World Journal of Advanced Engineering Technology and Sciences
eISSN: 2582-8266
Cross Ref DOI: 10.30574/wjaets
Journal homepage: https://wjaets.com/

(REVIEW ARTICLE)

Improvement in Safety and Productivity in Underground Mining Operations: A Review of the Role and Efficiency of Autonomous Mining Technologies

Gilbert Etiako Djanetey [1, *], George Kofi Amuah [2] and Joshua Whajah [3]

[1] *Department of Mining Engineering & Management, South Dakota School of Mines and Technology, U.S.A.*
[2] *John E. Simon School of Science and Business, Maryville University of St. Loius, U.S.A.*
[3] *Department of Mining Engineering & Management, South Dakota School of Mines & Technology, U. S. A.*

World Journal of Advanced Engineering Technology and Sciences, 2025, 16(03), 394-398

Publication history: Received on 05 August 2025; revised on 20 September 2025; accepted on 22 September 2025

Article DOI: https://doi.org/10.30574/wjaets.2025.16.3.1356

Abstract

Underground mining is a complex mining approach with less flexibility as compared to surface mining. It deals with challenges such as water control, ventilation, safety issues, cost of operations and others. Conventional underground mining exposes miners to hazards such as unstable rock structures, machinery-related accidents, and noxious gases. The advent of Artificial Intelligence (AI), machine learning, and process automation has the tendency to improve efficiency, reduce cost, ensure sustainability in mining operations. Over the years, mining companies have adopted various forms of technology in the form of robots, ventilation sensors, remote sensing, automated drills and haulage. There have been delays and setbacks in the adoption of such technological processes due to their cost implications and the fear of minimum return on investments, workers adapting to new trends and fear of job loss, the complexity of working underground, delays in operations that may arise during the period of integration which can affect productivity among others. This paper discusses the role of modern technology and processes, specifically autonomous mining technologies and their efficiency in improving safety and productivity in underground Mining operations. The paper focuses on reviewing current trends and case studies of adaptations of autonomous machinery and processes to evaluate the impact on mining operations in relation to safety and productivity. It also considers the limitations and challenges related to the process of automating underground mining and some of the social issues that may arise.

Keywords: Underground Mining; Automation; Efficiency; Productivity; Technology

1. Introduction

Underground mining is complex and exposes workers to risk. Workers are constantly under the threat of mechanical failure, accidents from falling rocks, and exposure to toxic gases (Adam & Kok, 2015). Miners are under constant pressure to maximize resources extraction ensuring productivity while minimizing risk and improving efficiency in operations (Long et al., 2024). The emergence of automation in mining is employed in areas such as haulage, ventilation, deformation monitoring and drilling (Shende, 2022). These systems have transformed mining operations by reducing human contact and enhancing safety. Although automation of mines is not entirely a new thing, recent advances have increased their scale and scope immensely (Rafezi & Hassani, 2023). Autonomous systems installed by mining operations reduce downtime, offer continuous operations, and operate with greater precision, all helping maximize productivity (Mora et al., 2023). Additionally, automation is revolutionizing underground mine safety by integrating data-driven predictive models and real-time hazard detection systems, enabling proactive risk mitigation, prompt prediction, and prevention of potential hazards (Gao & Fourney, 2021; Shende, 2022).

* Corresponding author: Gilbert Etiako Djanetey

Drilling and haulage are the major areas with vast automation today. Autonomous haulage enables ore and material transportation with unmanned exposure, which could reduce human operators' exposure to hazardous zones. These systems use GPS, remote devices, and LiDAR/Radar sensors to efficiently go through complex mining areas without incidence of collision. The other key technology includes the use of automated drilling rigs that independently carry out the drilling of precise holes for explosives placement, enhancing productivity and safety. Automated drills incorporated with real time monitoring systems help to easily monitor and identify defects by reducing breakdowns and improving machine efficiency (Rafezi & Hassani, 2023). The Hole Navigation Systems (HNS) technology facilities enable high-quality placement of holes, enhancing uniform fragmentation, ensuring effective blasting and safety (Epiroc, 2018). However, despite their value, significant barriers exist to the wide adoption of autonomous mining technologies, including infrastructure, technical expertise and high upfront cost.

This paper focuses on the role and efficiency of autonomous mining technologies in underground mining to improve safety and productivity. The review will also investigate the greater implications of automation on workforce dynamics, regulatory frameworks, and sustainable mining practices, providing insights into the future of underground mining.

2. Safety Improvement by Autonomous Technologies

Safety improvement is among the reasons for accepting adoption of autonomous technologies into underground mining (Djanetey & Yakin, 2025). Traditional mining activity places personnel in a high-risk environment where workers face risks from falling rocks, toxic gases and heavy machinery. Implementation of autonomous processes in mine operations shows lesser injury and fatality rate, with Randgold Resources having achieved a 29 percent quarter-on-quarter improvement in injury rates. Autonomous mining technologies aim to address hazards by reducing exposure to high-risk areas where humans will not work, thereby reducing the injury rate and fatalities.

2.1. Workplace Hazard Reduction

The most critical benefit of autonomous mining technologies would be reduced exposure to hazardous conditions. For instance, an autonomous hauling system permits the transportation of materials and ore without the intervention of a human driver. This would take workers out of high-traffic areas where accidents are more likely to happen. Autonpmous drilling and loading systems keep operators away from potential hazards, reducing the chances of injury from malfunctioning equipment and falling unstable rock formations. Collision avoidance systems incorporated in vehicles alert the driver of potential risks in a proactive and timely manner. The system also has the tendency to identify any object that could pose a hazardous risk in the drillers operating area, and it has the capability to be monitored remotely (Lund et al., 2024).

2.2. Improved Monitoring and Real-time Data

Another critical component with working autonomous mining systems is real-time monitoring technologies. With sensors and AI analytics, they continuously monitor the quality of air and gases, and the stability of structures in mines. Real-time gas detection sensors, for example, warn operators when methane concentration levels are higher than their safety limit, hence prompting immediate evacuation or the needed adjustment to ventilation (Chikande,2022). In 2021, Zitron Global, a leader in supply of underground ventilation systems, introduced an intelligent mine ventilation system for mining with the objective of improving the safety of mine and workers and reducing energy consumption by 40% thereby reducing operational cost.

3. Improvements in Efficiency in Underground Mining

Automation in underground mining has significantly enhanced operational efficiency by optimizing resource utilization, reducing downtime, and improving precision in various mining processes. Autonomous haulage and drilling systems streamline operations by minimizing human intervention, enabling continuous 24/7 operations, and reducing equipment idle time. One major efficiency improvement comes from automated haulage systems, which use GPS, LiDAR, and AI-powered route optimization to transport materials with minimal delays. These systems reduce fuel consumption and wear-and-tear on vehicles, ultimately lowering operational costs. Similarly, automated drilling rigs improve precision in blast hole placement, ensuring optimal fragmentation, reducing wastage, and enhancing ore recovery rates (Rafezi & Hassani, 2023).

Furthermore, predictive maintenance powered by IoT sensors allows real-time equipment monitoring, identifying potential failures before they occur. This reduces unexpected breakdowns, decreases maintenance downtime, and extends equipment lifespan, improving overall mine productivity. The integration of AI and machine learning in ventilation systems also optimizes air circulation, reducing energy costs while maintaining a safe working environment (Shende, 2022). With these advancements, underground mining operations are achieving higher efficiency levels, making automation a key driver of productivity and sustainability.

3.1. Reduction of Downtime and Maintenance Cost

Automated monitoring systems can predict and minimize equipment downtime in real time. Autonomous systems are equipped with advanced sensors and AI-driven analytics that track equipment health in real time, thus enabling predictive maintenance strategies. With the advent of autonomous systems, there is flexible and well-structured equipment maintenance,ensuring cost optimization. Consequently, mines with predictive maintenance systems record a reduction in unplanned downtime and have achieved a decrease in the costs associated with maintenance.

3.2. Labor Cost Savings and Workforce Efficiency

Autonomous systems reduce reliance on labor-intensive operations. Research suggests a very sharp increase in labor cost of about 80% in the United States while reliable automation and robotic systems keeps reducing in cost (Mori et al., 2018). The impact of mine automation would be seen more in the areas of drilling, blasting and haulage which accounts for about 70% of work force in a mine and with the upsurgence of such technologies labor and operation cost will be reduced drastically (Rogers et al.,2019). Autonomous haulage trucks at Rio Tinto mines operated 700hrs more hours than the conventional haul trucks in the mines and reduced load and hauls costs to about 15% (Long M. et al.,2024).

4. Case Studies of Productivity and Efficiency Gains

Case studies provide tangible proof of the productivity improvements related to automation. Automated ventilation systems installed in Boliden Mines in Sweden accounted for an annual energy saving of 50% compared to other systems reducing the operating cost of the mine to about 50% (Vella,2024). Additionally, autonomous drills have the tendency to detect changing rock conditions and can provide features such as drill planning and detecting voids ensuring much higher accuracy, and overall drill efficiency (Long M. et al., 2024). These examples illustrate how much autonomous technologies can help optimize key procedures in the mining industry. According to Leung et al., 2023, the operating cost of Rio Tinto reduced to 13% due to the adoption of autonomous haulage systems (AHS) in their operations. Barrick Gold Corporation operating in Elko, Nevada integrated Wi-Fi sensor in its mines and utilized other automations with the aim of reducing cost to an amount of $700 per ounce of Gold (Hogan, 2018). Additionally, Barrick also reported improvement in equipment life span for about 25% and 20% reduction in in the cost of maintenance by utilizing the use of AI predictive maintenance systems (Globe News Wire, 2024).

5. Limitations and Challenges of Implementing Autonomous Technologies

While autonomous mining technologies provide great advantages in terms of safety and productivity, their adoption has several technical, economic, and social challenges. Automation has been developed and used easily in surface mining due to the ease of access and installation of GPS and communication systems (Vella, 2024). Overcoming these challenges is thus central to realizing the full value of autonomous mining systems in industry.

5.1. Technical and Infrastructure Challenges

The key technical challenges to the wider adoption of autonomous mining technologies include robust infrastructure, such as high-speed data connectivity, real-time communication systems, and specialized maintenance support. Indeed, for their optimal performances, autonomous systems are dependent on continuous streams of data flowing from sensors, LiDAR, and so on. Poor communication in deep underground results from various levels of physical interference and requires expensive infrastructure such as fiber optic cables or 5G networks to get the job done. The issue of network reliability is crucial, and the loss of signal can halt mining operations and cause several other problems especially when the mine goes down to a depth of about 500 m and deeper (Molly, 2017). The issue of positioning of mine workers and localizing machines in underground mines is a major challenge due to the absence of satellite signals (Long M. et al., 2024). The introduction of Simulation localization and mapping (SLAM) which combines data from sensors for operations addresses the issue of localization underground. The limitation of SLAM is that it requires more powerful computer systems and does not perform well in dynamic environments (Long M. et al, 2024). Autonomous technology requires more technical expertise in computing, software and computer resources, which generally comes with limitations. Autonomous technologies are complex and require specialized maintenance. Unlike traditional machinery, automated systems require skilled technicians for operations and maintenance.

5.2. High Initial Cost and Economic Hindrances

The second critical challenge is the economic viability of autonomous mining technologies, especially for small and mid-sized firms in the mining business. The initial investment required for the deployment of these systems involves the upgrading of equipment and infrastructure improvement. Automated Haulage Trucks in underground mines, for example requires huge investment in infrastructure and this has made the technology slower to adopt (Long M. et al,2024). Apart from high capital costs, there are recurring expenses on technology upgrading, routine maintenance, and people training. These systems require periodic software upgrades to maintain compatibility with evolving innovations in AI and data processing.

5.3. Human and Social Factor

Automation reduces human labor in operational roles, raising concerns about job displacement. Workers may resist the transition to autonomous systems due to the risk of job loss even though autonomous technologies do not necessarily result in job displacement (Long M. et al.,2024). Workers will tend to have less experience with the new workflow which will also require companies to retrain workers (Gölbaşı & Dagdelen, 2017). This has proven to be costly and time-consuming. The probable loss of employment means that governments may lose some taxes and hence governments may seek to pose higher taxes and royalties (Gölbaşı & Dagdelen, 2017). The emergence of automation will call for safety regulations in mining to be reviewed so that the adoption of such technologies will not override the safety needs of workers and the environment. With the emergence of automation, Corporate social responsibilities of mining companies could take a shift, and economic activities could dwindle (Rogers et al.,2019).

6. Conclusion

Autonomous mining technologies have brought improvements in safety and productivity in underground mining operations. These systems include autonomous haulage vehicles, drilling rigs, and real-time monitoring and remotely controlled systems that have successfully reduced human exposure to hazardous environments and improved the operation's efficiency. However, the adoption of all these technologies comes with its own challenges. Major issues include initial investments, human and social factors, availability of proper infrastructure, and adaptation of the workforce. Moreover, job losses and issues related to adherence to regulatory requirements must be addressed. Artificial intelligence, machine learning and Internet of Things (IoT) have the tendency of shaping the future of mining to be safer, more efficient, and sustainable. The future of autonomous underground mining, however, depends on supportive regulatory environments and industry standards that ensure safety, data integrity, and the protection of the workforce.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

References

[1] Adam, S., & Kok, J. (2015). Application of continuous drilling technologies in coal mining. In *Proceedings of the 2015 Coal Operators' Conference on Faculty of Engineering and Information Sciences* (pp. 249–258). New South Wales, Australia.

[2] Chikande, T. (2022). *Application of fourth industrial revolution technologies to ventilation design and* environmental monitoring criteria for platinum mining in Zimbabwe (Doctoral dissertation). University of the Witwatersrand, Johannesburg.

[3] Deloitte. (2024). Technological advancement elevating health and safety in mining operations. https://www2.deloitte.com/content/dam/Deloitte/us/Documents/energy-resources/us-mining-and-metals.pdf

[4] Djanetey, G.E. and Yakin, Z., 2025. Ground control systems for deep underground mining: Advancing safety and resource recovery in high-stress mining environments. World Journal of Advanced Research and Reviews, 27(1), pp.2134–2142. doi:https://doi.org/10.30574/wjarr.2025.27.1.2751

[5] Epiroc. (2018). Hole Navigation System (HNS): A SmartROC option for safe, easy drilling and improved productivity. https://www.epiroc.com/content/dam/epiroc/surface-and-exploration/1-surface-drill-rigs/1-smartroc/options/hns/web_pdf_hns/9868001701%20HNS%20brochure%20Eng%20WEB.pdf

[6] Gölbaşı, O., & Dagdelen, K. (2017). Equipment replacement analysis of manual trucks with autonomous truck technology in open pit mines. In Proceedings of the 38th International Symposium on the Application of Computers and Operations Research (APCOM 2017) in the Mineral Industry.

[7] Globe News Wire. (2024). Mining automation market set to surpass USD 7.37 billion by 2032. https://www.globenewswire.com/fr/news-release/2024/08/13/2929372/0/en/Mining-Automation-Market-Set-to-Surpass-USD-7-37-Billion-By-2032-Astute-Analytica.html

[8] Hogan Lovells. (2018). The benefits and pitfalls of mining automation. https://www.mining.com/web/benefits-pitfalls-mining-automation/

[9] Leung, R., Hill, A. J., & Melkumyan, A. (2023). Automation and AI technology in surface mining with a brief introduction to open-pit operations in the Pilbara. arXiv Preprint, arXiv:2301.09771.

[10] Long, M., Schafrik, S., Kolapo, P., Agioutantis, Z., & Sottile, J. (2024). Equipment and operations automation in mining: A review. Machines, 12(10), 713. https://doi.org/10.3390/machines12100713

[11] Lund, E., Pekkari, A., Johansson, J., & Lööw, J. (2024). Mining 4.0 and its effects on work environment, competence, organisation, and society: A scoping review. Mineral Economics, 1–14. https://doi.org/10.1007/s13563-024-00379-1

[12] Martin, C. (2017). Kibali Africa's most mechanized gold mine Randgold.Mining Weekly. https://www.miningweekly.com/article/kibali-africas-most-mechanised-mine-randgold-2017-11-02

[13] Molly. (2017). The minerless mine: Ericsson's Kankberg project is a glimpse into the future ofautomation.https://www.globenewswire.com/fr/news-release/2024/08/13/2929372/0/en/Mining-Automation-Market-Set-to-Surpass-USD-7-37-Billion-By-2032-Astute-Analytica.html

[14] Mori, L., Saleh, T., Sellschop, R., & Van Hoey, M. (2018). Unlocking the digital opportunity inmetals.McKinsey&Company.https://www.mckinsey.com/~/media/McKinsey/Industries/Metals%20and%20Mining/Our%20Insights/Unlocking%20the%20digital%20opportunity%20in%20metals/Unlocking-the-digital-opportunity-in-metals_Jan-2018.pdf

[15] Rafezi, H., & Hassani, F. (2023). Drill bit wear monitoring and failure prediction for mining automation. International Journal of Mining Science and Technology, 33(3), 289–296. https://doi.org/10.1016/j.ijmst.2023.01.008

[16] Rio Tinto. (2018). Rio Tinto's autonomous haul trucks achieve one billion tonne milestone. https://www.riotinto.com/en/news/releases/2018/ahs-one-billion-tonne-milestone

[17] Rogers, W. P., Kahraman, M. M., Drews, F. A., Powell, K., Haight, J. M., Wang, Y., & Sobalkar, M. (2019). Automation in the mining industry: Review of technology, systems, human factors, and political risk. Mining, Metallurgy & Exploration, 36, 607–631. https://doi.org/10.1007/s42461-019-00107-0

[18] Shende, H. C. (2022). An improvement of powder factor by an electronic-based computational modeling system in underground coal mining. NeuroQuantology, 20(15), 3487–3496. https://www.neuroquantology.com/article.php?id=6675

[19] Valastro, M. (2023). Intelligent risk mitigation system for underground coal mine explosions (Honours thesis, University of Sydney). https://corehesion.com.au/wp-content/uploads/2024/03/Mval6291_Thesis.pdf

[20] Vella, H. (2024). Exploring the environmental benefits of autonomous underground mining equipment.https://www.mining-technology.com/features/environmental-benefits-of-autonomous-underground-mining-equipment/

[21] Zitron Global. (2021). Innovation towards autonomous mining. https://zitron.com/mining-automation-for-underground-ventilation-systems/