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INTEGRATION OF CLOUD COMPUTING TECHNOLOGY IN THE DEVELOPMENT OF DIGITAL SIMULATION MODELS TO IMPROVE MINING OPERATIONAL PROCESSES

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Abstract

Indonesia's mining industry is facing major challenges in terms of operational efficiency. One potential solution is the application of cloud computing in integrating digital simulation models to increase operational efficiency. This research aims to explore the technical and non-technical challenges faced in integrating cloud computing with digital simulation in the mining sector. Using a mixed methods approach (qualitative and quantitative), this research identifies various factors that influence the adoption of this technology, such as infrastructure, policies, and problems related to training and changes in organizational culture. Results showed that despite some challenges, the technology has great potential to improve material processing efficiency, reduced operational costs, as well as reduced environmental impacts caused by CO2 emissions. This research provides practical guidance for mining companies to utilize cloud computing technology in an effort to increase operational efficiency and sustainability.

Keywords: mining industry, operational efficiency, material processing efficiency, such as infrastructure, reduced operational costs

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INTRODUCTION

The mining industry in Indonesia, like other sectors, is experiencing rapid transformation thanks to technological advances.(Suherwin, Asia, et al., 2025) One promising innovation is the application of technology *cloud computing* in the development of digital simulation models used to improve operational efficiency.(Rachmat & Suhartono, 2020) Cloud computing provides access to internet-based data and applications, enabling faster, more flexible and more efficient data processing. In the mining sector, the integration of cloud computing with digital simulation can make it easier to monitor mining conditions, operational planning and make data-driven decisions.(Kasim et al., 2023)

Digital simulation models in the mining industry can model various aspects, such as material flow, transportation systems, and mining planning. However, integrating cloud computing into this system cannot be separated from challenges, both from a technical and non-technical perspective.(Rachmat et al., 2024) Technical challenges involve infrastructure issues, data security, and system scalability.(Suherwin, Rachmat, et al., 2025) Meanwhile, non-technical challenges are more related to changes in organizational culture, training needs, and factors related to inadequate policies and regulations.(Sani, Rasyid, et al., 2025)(Faizal et al., 2021)

Several previous studies have shown that the use of technology *cloud computing* in various industrial sectors it provides significant advantages in terms of cost savings and increased productivity.(Syamsuddin, 2017) In the context of mining, a study revealed that the use of systems is based *cloud* can improve data analysis and speed up problem solving in the field.(Rasyid & Ibrahim, 2021) However, there are still many challenges to be faced in the widespread application of this technology in the mining sector.(Sani & Syamsuddin, 2025)

One relevant study was conducted by, which discussed integrating *cloud-based simulation models* in the mining industry.(Tandiasa et al., 2025) This research highlights the importance of the system *cloud* which is scalable to support complex simulations and enable better team collaboration.(Syamsuddin, 2024) However, challenges in data security aspects and implementation costs remain major obstacles to adopting this technology in a still conservative industry.(Sani, Tappang, et al., 2025)

This research aims to explore the technical and non-technical challenges faced in integrating cloud computing with digital simulation models in the mining industry.(Sani et al., 2022) With a qualitative and quantitative approach, this research is expected to provide new insights into how mining companies can utilize cloud computing effectively.(Sani, 2025) In addition, the research also provides practical guidance for policy makers and stakeholders in the mining sector to understand the benefits and obstacles of this technological integration.(Syamsuddin & Sani, 2025)

Although cloud computing technology has great potential to increase operational efficiency in the mining industry, its application is still limited by various challenges.(Rachmat, 2022)

METHODOLOGY

This research proposes to use methods *mixed methods*, namely a combination of qualitative and quantitative approaches. In the first phase, this research will conduct case studies on several mining companies that have tried to integrate the cloud computing with digital simulation. Qualitative data will be collected through interviews with stakeholders, such as IT managers, project heads and operational staff.

In the second stage, this research will carry out experiments with actual data to evaluate the performance of digital simulation models integrated with cloud computing. This testing will be carried out using existing simulation software and modifying the system to accommodate cloud computing.

Implementation of the solution will be carried out by developing a cloud computing integration framework with a digital simulation model that can be used by mining companies. This framework will be designed to be adapted to the specific needs of the company and the different scales of operations.

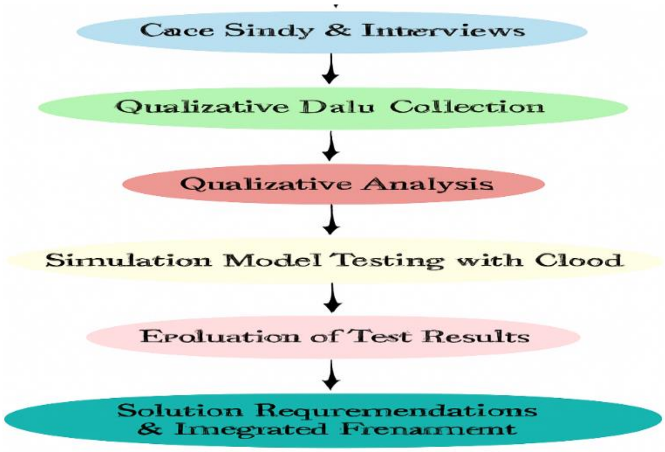

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Diagram 2.1 Research

RESULTS AND DISCUSSION

3.1 Test Data

In this study, the dummy data used included operational parameters of the mine, such as the volume of material moved, transportation time and processing capacity. This data will be fed into a simulation model integrated with cloud computing to test the speed and accuracy of data processing.

Table 3.1 Testing Data

Parameters	Description	Value
Material Volume (Tons)	Amount of material removed	5000
Transportation Time (Hours)	Time required for transportation	8
Processing Capacity (Tons/hour)	Hourly mine processing capacity	100
Processing Efficiency (%)	Percentage efficiency in processing	85
Number of Trucks (Units)	Number of trucks used for transportation	3
Operational Costs (IDR)	Costs incurred for hourly operations	2,000,000
CO2 emissions (Kg)	Carbon emissions produced during operations	15
Downtime Time (Hours)	System time is off or downtime	2

3.2 Implementation of Testing

Tests will be carried out in several scenarios, involving variations in the amount of data processed and the scale of mining operations. Each scenario will measure system performance, including response time, cost efficiency and system reliability in dealing with changes occurring in the field.

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Step 1: Simulation Testing

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To test the results of this data input, 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: Test Simulation

1. Calculating Transportation Time

To calculate transportation time, we use the following formula:

$Transportation\ Time\ (Hours) = Material\ Volume\ (Tons) Number\ of\ Trucks\ (Units)\ x\ Truck\ Capacity\ (Tons\ per\ trip)$

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

$Transportation\ Time\ (Hours) = 5000\ (Tons) 3\ Trucks\ x\ 100\ Tons\ Per\ Truck = 16.67\ Hours$

2. Calculating Operational Costs

To calculate hourly operational costs, use existing data:

Total Operating Costs = Hourly cost × Operational Time

If we assume operational time is **8 hours**:

Total Operating Costs = 2,000,000 × 8 Hours =16,000,000

3. Calculating Processing Time

To calculate the time required to process the material, use the following formula:

$Transportation\ Time\ (Hours) = Material\ Volume\ (Tons)\ /\ Processing\ Capacity\ (Tons\ per\ Hour)$

$Transport\ Time\ (Hours) = 5000\ (Tons) / 100\ (Tons\ per\ Hour) = 50\ Hours$

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However, if you consider processing efficiency (85%), then a more realistic processing time is:

$$Efficient\ Processing\ Time = 50\ Hours\ x\ 0.85 = 58.82\ Hours$$

4. Calculating CO2 Emissions

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

Total CO2 Emissions = 15 Kg × 8 Hours = 120 Kg

5. Calculating Processing Efficiency

Processing efficiency is given in the data at 85%, which means that from 100% capacity, 85% of the material can be processed efficiently. In this case, 85% of the 5000 tonnes to be processed are:

Efficient Materials = 5000 Tons × 0.85 = 4250 Tons

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

Table 3.1 Simulation Testing

No	Operational Aspects	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 simulation results report table which includes analysis of time, costs, processing efficiency and environmental impacts based on simulated data

Table 3.2 Mine Operational Simulation Results Report

No	Operational Aspects	Test Results	Analysis & Recommendations
1	**Transportation Time**	16.67 Hours (Truck Optimization)	More optimal use of trucks reduces transportation time.

2	**Operational Costs**	16,000,000 IDR (8 Operating Hours)	Operating costs for 8 hours. Recommendations for cost savings by improving the efficiency of truck and fuel use.
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 with increased tool efficiency and reduced downtime.
5	**Co2 emissions**	120 Kg (During 8 Hours of Operation)	Environmental impacts need to be considered. Improved operational efficiency can reduce emissions.
6	**Efficient Materials**	4250 Tons	85% of efficiently processed materials. Further efforts to improve processing efficiency.
7	**Cost Recommendations**	N/A	Further evaluation of operational costs taking into account time and efficiency reductions in processing and transport.
8	**Environmental Recommendations**	N/A	Efforts to reduce CO2 emissions by increasing processing and transportation efficiency.

CONCLUSION

Based on the results of tests on operational aspects of the mine, it can be concluded that optimization of the use of trucks for transportation can significantly reduce transportation time, with simulation results showing transportation time by 16.67 Hours. For operating costs, although costs for 8 operating hours are recorded 16,000,000, efficiency improvements in the use of trucks, fuel and labor can further reduce these expenses. Material processing time that initially takes up 50 Hours can be improved by improving tool efficiency and reducing downtime, resulting in efficient processing time of 58.82 Hours. Although processing efficiency has improved, there is still the potential to maximize efficiency and reduce time further with the application of more advanced technologies and processes. Simulation results show that CO2 emissions are produced during 8 hours of operation reach 120 Kg, which indicates that the the operational environmental impact needs to be be considered. Optimizing processing and transportation will not only increase efficiency, but also reduce CO2 emissions. Further, 85% of the processed material is successfully processed efficiently. Although good enough, there is still room to improve material processing so that more material can be processed efficiently. In addition, further operational cost evaluations are

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needed to better explore savings that could be made, while measures to reduce environmental impact should also be a major focus. Thus, while the test results show the efficiencies achieved, further improvements in each operational aspect will support the achievement of more optimal objectives in terms of cost, time and CO2 emission reductions, while improving the overall performance of mining operations.

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