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PRODUCTIVITY IMPROVEMENT IN COAL MINING: A REVIEW

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ABSTRACT
Design / Methodology / Approach:
This comprehensive literature review employed a systematic approach to identify the primary factors that influence productivity in open-pit mining. The study involved an extensive analysis of existing research, industry reports, and case studies related to operational issues, environmental and geological factors, resources and infrastructure, technology, human resources, and governmental and other regulatory issues.
Results:
The study identified six key areas crucial for productivity enhancement in open-pit mining: operational issues, environmental and geological factors, resources and infrastructure, technology, human resources, and governmental and regulatory issues.
Practical Implications:
The findings of this study offer valuable insights for mining companies seeking to enhance productivity in open-pit mining operations. By focusing on the identified key areas, companies can develop targeted strategies to improve efficiency and reduce costs.
Originality / Value:
This research contributes significantly to the literature on productivity in open-pit mining by providing a comprehensive analysis of the factors influencing operational efficiency. The study's systematic approach and broad scope offer a detailed understanding of the interplay between various elements affecting productivity.

Keywords:
Coal Mining, Productivity, Indian Mines

I. Introduction

Minerals are invaluable finite and non-renewable natural resources, essential for the development and economic growth of numerous industries. They significantly influence our society both directly and indirectly. Everyday items ranging from morning essentials like toothpaste and makeup to office technologies such as computers and phones, as well as everyday necessities like television, eyeglasses, medications, and vitamins, all derive from minerals and metals. The mining sector plays a crucial role in the global economy and is fundamental to the initiation of the resource supply chain. Nonetheless, the extent of mining's contribution varies significantly across national economies.

In 2022, the global value of mineral production was almost four times greater than in 2020, largely propelled by rapid growth in emerging economies like China and India, and a significant increase in commodity prices (International Council on Mining & Metals, 2022). In the same year, the top 20 mineral-producing countries had a combined production value of US$ 817,569 million (World Bank, 2022). In terms of GDP contributions in 2022, the mining sector accounted for 1.5% in India, 0.6% in the USA, 0.8% in Canada, 9.8% in Australia, and 4.5% in South Africa (World Bank, 2022).

Author Contributions
Conceptualisation – AA & TKB; Methodology – TKB; Validation- TKB; Formal Analysis- TKB & AA; Investigation- AA & TKB; Resources- AA & TKB; Writing- Original Draft- AA; Writing – Review & Editing- TKB; Supervision- TKB; Project Administration- AA & TKB; Funding Acquisition- None.

Additionally, the mining industry is a significant source of foreign exchange earnings for countries that export minerals.

Mining fosters an economic ecosystem that includes capital markets, equipment manufacturers, labor, goods and services suppliers, financiers, and more. Although direct mine employment typically constitutes only 2%–3% of a nation's total workforce (International Council on Mining & Metals, UK), its economic impact is significant. The industry encounters various challenges including economic fluctuations, technological advancements, societal changes, and environmental concerns, which collectively influence productivity and sustainability (Bearman, 2013; Prior et al., 2012). Despite the protection from prolonged high commodity prices in past years, mining companies are not immune to financial pressures. Recent declines in commodity prices have squeezed margins, necessitating a renewed focus on cost rationalization (Chris Thomas, Partner, Energy & Resources, UK; Deloitte, 2021). This economic pressure demands continuous cost management to prevent impacts on profits, shareholder returns, and capital investments (Deloitte, 2016).

Mitchell and Steen (2014) argue that to recover from losses incurred during the high commodity price period and to regain competitiveness, the mining sector must enhance productivity and adapt to increasing real wage costs. Mining, by its nature, deals with the extraction of finite natural resources, and the process of open-pit mining shares similarities with supply chain operations. Each step in an open-pit mine involves various inputs and processes that lead to the next activity, requiring careful management of manpower, costs, equipment, and time to efficiently operate.

This comprehensive literature review investigated the main factors that are responsible for productivity improvement in open-pit mines. The significant findings identified six key areas: operational issues, environmental and geological factors, resources and infrastructure, technology, human resources, and governmental and other issues.

2. Rationale

This review is a broad spectrum of sources, including research papers, conference proceedings, technical reports, and articles across various disciplines such as economics, psychology, engineering, and human resources. These sources collectively explore factors influencing productivity and efficiency in surface mining operations worldwide. The key factors identified are categorized into several areas:

- Operational challenges
- Environmental and geological concerns
- Resource and infrastructure considerations
- Technological advancements
- Human Resource Issues
- Government and Other Issues

3. Operational Challenges

Mining companies globally are adapting their operations to be more dynamic, efficient, and adaptable to the changing demands of the industry. Despite the complexities, these companies strive to enhance productivity by minimizing waste and increasing operational flexibility. Researchers like Liu and Kozan (2012) studied operational difficulties in Australian iron ore sites, highlighting issues in mining design and production logistics that affect output. They proposed a network flow graph to optimize mining sequences, enhancing system integration and optimizing key operational factors, thereby potentially reducing equipment costs and enhancing production efficiency. Parreira and Meech (2000) examined data from BHP-Billiton's Nickel West Division to explore autonomous haulage systems' impacts on production.

Using simulation software, they identified improvements in various performance indicators, leading to reduced operational costs. In a study by Ramulu et al. (2012) at a Coal India Limited site, the team explored blasting optimization across different rock types to improve operations significantly. Their findings demonstrated enhanced rock fragmentation and reduced vibrations, improving the overall drilling and blasting processes. Sundar and Acharya (1995) focused on improving blasting techniques and resource allocation at an iron ore mine operated by Steel Authority of India Limited. Their approach used integrated software models to optimize resource use, enhancing ore production and waste management. Research in the copper and gold mining sectors by Groeneveld and Topal (2011) revealed that equipment reliability and economic uncertainties critically impact mining operations, highlighting the need for flexible design strategies to cope with these challenges. This wide-ranging review underscores the multifaceted issues impacting production in the mining industry, illustrating the global efforts to address these challenges through innovative strategies and technologies.

4. Environmental and geological concerns

Initiating a new mining project or expanding an existing one involves substantial financial investment. The costs incurred are influenced by a series of interconnected geological and technical considerations specific to mining procedures. Misguided or poorly calculated strategies can lead to increased consumption of materials and labor, thereby escalating overall expenses. This impacts various operational aspects such as transportation, ventilation, and production processes.

Complex decisions in mining operations can have profound implications, necessitating an approach grounded in thorough experimental geological research and adherence to regulations set by authoritative bodies. In a study by Bradley and Sharpe (2009), an examination was conducted on the productivity within the Canadian mining sector using data from the Centre for the Study of Living Standards. The analysis, which employed Tang and Wang's (2004) methodology, compared the periods 1989–2000 and 2000–2009, highlighting factors such as resource quality decline and stringent environmental regulations that influence productivity.

Carrasco et al. (2016) noted that discarding low-value minerals early in the production process can alleviate many operational constraints, thereby enhancing flexibility. This is achieved through early evaluation of metal concentrations, which reduces reliance on significant capital investments and boosts metal output efficiency due to better feed grades and lower energy consumption per unit of metal produced.

Groeneveld and Topal (2011) identified factors such as the variability in mineral grade, ground conditions, and ore recovery as key uncertainties in open-pit mining that can impact operational efficiency. Okely (2009) discussed the necessity for periodic assessment of ore quality to optimize the mining extraction plans based on the stratigraphy of deposits.

Brodzikowski and van Loon (1990) highlighted unpredictable conditions like slope stability and substrate inhomogeneity as potential causes for equipment malfunctions and operational disruptions. Their research advocated for paleogeographic reconstructions and detailed geological surveys to inform structural planning, enhancing safety and cost-effectiveness in mining operations. Topp et al. (2008) identified environmental and geological factors such as deposit depletion and adverse weather conditions as contributors to reduced productivity.

Kumar and Huang (1993) conducted a detailed study at the Kiruna Iron Ore Mine in Sweden, renowned for its implementation of advanced mining technologies and reliability techniques. Using the SIMURES simulation program over a span of 100 days, they analyzed critical operational factors, finding that system availability was at 76%, with geo-mechanical stability and borehole integrity at high percentages. They suggested using such simulations to anticipate ore shortages and efficiently plan mine production.

5. Resources and Infrastructure issues

Managing business organizations presents a significant challenge that has intensified since the advent of scientific management. The industrial revolution ushered in an era of mechanization, phasing out older labor practices and transforming the core structure of organizations, including those in the mining industry. As the demand for minerals grew, the importance of efficiently utilizing resources such as

materials, manpower, machinery, money, and time became paramount. Organizations that fail to effectively coordinate these elements, often referred to as the five M's, risk inefficiency and failure.
In a study focusing on the British coal sector, Leedal (2006) examined the challenges posed by uncertainty and information scarcity, which hinder effective forward planning and development control. His research involved interviews with officials from government-recognized mineral organizations, highlighting how the planning system's limitations, particularly in addressing public concerns and resolving conflicts at early stages, can lead to resource depletion and suboptimal consensus at the development control phase.
Rennel and Beck (2007) pointed out that despite its relatively low-tech nature, the mining industry has seen productivity gains through the deployment of larger equipment. Similarly, Dindarloo et al. (2016) compared the performance of two types of shovels over a year at the same mine. Their analysis showed that electric rope shovels had better availability and higher effectiveness compared to hydraulic shovels, suggesting a potential for productivity improvement through the selection of appropriate machinery.
Galiyev et al. (2000) explored the productivity potential of a transportation system at an opencast mine in Kazakhstan using simulation logic-statistical modeling. Their findings demonstrated a notable improvement in rock and ore transportation, as well as a decrease in expenditure per cubic meter of rock mass, thanks to the adoption of the most rational options identified by the simulation.
Research by Akcakoca et al. (2008) identified low labor productivity as a crucial factor diminishing profit margins in mining, while Topp et al. (2008) analyzed the broader influences on multifactor productivity, including resource inputs and infrastructure constraints. Kumar and Huang (1993) studied system availability and identified critical factors necessary to achieve optimal operational efficiency.
Cooper (2012) highlighted a skills shortage in the Australian mining industry, exacerbated by the remote locations of mines and less attractive job conditions in previous decades. He suggested that leveraging remote monitoring technologies and employing CCTV networks for maintenance could significantly reduce onsite expert requirements, cut costs, and address skill shortages, allowing for more competitive operations in the global minerals market.

6. Technology Issues
Technology plays a pivotal role in the entire lifecycle of mining operations, including exploration, production, mine closure, and land reclamation. Its application significantly boosts mining productivity through innovation, enabling cost savings and enhanced safety. Technologies are often used to reevaluate and potentially reactivate mines that were once considered nonviable.
In the 1980s, US copper mines experienced a remarkable turnaround after struggling in the previous decade, as discussed by Tilton and Landsberg (1997). This resurgence was primarily attributed to significant improvements in labor productivity, driven by the adoption of new technologies and innovative practices. Similarly, Okely (2009) highlights that implementing cutting-edge technology significantly enhances mining productivity.
Research by Shebeb (2002) on Australian gold mines from 1969 to 1995 demonstrates the dramatic impact of technological advancements on productivity, with gold output increasing from 17 tons in 1980 to 255 tons in 1995. Topp et al. (2008) noted that technological changes played a crucial role in boosting multifactor productivity, whereas Akcakoca et al. (2008) observed that lower technology levels negatively impacted productivity and profitability. Kandoi (2013) emphasizes the necessity of adopting advanced technology and efficient operational practices in mining, especially as easily accessible mineral reserves are depleted and remaining deposits are often of lower quality and harder to access.
Bradley and Sharpe (2009) identified technological innovation as a key factor in mining productivity.
De Jagar et al. (2004) studied Kumba Resources in South Africa, noting its use of the Total Operations Performance (TOP) framework to cut costs through reengineering and continuous improvement programs, which improved costs by 3% annually. They introduced the Four Bubbles Notion to stabilize

the work environment and foster supportive behaviors, which they termed the CI maturity model for enhancing continuous improvement capabilities.
Dzakpata et al. (2016) compared the efficiency of traditional truck-shovel operations to conveyor systems in Australian mines, finding that conveyor systems can increase shovel operation productivity by 20%-25% and enhance operational time efficiency by 25%.
A 2015 study by Deloitte and PDCA involving 19 mining companies used an innovation scorecard survey to assess innovation efforts. The study revealed that 70% of innovation investments were in core innovations, 20% in adjacent innovations, and 10% in transformational innovations.
Brown et al. (2000) researched the disadvantages of direct current (DC) machinery compared to alternating current (AC) machinery in mining. Their study advocated for replacing DC machinery with AC counterparts in mining equipment such as shovels, draglines, and haul trucks to boost productivity, highlighting AC machinery's higher production rates, reliability, lower maintenance costs, and improved compatibility with power grids. The transition to AC drives led to a 20% increase in shovel production and a 50% increase in hauler capacity.

7. Human Resource Issues

The involvement of human resources in the mining industry raises significant concerns, and it is an issue that cannot be fully eliminated. Given the complexities of the mining environment, managing human resources is particularly challenging. Key challenges include providing basic amenities, designing shift work, managing safety practices, achieving a work-life balance, and dealing with social and political issues, among others. To effectively handle these challenges, mining companies need to adopt a proactive and positive approach toward these 'people factors.'
Research conducted by Lawrence (1974) on the South African mining industry identified specific human factors that impact productivity. He defined these factors under the acronym CORE: Competence, Opportunity, Recognition, and Expectations/Enrichment. His research summarized various studies indicating a causal relationship between work attitudes, performance, and productivity. Lawrence analyzed several human behavior models, such as the satisfaction-performance model and the performance-rewards cycle model, to conclude that addressing CORE factors positively influences productivity in mining.
Goodman and Leyden (1991) analyzed data from the Carnegie Mellon Coal Research Project in the USA, studying the impact of worker familiarity on productivity. They examined environments in two different mines and found that changes in staffing due to absenteeism disrupted the familiarity levels within teams, affecting productivity. Their findings suggested that an increase in familiarity could lead to an 11% rise in production levels.
Byrnes et al. (1998) explored productivity differences between unionized and non-unionized opencast coal mines in the USA using non-parametric tests and econometric approaches. Their research from 1975 to 1978, with a sample size of 113, showed that unionized mines typically had higher productivity, reinforcing the positive impact of unions on productivity.
In later studies, various researchers identified different factors influencing productivity. Kumar and Huang (1993) focused on operator availability, linking it to system availability. Akcakoca et al. (2006) identified labor responsibility as crucial for productivity at the Garp Lignite Enterprise in Turkey. Topp et al. (2008) and further studies by Akcakoca (2008), Okely (2009), and Bradley and Sharpe (2009) pinpointed training, work practices, labor relations, and capital intensity as key factors affecting productivity in mining.
Research by Takahashi (2011) in the Australian coal mining industry found that eliminating task demarcations between production and maintenance could enhance productivity through multitasking, a principle that didn't apply similarly within production groups alone. Study by GlobalData (2012) on the South African mining industry involved collecting both primary and secondary data to assess various metals. The study highlighted significant financial losses due to labor unrest in specific sectors, quantifying the substantial impact of human resource challenges in the mining industry.

8. Government and Other Issues

Mining companies face constant challenges to operate safely, productively, efficiently, and profitably, especially as high-grade ore deposits become depleted. This leaves them with options like exploiting lower-grade ores or venturing into remote locations. Additionally, legislative bodies continue to introduce numerous regulations that complicate operations while prioritizing human safety.

The global mining sector encounters growing socio-economic and political pressures that necessitate incorporating more intricate considerations into strategic planning. The industry must navigate issues like persistent cost inflation, unpredictable commodity prices, stringent regulations, and increasing labor shortages. This complex environment has led some analysts to foresee a "perfect storm" of converging forces impacting the sector, urging a reassessment of regulatory compliance strategies.

Research by Bradley and Sharpe (2009) on the Canadian mining industry focused on productivity performance, identifying factors such as decreasing capital intensity, taxation, and high energy prices, alongside elevated spending on environmental regulation and protection.

Similarly, Groeneveld and Topal (2011) examined uncertainties in Australian copper and gold mines, identifying market price fluctuations and legislative changes affecting rigid mine designs as key uncertainties influencing business outcomes. Akcakoca et al. (2006) also highlighted how legislation impacts labor productivity in Turkey's Garp Lignite Enterprise, noting that legislative and administrative controls on man-hours were significant contributors to reduced productivity, along with the overemployment of manpower.

Okely (2009) explored various factors affecting mining productivity, including changes in the costs of procurement and emergency situations. He advocated for better control and analysis of the mining supply chain, reducing unnecessary expenditures, leveraging expertise, and consulting reliable sources during crises. Further research by Akcakoca et al. (2008) indicated that high operating costs and low sales revenue were among several factors diminishing productivity and profitability. Topp et al. (2008) in their work for the Australian Government, pointed out that the nature of mining capital significantly influences multi-factor productivity.

9. Literature Gap and Future Research Work

The literature review on surface mining operations worldwide offers a comprehensive understanding of the various factors influencing productivity and efficiency but shows notable gaps when it comes to the specific context of Indian coal mines. Key areas lacking detailed examination include the environmental and geological impacts within India's unique geological settings, where more localized studies could provide crucial insights for more sustainable mining practices. Additionally, there is a shortage of analysis on how modern technological advancements fare within the particular conditions of Indian coal mines, such as the effectiveness of autonomous haulage systems and advanced blasting techniques, which must be evaluated against local operational conditions, workforce competencies, and infrastructure readiness. Furthermore, while general human resource issues in mining are addressed, there is a clear need for more focused research on the specific workforce challenges in the Indian coal mining sector, including labor relations, training adequacy, worker safety, and community engagement, all vital for enhancing productivity and operational efficiency.

Declaration of Interests

The authors have no competing interests to declare.

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