LUMEN ET VIRTUS
ISSN: 2177-2789

MECHANICAL ENGINEERING APPLIED TO MINING: INNOVATIONS IN EQUIPMENT AND PROCESSES

https://doi.org/10.56238/levv15n43-154

Submitted on: 11/20/2024 **Publication date:** 12/20/2024

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ABSTRACT

Mechanical engineering drives important advances in mining through innovative equipment design and optimized processes. The application of autonomous vehicles and digital systems has improved efficiency and safety in operations, allowing machines such as haul trucks and crushers to increase productivity and minimize human exposure to risk in environments that demand heavy ore transport and fragmenting. Predictive maintenance, using sensor-based monitoring and data analysis, assists engineers in anticipating failures, reducing downtime, and supporting informed decision making—crucial for strategic operation of complex machines like centrifugal pumps and vibrating screens. Material innovations, such as wear-resistant alloys used in grinding or classifying equipment, contribute to longer operational lifespans and reduce costs associated with part replacement. The use of remote operation centers and advanced control in processes such as comminution (crushing and grinding) and flotation helps engineers optimize energy use, material recovery, and reduce environmental impact. Additive manufacturing is emerging as a solution for faster local production of spare parts, decreasing the reliance on supply chains and ensuring faster equipment recovery. These innovations reflect the central role of mechanical engineering in shaping an efficient, sustainable, and safe future for mining operations—in an industry where maintenance and reliability strategies, continuous improvement, and multidisciplinary collaboration yield increasing operational benefits for mineral extraction and processing.

Keywords: Mechanical Engineering. Mining Innovation. Autonomous Equipment. Predictive Maintenance. Material Innovation. Digital Systems. Sustainable Mining.

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1 INTRODUCTION

Mechanical engineering has played a fundamental role in advancing mining technology, specifically through the innovation of equipment and processes essential for mineral extraction and processing. Recent years have witnessed a significant transformation, marked by the integration of automation and digitalization inspired by Industry 4.0 principles, which include real-time data, autonomous systems, and advanced material technologies (Dahl et al., 2020).

Innovations in mining equipment have included the development of autonomous vehicles and machinery capable of operating in hazardous environments with minimal human intervention. Autonomous haul trucks and drilling rigs, for example, have contributed to enhanced operational efficiency and safety (Ritz-Lindlgruber et al., 2018). Predictive maintenance, enabled by the use of Internet of Things (IoT) sensors, has become increasingly prevalent. This approach allows machines to report their status, anticipate failures, and reduce unplanned downtime, directly impacting productivity (García et al., 2021).

Material science has also impacted mining equipment, with the introduction of lighter and more wear-resistant alloys and composites. These materials help reduce equipment weight, extend operational lifespan, and decrease energy consumption. Advanced mineral processing technologies, such as high-pressure grinding rolls (HPGR) and improved flotation cells, have increased the efficiency and selectivity of mineral separation, minimizing waste and environmental impact (Gupta & Yan, 2016).

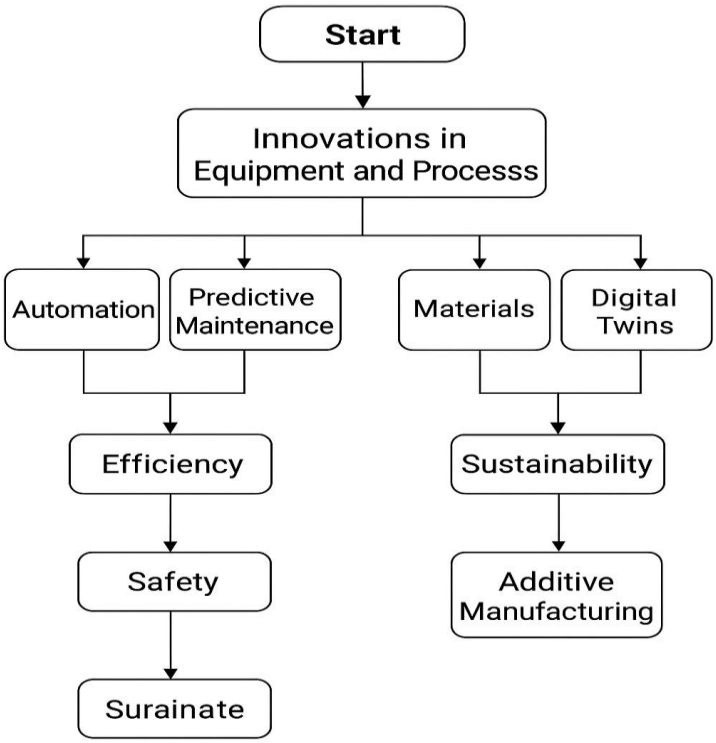
Digital twins, which are virtual models replicating physical equipment and systems, have enabled the simulation and optimization of mining operations. These models support engineers in decision-making, process improvements, and predictive analysis of equipment response under different conditions (Tao et al., 2018). Remote operation centers have further advanced mining management by allowing technicians to monitor and control machinery from safe, centralized locations, thereby increasing safety and reducing the need for onsite personnel in remote locations.

The flowchart titled *"Mechanical Engineering Applied to Mining: Innovations in Equipment and Processes"* illustrates the main technological innovations transforming modern mining operations. It begins with the central concept of mechanical engineering driving innovation in mining equipment and processes. From this foundation, key branches represent six major advancements: automation and autonomous systems, predictive maintenance, material innovation, digital twins, remote operation centers, and additive manufacturing. Each of these innovations contributes to specific operational outcomes—enhanced efficiency through automation and predictive maintenance, improved safety via

remote and autonomous systems, and greater sustainability achieved through advanced materials, digital simulation, and localized 3D printing of spare parts. Together, these technologies demonstrate how mechanical engineering fosters a safer, more efficient, and sustainable future for the mining industry.

Figure 1

Mechanical Engineering Applied to Mining: Innovations in Equipment and Processes



Source: Created by author.

Additive manufacturing, commonly known as 3D printing, is making strides in the mining sector by enabling on-demand production of spare parts and components directly at the mine site. This innovation streamlines logistics, reduces dependency on complex supply chains, and shortens equipment downtime during maintenance events (Cunico & Seabra, 2021).

Overcoming the challenges of adopting these technologies requires ongoing investment in research, training, and collaborative efforts between industry and academia. While initial costs and organizational adaptation can be substantial, the long-term benefits in efficiency, sustainability, and safety underscore the critical role of mechanical engineering in shaping the mining industry's future (Cunico & Seabra, 2021; Dahl et al., 2020; Tao et al., 2018).

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