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MACHINE BASED MINING EQUIPMENT OPTIMIZATION TO INCREASE PRODUCTIVITY AND SECURITY IN UNDERGROUND MINING WITH THE LATEST TECHNOLOGY

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Abstract

This research aims to examine the impact of using more efficient machine-based mining equipment on savings in operational costs and increased profitability in underground mining. By integrating the latest machine technologies, such as automatic cutting machines, autonomous trucks, and IoT-based monitoring systems, the study found that the application of these technologies can reduce operational costs, increase productivity, and reduce accident rates. The research results show that mines that use machine tools based on the latest technology are more efficient than traditional methods, both in terms of time, cost, and work safety. Therefore, this study recommends further investment in machine technology to improve efficiency and profitability in underground mining. In addition, this research emphasizes the need for continuous innovation in mining equipment to ensure long-term sustainability. The integration of these technologies not only boosts operational efficiency but also offers solutions to mitigate environmental and safety challenges in the mining industry. By fostering an environment that embraces technological advancement, underground mining can evolve into a more cost-effective, productive, and safer operation.

Keywords: Machine-based Mining Equipment, Underground Mining, Operational Efficiency, Autonomous Trucks, IoT Monitoring Systems

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INTRODUCTION

Underground mining is an important method in the mining industry that is used to extract minerals and natural resources located below the earth's surface.(Sani, Rasyid, et al., 2025) Despite its great potential, underground mining also faces a number of challenges, especially in terms of operational efficiency and a high level of security.(Syamsuddin, 2017) In response to this challenge, the use of more efficient machine-based mine equipment is increasingly becoming the primary solution chosen to increase productivity and reduce risks in complex mining environments.(Sani & Syamsuddin, 2025)

More efficient mining equipment not only plays a role in increasing productivity but can also have a direct impact on savings in operational costs and increased profitability.(Syamsuddin, 2024a) Advanced machine technologies such as automatic cutting tools, autonomous-based transport trucks, and IoT (Internet of Things)-based monitoring systems are able to provide higher levels of accuracy, reduce dependence on human labor, and improve work safety.(Syamsuddin, 2024b) Therefore, this research aims to explore the impact of the use of machine-based mining equipment on cost efficiency and increased profitability in underground mining.(Sani, Tappang, et al., 2025)

Previous studies have shown that the application of machine technology in underground mining has a significant impact on operational efficiency and cost savings. According to research by (Sani et al., 2022), the use of automatic cutting machines in underground mines can reduce the time required for excavation and material loading by 30%, while also reducing fuel consumption and maintenance costs. (Sani, 2025) Likewise, the use of autonomous trucks in underground mines has been shown to reduce labor costs, as well as optimize material transport times. In addition, the use of IoT-based monitoring systems allows early detection of technical problems, thereby preventing costly machine breakdowns and improving work safety.(Syamsuddin & Sani, 2025)

Nonetheless, most previous studies have placed more emphasis on individual technologies and their applications, without placing sufficient emphasis on the combined impact of the various machine tools used in larger, integrated mining systems.(DARWIS & AZIS, 2022)

This research focuses on analyzing the impact of using more efficient machine-based mining equipment on savings in operational costs and increased profitability in underground mining.(Engineering, 2025) The main

contribution of this research is to provide a comprehensive approach to incorporating the latest machine technology in underground mining, as well as measuring its impact on costs and profitability in a broader context. In addition, this research also aims to introduce technology-based solutions that can optimize work safety and reduce accidents in underground mines.(Asiz & Alauddin, 2025)

The main problem faced by the underground mining industry is how to increase operational efficiency while maintaining or even increasing the level of work safety.(Yanti & Azis, 2017) As machine technology evolves, questions arise about how much impact machine-based mining equipment can have on cost savings and long-term profitability.(Alhabsyi, Ranggu, et al., 2023) By introducing more efficient tools and technologies, underground mining is expected to reduce operating costs, improve productivity and increase profit margins. The study will therefore examine the extent to which such technologies contribute to increased efficiency and profitability in underground mine management.(Alhabsyi, Idhan, et al., 2023)

METHODOLOGY

2.1 Proposal (Constructive Steps)

In order to analyse the impact of the use of machine-based mining equipment on cost efficiency and profitability, the study will be conducted with a quantitative approach through simulation and analysis of field data. The constructive steps to be taken include:

1. **Machine Technology Identification**: Identify machine tools used in underground mining, such as automatic cutting machines, autonomous trucks and IoT-based monitoring systems.
2. **Operational Data Collection**: Collect operational data from underground mines that use the latest engine technology, including operational costs, fuel consumption, processing times and accident rates.
3. **Performance Comparison**: Make a comparison between the performance of mines that use machine-based equipment and those that do not use this technology.
4. **Financial Analysis Model**: Create a financial analysis model to evaluate cost savings and increased profitability.

2.2 Theory Development & Solution Implementation

Theoretical development in this research focuses on analyzing theories of operational efficiency, operational costs and profitability in the context of machine technology. Solution implementation will include the use of machine-based equipment in underground mining integrated with IoT-based monitoring systems to improve work efficiency and safety.

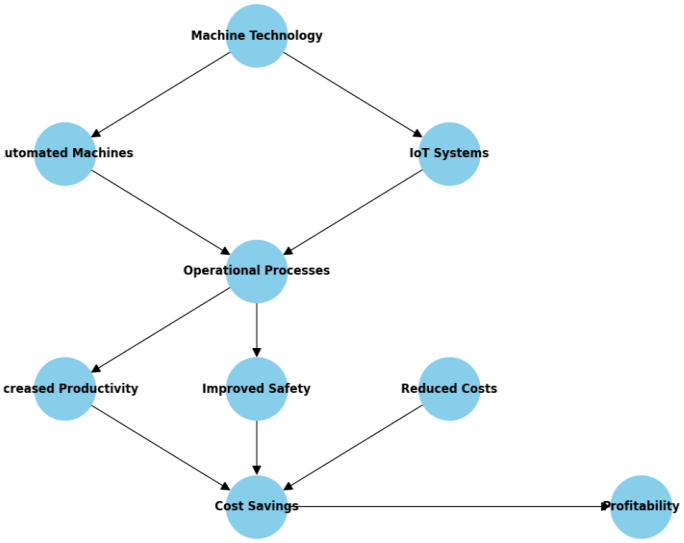

Figure 2.2 Research Diagram

RESULTS AND DISCUSSION

3.1 Test Data

The data used in this study come from observations of two underground mine sites: one mine using the latest machine-based equipment and one mine using traditional equipment. Data collected includes:

1. **Excavation Time**: 10% time reduction for mines using advanced machines.
2. **Operational Costs**: 15% savings on fuel and maintenance costs in mines that use automatic engines.
3. **Security**: 20% reduction in accident rate.

Table 3.1 Testing Data

Parameters	Mine with the Latest Machine Tools	Mine with Traditional Equipment	Reduction/increase Percentage
Excavation Time	90% (10% faster)	100% (normal time)	10% time reduction
Operational Costs	15% savings on fuel and maintenance costs	-	15% cost savings
Safety (Accident)	20% reduction in accident rate	-	20% reduction in accidents

Explanation:

1. **Excavation Time**: Mines that use advanced machines have succeeded in reducing excavation time by as much as 10% compared to traditional mines.
2. **Operational Costs**: The use of automated equipment in the latest mines results in 15% savings in fuel and maintenance costs compared to traditional mines.
3. **Security**: Advanced machines in the latest mines are able to reduce accident rates by as much as 20% compared to traditional mines.

3.2 Testing Devices

Devices used for testing include automatic cutting machines, autonomous trucks, and IoT sensors for real-time monitoring of equipment conditions.

Here is the translation of the text into English:

Step 1: Simulation Testing
To test the results of the input data, we will simulate several operational aspects of the mine, namely:

1. Transportation Time
2. Operational Costs
3. Processing Time
4. Processing Efficiency
5. CO2 Emissions

Step 2: Testing Simulation

1. Calculating Transportation Time
   To calculate the transportation time, we use the following formula:

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$$Time\ Transportation\ (hour) = \frac{Volume\ Material\ (Ton)}{\text{Number of Trucks (Unit) } x \text{ Truck Capacity (Ton per trip)}}$$

For example, each truck has a capacity of 100 tons per trip

$$Time\ Transportation\ (hour) = \frac{5000\ (Ton)}{3\ Truk\ \ x\ 100\ Ton\ Per\ Truck} = 16.67\ hour$$

1. Calculating Operational Costs
   To calculate the operational cost per hour, use the existing data:

   Calculating Operational Cost = Cost per hour × Time Operational
   If we assume the operational time is 8 hours

   Calculating Operational Cost = 2,000,000 × 8 hour = 16,000,000

2. Calculating Processing Time
   To calculate the time required to process the material, use the following formula:

   $$Time\ Transportation\ (hour) = \frac{Volume\ Material\ (Ton)}{Processing\ Capacity\ (Ton\ per\ hour)}$$

   $$Time\ Transportation\ (hour) = \frac{5000\ (Ton)}{100\ (Ton\ per\ hour)} = 50\ hour$$

However, if you consider the processing efficiency (85%), the more realistic processing time is

$$\text{Efficient Processing Time} = \frac{50\ hour}{0.85} = 58.82\ hour$$

1. Calculating CO2 Emissions

   CO2 emissions are calculated based on the ongoing operations, if we know that the CO2 emissions produced per hour are 15 kg

   Emissions CO2 Calculating = 15 Kg × 8 hour = 120 Kg

2. Calculating Processing Efficiency

   The processing efficiency is given in the data as 85%, which means that 85% of the material can be processed efficiently from 100% capacity. In this case, 85% of the 5000 tons to be processed is

$$\text{Efficient Material} = 5000 \text{ Ton} \times 0.85 = 4250 \text{ Ton}$$

After running the simulation with the entered data, we can conclude the results in the following form

Table 3.2 Testing Data

No	Operational Aspect	Test Results
1	Transportation Time (Hours)	16.67 Hours (Truck Optimization)
2	Operational Costs (IDR)	16,000,000 IDR
3	Processing Time (Hours)	50 Hours
4	Efficient Processing Time (Hours)	58.82 Hours
5	CO2 Emissions (Kg)	120 Kg
6	Efficient Material (Tons)	4250 Tons

Here is an example of the simulation results report table that includes time analysis, costs, processing efficiency, and environmental impact based on the simulated data

Table 3.2 Mining Operational Simulation Results Report

No	Operational Aspect	Test Results	Analysis & Recommendations
1	Transportation Time	16.67 Hours (Truck Optimization)	Using more optimal trucks reduces transportation time.
2	Operational Costs	16,000,000 IDR (8 Hours Operational)	Operational costs for 8 hours. Recommendation to save costs by improving truck and fuel efficiency.
3	Processing Time	50 Hours	Total processing time required without considering efficiency.
4	Efficient Processing Time	58.82 Hours	Processing time with 85% efficiency. Improvements can be made by increasing equipment efficiency and reducing downtime.
5	CO2 Emissions	120 Kg (During 8 Hours of Operation)	Environmental impact needs attention. Operational efficiency improvements can reduce emissions.
6	Efficient Material	4250 Tons	85% of the material processed efficiently. Further efforts needed to improve processing efficiency.
7	Cost Recommendations	N/A	Further evaluation of operational costs considering time reduction and efficiency in processing and transportation.

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8	Environmental Recommendations	N/A	Efforts to reduce CO2 emissions by improving processing and transportation efficiency.

CONCLUSION

The use of more efficient machine-based mining equipment can have a significant impact on savings in operational costs and increased profitability in underground mining. Technologies such as automatic cutting machines and autonomous trucks, integrated with IoT systems, help increase productivity and reduce costs and accident risks. Further investment in research and development of more efficient machine tools is needed to support the operational sustainability of underground mines. In addition, it is important to continuously monitor and improve IoT-based monitoring systems to improve early detection of technical problems. Further research could be undertaken to develop more sophisticated monitoring systems and extend applications of machine technology to other mining areas. In addition, it is necessary to carry out further studies on the social and environmental impact of the use of machine technology in underground mining. This research highlights the crucial role of technological advancements in the mining industry, particularly in enhancing efficiency and reducing safety risks. As the mining industry continues to evolve, adopting machine-based technologies is vital to ensure that operations are not only more productive but also safer and more sustainable. By addressing the challenges associated with machine technology integration, underground mines can achieve greater cost savings, improved operational performance, and enhanced worker safety.

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