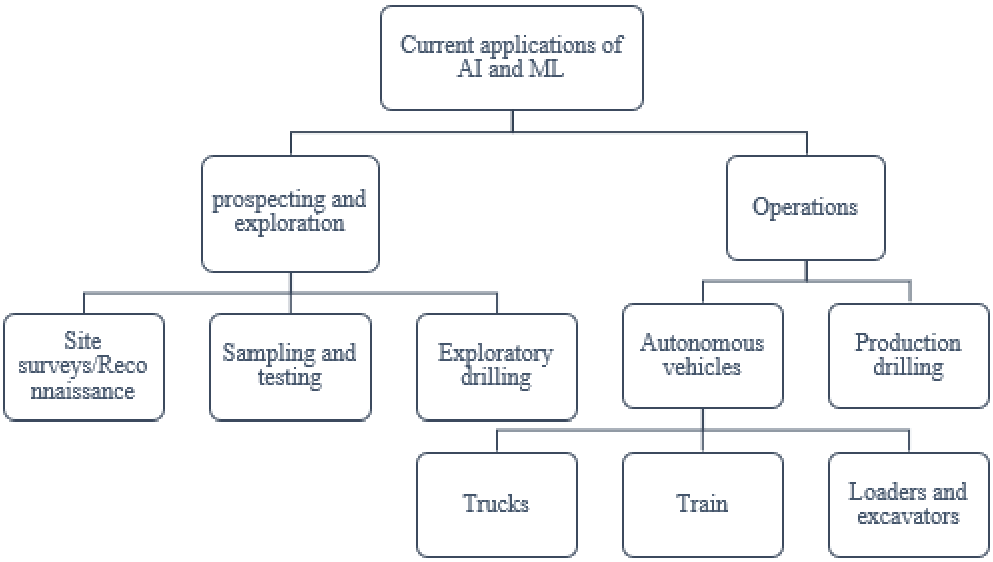
Exploratory and Production Drilling

AI and machine learning can be applied to develop autonomous drills that can locate the potential sites identified in the prospecting stage and perform drilling activities and can feed the drill log data to the system. This technology can also be implemented during production drilling. Typically, a drill cycle includes moving the drill to the desired location, setting up the drill at that location, leveling up and start drilling, applying adequate load or energy to drill as per requirements of the rock and strata, cleaning the drill and hole, remove the drill after completing the hole to a predetermined depth and moving the drill to the next location. Currently, these processes are done manually but it can be automated and AI can control the process. One such attempt is underway at BHP Billiton where autonomous drills are fitted with sensors, inclinometers, and other instruments to perform drilling tasks autonomously and feed data to the data analysis packages for further refining of the drill machine (Crozier, 2016).

Mining Operations

AI can greatly improve the productivity and efficiency of mining operations. Mining by its very nature is a dangerous and hazardous operation (Paithankar, 2011). Limited working space, poor lighting, accumulation of hazardous waste and poisonous gases, dust particles from metals, nonmetals and toxic substances, radioactive materials, poor air supply, use of explosives, and unstable roofs are among the factors that make mining operations dangerous. However, with the help of AI, machine learning, and autonomous technologies, the exposure of workers to dangerous underground and surface operations can be minimized. Machines can autonomously monitor the atmosphere, send signals and warnings, locate problematic areas, and work continuously even in dangerous situations. Hence, the implementation of AI, machine learning, and autonomous technologies is increasing in mining operations (Vella, 2017).

Figure 1. Sectors of the mining industry where AI, machine learning, and autonomous technologies implementation is currently in progress



Autonomous Vehicles

Several manufacturers have been working on autonomous mining haulage trucks and Caterpillar operated its first fleet of autonomous trucks in Australia (Caterpillar, 2017). BHP and RioTinto are currently using a fleet of autonomous trucks and have reported a 15% reduction in operation cost compared to manually operated trucks (Dyson, 2017; Simonite, 2016). These autonomous trucks can operate 24/7 without the need of rest breaks and changes in shift.

Although Tesla and Google have been working on a self-driving car for some time now, they have some setbacks in terms of rules, regulations, and infrastructure requirements (Chopra, 2017). However, mining sites provide an excellent launch pad for autonomous vehicles. The roads are mostly clear of other traffic, can be designated just for these vehicles, and infrastructure within the site is already developed, and privately owned and maintained so upgrade and remodeling is easier compared to public roads and infrastructure. That is why in addition to self-driving haulage trucks, autonomous loaders, trains, and excavators are being developed to meet mining industry needs.

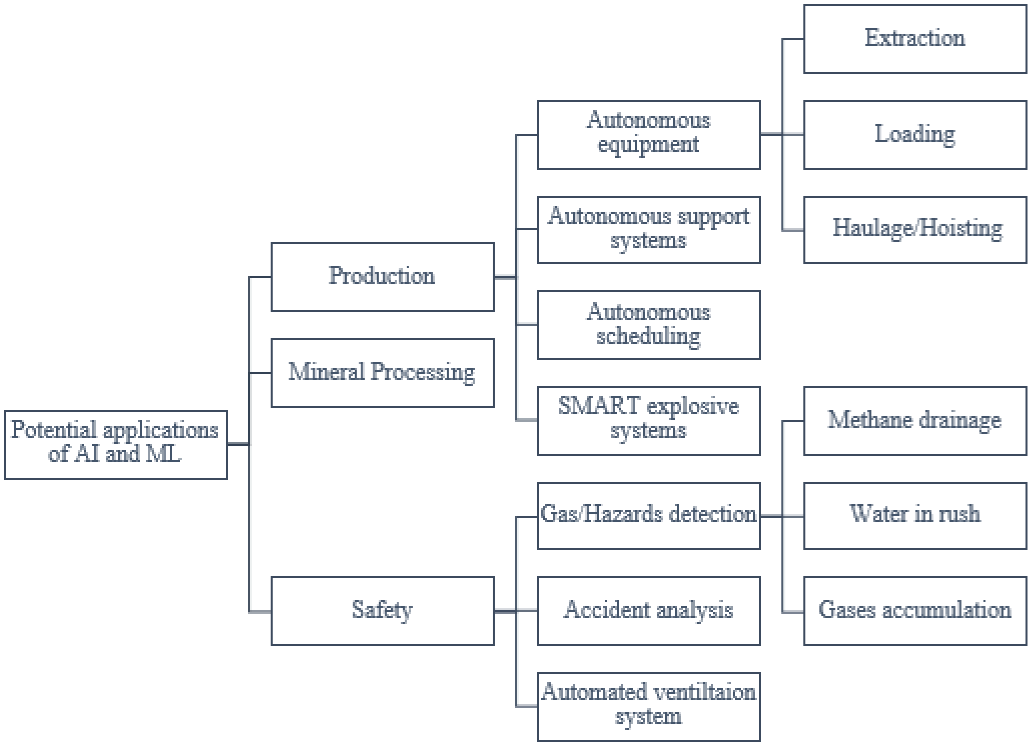
POTENTIAL APPLICATIONS OF AI IN MINING INDUSTRY

Figure 2 shows the sectors of the mining industry that have the potential for implementing these technologies. In some of these areas, active research and effort are underway. The following discusses these potentials.

Gases and Hazard Detection

An important application of AI to the mining industry can be the detection of hazards, especially dangerous gases, toxic dust, and radiations in the mine. AI systems can be developed to inspect the worksite ahead of workers by using robots, sensors, and by collecting data from preinstalled monitoring stations. These stations can trigger alarms, give warning signals, and block the affected area to decrease further expansion of hazard. When connected to mine fans and ventilation networks through intelligent systems, AI systems can direct the air flow, increase or decrease the air quantity

Figure 2. Mining sectors having big potential for implementation of these technologies



and pressure of mine fans, and start and stop certain fans to automatically direct the hazards out of mine. This can enhance the safety of mining operations, reduce downtime, increase productivity, and decrease accidents and related costs.

Production

Shearers, coal cutters, jumbos, conveyors, cutting heads, and road headers are integral parts of the mining production cycle (EIA, 1995). AI and machine learning can be implemented on these machines to direct their operations, automate application of energy at cutter heads to match the rock strength and hardness, monitor gas and methane inrush during operation, continuously monitor roof condition while in operation, and disseminate data about working conditions to make informed decision and take corrective actions well in advance of escalation of problems.

Sampling

Autonomous samplers can sample minerals, atmosphere, gases, dust, and toxic materials even in areas of high concentration. Continues monitoring intelligent systems can provide early warnings, suggest preventive measures, and reduce the need for workers access to the hazardous area for sampling. These AI systems can reduce the need to bring samples for laboratory testing by providing images, conducting in situ tests, and communicating results as and when needed.

Autonomous Support Systems

Another area of AI and machine learning implementation is autonomous support systems and several companies are researching to provide first such autonomous system that will reduce the need of human intervention for this delicate and dangerous mining operation (Van Duin, Meers, Donnelly, & Oxley, 2013). Roof support is one of the most important and most hazardous tasks of mining operation (Ghasemi et al., 2012; Peng, 2015). Several accidents occur because of roof falls while supporting operation is underway (MSHA, 2017). Weak areas of the roof and strata, water inrush, and release of hazardous gases pose a high risk to this work. This dangerous operation can be automated where roof support can be made an integral part of the autonomous cutting machine that shields the areas after cutting and install bolts and temporary support to the worked out exposed strata while moving ahead for further production. This temporary support provides adequate time for installation of permanent support.

Mineral Processing Application

AI-based systems can be designed to sort useful minerals and gang material from the run of mine production. These systems can use color-sorting, x-ray transmission or near-infrared sensors to remove waste from useful mineral. They can be designed to exploit differences in physical properties (specific gravity, density, luster, and heft), mineralogical compositions and chemical properties. The application of these systems before grinding and crushing machines can greatly increase the efficiency of the comminution process and reduce energy cost as crushing and grinding are most energy consuming and least energy efficient parts of the mineral processing cycle (Jeswiet & Szekeres, 2016).

Accident Analysis

Data analysis and visualization techniques can be used to analyze causes and factors leading to accidents and preventive measures can be designed with more focus on removing the causes of accidents. Intelligent systems designed with a focus on removal of potentially hazardous situations, decrease or complete removal of human presence from dangerous and hazardous works such as transporting, loading and blasting explosives, installing roof supports, and removing hazardous gases and dust can help in reducing accidents and fatalities.

CHALLENGES IN IMPLEMENTING AI IN MINING INDUSTRY

Although the implementation of AI and autonomous technology in mining started more than a decade ago, the pace of implementation is painfully slow and has faced several hurdles and setbacks. One of the biggest challenges in implementing technology is resistance from workers, supervisors, and even AI researchers who are not sure of the actual impacts of this technology will create on jobs, economics, social system, working relations, and on the societal makeup (Kappal, 2017; Siau, 2018; Siau & Yang, 2017). People's reaction to this technology is challenging and based on their reactions, Mark Knickrehm identifies five schools of thoughts. Understanding these perspectives can help in creating strategies to overcome these challenges. These groups include the dystopian who are wary of technology, the utopians who welcome technology, the optimists, the skeptics, and the realists (Knickrehm, 2018). The opposition is mostly based on the fear of losing jobs to technology, unknown behavior of AI and autonomous systems, unequal distribution of wealth and capital, complicated and complex interaction and relationship with technology, and unclear future of technology implementation (Siau, 2017; Siau & Wang, 2018; Wang & Siau, 2019). It is also not clear how individual and group decision making can be supported by technology in AI (Nah & Benbasat, 2004; Nah, Mao, & Benbasat, 1999).

Other factors that are slowing down the implementation of AI and automation are sluggish improvements in intelligent systems, difficulty in obtaining regulatory approvals, huge initial investment and capital requirements, inadequate infrastructure for the implementation of technology, limited availability of skilled personnel, difficulty in obtaining capital funding when the future and benefits of implementing technology are not yet clear, and declining availability of high grade ores and mineral resources that does not warrant large capital investment.

RESEARCH QUESTIONS, METHODOLOGY, AND PROCEDURE

AI and autonomous technologies implementation to the mining industry are still in their infancy and not much data is available to quantify the impact of this implementation on the industry. Thus, it was appropriate to use qualitative approaches to assess how this implementation was received by different stakeholders in the industry and what their perceptions were about the threats, challenges, benefits, and potential impacts of this implementation. Keeping in view this objective, the following questions were designed to collect the relevant data:

1. What do you consider AI, machine learning, and autonomous technologies?
2. Did you use or are you planning to use AI, machine learning, and autonomous technologies in your research, projects or in your work?
3. What are some of the major impacts of implementing these technologies and their advantages and disadvantages?
4. What are the main hurdles/challenges in implementing these technologies?
5. What is the way forward and how to successfully implement autonomous technologies in the mining industry?

As these open-ended questions are subjective, the qualitative method of research design, data collection, and analysis were employed. One-on-one interviews were carried out to gather the perceptions, suggestions, viewpoints, and opinions of the stakeholders. The interview method provided more flexibility in terms of engaging in open and frank discussions, allowing follow-up questions to clarify issues or points of view, and a better understanding of an interviewee's position.

INTERVIEW OUTCOMES

In total, twenty interviews were conducted. Ten of the interviewees were graduate students, five were doing Ph.D. conducting research on various aspects of mining and mineral processing including vibration controls, flow optimization, automated flotation, automated operations control, and generation of automated muck pile profiles. One student had completed masters in petroleum engineering and had done research in submersible drilling applications for both mining and petroleum. Three were completing masters in mining engineering, one as a distance student and two were on-campus students. They all had worked in the mining industry in different positions and in different mining companies. One was an undergraduate student taking graduate courses and planning to do graduate studies in AI and machine learning.

Seven interviewees were faculty members with expertise in mineral processing, rock mechanics, environmental impacts of mining, mining optimization and mining systems, and computer applications for the mining industry. One was an assistant professor, three were associate professors, and three were at the rank of full professor. They all were teaching and doing research in mining departments at three research universities in the Midwest and on the East Coast.

Three interviewees were industry professionals working as operations manager, reliability engineer, and mining engineer. Here are some key data about the interviewees:

1. Average working experience of the interviewees was about 8 years – ranging from 1 year in the industry to over 20 years in the industry;
2. Minimum education of the interviewees was undergraduate degree in mining engineering;
3. Out of the 20 interviewees, 10 had advanced graduate degrees and were involved with areas closely related to AI, Machine learning and Automation technology;
4. 90% of the interviewees were male which is typical of the mining industry.

Below are some of the findings from their interviews.

What is AI, Machine Learning and Autonomous Technology?

This question was asked to gauge the interviewees' understanding of AI, machine learning, and autonomous technologies. Interestingly, all interviewees had slightly different ideas of AI and machine learning. Some common features attributed to AI and machine learning mentioned by the interviewees are:

- Systems or machines that are self-learning and can improve themselves over time;
- Training the machines that can work intelligently like human;
- A system that operates automatically without needing much human intervention after initial deployment.

Some interesting characteristics of AI and machine learning reported by interviewees are as follows:

AI is a prediction tool that can learn on its own and can train itself after we train it. (A Ph.D. student in mineral processing)
AI and machine learning are algorithms that learn over time to improve decision making and are self-learning. (A mining professor)
Machine learning is when you train a robot to do specific tasks. You will train it the first time, train it one more time and then it will know how to navigate and how to operate whereas AI is a broader term not always applicable to machines. (A mine manager)

Did You Use or Are You Planning to Use AI, Machine Learning and Autonomous Technologies in Your Research, Projects or in Your Work?

This question asked the interviewees if they were using any type of AI, machine learning, and autonomous technologies in their research, projects, and field or routine work. 11 out of 13 interviewees answered in affirmative that they were using some kinds of AI, machine learning, and autonomous technology. Two interviewees did not use AI in their current projects but were planning to use it in their future research and projects. Following are areas the interviewees either used or were planning to use these technologies:

- To monitor the effects of changing variables on the flotation process while conducting experiments;
- Using fuzzy logic and neural networks to train data so that it can predict the effect of changing one variable out of several variables on the flow process;
- Prediction of vibration effects on the operator while operating heavy mining equipment in a rugged terrain;
- Developing an AI-based algorithm to determine underground GPS demand zones;
- AI-based model to develop emergency management and guidance systems in the underground mines;
- Prediction of failures and need and arrangements of maintenance;
- Robots in mine rescue and emergency operations.

What Are Some Major Impacts of Implementing These Technologies and Their Advantages and Disadvantages?

Increased productivity, improved safety, and reduced operating costs were some of the common advantages of using these technologies in the mining field described by the participants. Figure 3 shows some of these advantages. An interesting advantage of using these technologies was related to the predictive capabilities of AI and machine learning. All researchers were of the view that these technologies have the potential to reduce the number of experiments, field work, and lab tests needed to get the desired results and accuracy for interpretation of results. The AI systems can be fed with a fraction of data generated in the lab as training data and then can be used to predict the behavior of models based on that data. These predictions can be checked against some of the experimentally generated data and correction can be applied and an AI system can be retrained to improve the accuracy of results. As described by one on the Ph.D. researcher working in the operations research lab of a university.

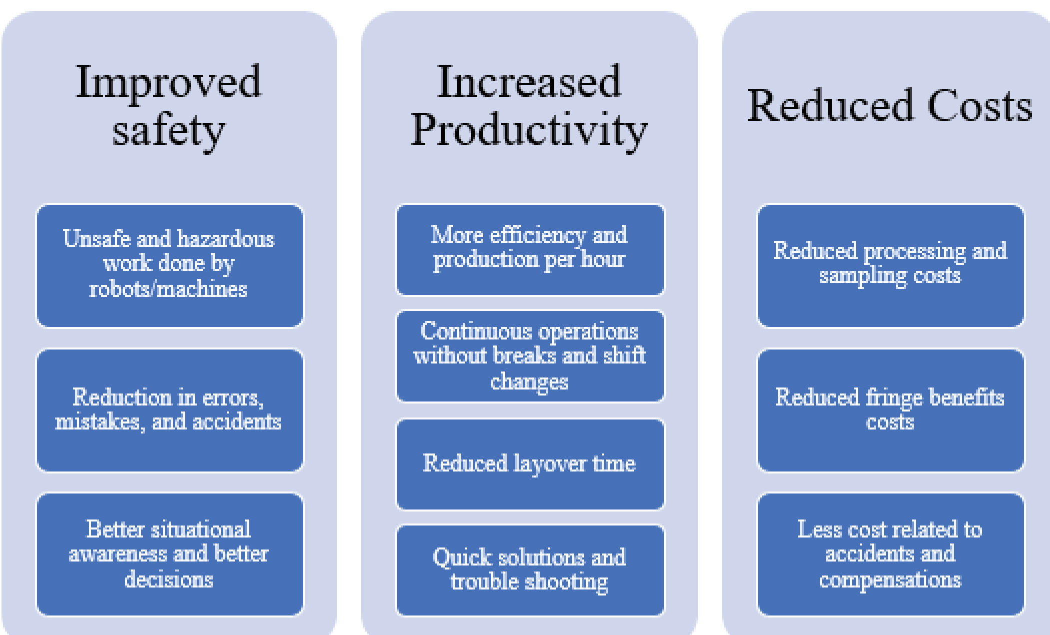
Based on my experimental design I had to conduct 1700-1800 experiments to get reliable results, however, using AI-based system I was able to reduce the number of experiments by around 80%. I used my data and trained AI system and use predictive analysis to predict the results and I got my results within the required accuracy. That greatly reduced cost and time needed for my research study.

Other advantages described by the interviewees are listed below.

Advantages

- Unsafe jobs, work, and hazardous tasks worked by robots instead of human;
- Increased efficiency of work and processes;
- Reduction in labor cost and improved safety;
- No health, vison, and dental insurance, retirement, and other costs needed for machines;
- Reduced errors, mistakes, and accidents resulting in reduced operational costs;

Figure 3. Some major advantages of these technologies



- Quick solutions to problems;
- Reliable results from a reduced number of experiments;
- Reduction in the number of expensive field and lab experiments, and increased reliability of prediction and predictive algorithms;
- 24/7 availability resulting in increased productivity;
- Improved safety (roof bolter as an example) as robots doing hazardous work;
- Better guidance and control system for mine rescue and safety operations;
- Systems are filling the gap of labor availability and labor needs in the industry;
- AI systems have more situational awareness and can make better decisions in hazardous, accidents, and emergency situations;
- Increased speed of good decision;
- Simple and timely solutions to complex problems.

Disadvantages

The most commonly mentioned disadvantage of these technologies is their impact on the availability of jobs. The majority (>90%) of the interviewees were of the view that these technologies would have a negative impact on the employment opportunities for people and the number of available jobs would reduce significantly. Interestingly, no one knew the exact extent of job losses to the technology or how many new jobs would be created by these technologies. As described by a professor in mining engineering department, “Generally, the operating mines bring a positive economic impact in the communities in which they are operating in terms of new employment opportunities and creation of jobs. But if all these jobs are lost to automation and technology, what is the advantage to the community in terms of employment opportunities.” Some disadvantages mentioned by the interviewees are listed below:

- Loss of jobs;
- Complex human-machine interaction and psychological issues while working with machines like feelings of isolation and non-companionship;
- Reliability of results as it is still based on trial and error;
- Loss of control over intelligent machines;
- Improper use of technology like autonomous weapons and explosives;
- Too much reliance on machines can lead to poor decision making as technology has the potential to be misused if not deployed properly;
- Security vulnerability (e.g., bugs, viruses, system hacking);
- Ethical implications and responsibilities for unsafe behavior;
- No employment for communities where mines are being developed.

What Are the Main Hurdles/Challenges in Implementing These Technologies?

The most common challenge in the implementation of these technologies in the mining industry is the lack of expertise in this field and unavailability of skilled labor force needed for the implementation. The second challenge is the large amount of capital needed for the automation of systems and operations. A consensus among the interviewees is that not all mining companies have the necessary capital for the implementation of these technologies, especially when relatively cheaper labor is still available for most of the mining operation needs. Dynamic nature of mining is another big challenge that is considered a hurdle in the implementation of AI and machine learning. The variables governing mining operations are numerous and mostly unpredictable, thus making it very hard if not impossible to fully apply autonomous systems and operations. Geological conditions, stratigraphic changes, stressed and strained regimes, water and gases inrush, constricted spaces underground, and difficulty in transmitting signals to and from systems and machines underground are a few factors that have to be overcome before commercial implementation of these autonomous technologies and AI systems in the mining industry can take off. Following are challenges highlighted by the interviewees in the implementation of these technologies and Figure 4 depicts some of these challenges:

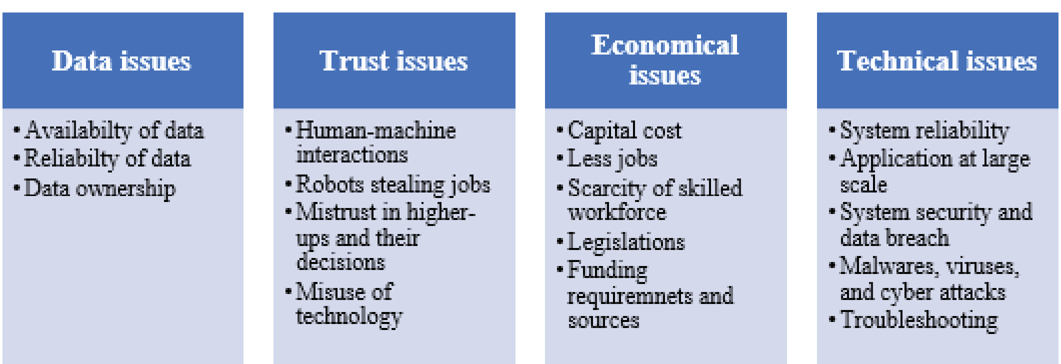
- Availability of reliable data as most data is proprietary;
- Commercial feasibility, and design and set-up for large scale implementation;
- Current reliability of systems;
- Trust issues;
- Hard to model dynamic and ever-changing mining environment (e.g., profile of muck pile);
- Economic challenges as investment can be a big issue;
- Nonavailability of trained people to operate, maintain, and implement these systems;
- Not used at industrial scale especially in the mineral processing industry;
- Highly variable factors may lead to difficulty in getting the required accuracy.

What is the Way Forward and How to Successfully Implement Autonomous Technologies in the Mining Industry?

All interviewees were of the view that these technologies can provide excellent solutions to the mining, and its hazardous and environment degrading operations. It has the potential to boost the industry by increasing production and productivity, reducing the exposure of human labor to hazardous operations and environment, increasing operational efficiency, reducing environmental footprint resulting from reduced energy and fuel consumptions, and adoption of best practices. As stated by one of the mine managers, “There is no escape from these technologies. They are the future of mining and the companies adopting these technologies and transitioning to adopt these technologies will be competitive in the future markets. However, we need the resolve from c-level management, policy makers, legislators, investors, AI practitioners, autonomous system developers, social scientists and researchers, and labor representatives to work together and hold dialogues to resolve the technology’s economic, social, societal, financial, and psychological issues.” Some suggestions presented by the interviewees about the future implementation of these technologies are listed below:

- More trained people
- More experimental and pilot studies
- Psychological interactions, and social and economic impacts
- More investment

Figure 4. Some of the major challenges in implementing AI and machine learning in mining



- Commitment from higher management, and confidence building of lower management and workers
- Solutions for economic disparity

DISCUSSIONS AND IMPLICATIONS

Of all the interviewees, the majority were familiar with the AI, machine learning, and autonomous technologies being implemented in the mining industry and were either directly or indirectly involved in using some aspects of these technologies in their work, research, and studies. However, the definition of what constitutes AI and machine learning were considerably different among the interviewees. They all viewed this technology as an imperative for improved efficiency, safer operations, and reduced environmental load of mining, and has the potential to improve the mining industry by introducing smart systems and robots to perform hazardous jobs. Interestingly, the majority of them was of the view that there was still a need to have more data, research, studies, and analysis to gauge the social, economic, societal, psychological, normative, legal and behavioral implications, and impacts of these technologies before embarking on full implementations. One of the biggest issues that came out of these discussions was the issue of trust, especially at this stage of technology development. There were also concerns about the complete lack or the clarity of legal, legislative, and statutory framework for these technologies. As mining is a highly regulated industry, it is hard to build the confidence of investors in these technologies when future legislations controlling these technologies are not clear yet.

CONCLUSION

AI, machine learning, and autonomous technology have the potential to bring a new revolution to the mining industry by reducing cost, improving productivity and efficiency of operations, and by decreasing the environmental footprint of mining through use of intelligent systems. The mining industry is slowly moving towards the implementation of these systems, especially in the field of autonomous machines and self-driving vehicles. However, to realize the full potential of these technologies in various operations of mining, more concerted efforts are needed.

As more and more mining companies are taking the initiative to implement intelligent systems based on AI and autonomous technologies, more and more data will be available on the successes and failures of these attempts, their impact on jobs and employment numbers, future skills and training requirements, economic, societal, and social impacts of AI implementation. This will provide more solid data to analyze various impacts, to evaluate current issues and future trends, and to provide a basis for better understanding of the implications of AI implementations in the mining industry.

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Zeshan Hyder holds a Ph.D. in mining engineering from Virginia Tech. He worked as an Assistant Professor in the Mining Engineering Department at Missouri S&T. His research interests include AI, machine learning, data science, business analytics, mine ventilation, and GIS applications. He can be reached at zhfy6@mst.edu.

Siau Keng is professor and chair of Business and Information Technology Department at Missouri S&T. Professor Siau is consistently ranked as one of the top information systems researchers in the world based on h-index and productivity rate. In 2006, he was ranked as one of the top ten e-commerce researchers in the world (Arithmetic Rank of 7, Geometric Rank of 3). In 2006, the citation count for his paper "Building Customer Trust in Mobile Commerce" is ranked in the top 1% in the field as reported by Essential Science Indicators. His research has been funded by NSF, IBM, and other IT organizations. His current research interests include AI, Robotics, and Automation and their Economic and Social Impact, Business Analytics, and Data Science. He can be reached at siauk@umsystem.edu.

Fiona Fui-Hoon Nah is a Professor of Business and Information Technology at the Missouri University of Science and Technology. She is a co-founder of the Special Interest Group on Human-Computer Interaction (SIGHCI) within the Association for Information Systems (AIS) and the Editor-in-Chief of AIS Transactions on Human-Computer Interaction. Her publications have appeared in journals such as MIS Quarterly, Journal of the Association for Information Systems, and International Journal of Human-Computer Studies. Her research interests include human-computer interaction, virtual communities and collaboration, electronic and mobile commerce, enterprise resource planning, information security, and neuro-IS. She can be reached at nahf@mst.edu.