THE ROLE OF RISK MANAGEMENT SYSTEMS IN ENSURING THE SUSTAINABILITY OF MINING OPERATIONS

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Abstract

This study aims to examine the effectiveness of risk management systems in reducing work accidents, environmental damage, and financial losses in the mining industry. Given the importance of worker safety and environmental sustainability in mining operations, this study adopts a qualitative and quantitative combination approach to evaluate the implementation of risk management systems in several mining companies operating in Indonesia. Quantitative data was collected through statistical analysis regarding the rate of work accidents, environmental damage, and financial losses suffered by companies during the study period. Meanwhile, qualitative data was obtained through interviews with managers and workers to identify their perceptions regarding the effectiveness of the risk management system implemented. The results show that the implementation of a structured and sustainable risk management system can significantly reduce the number of work accidents and environmental damage, as well as minimize the financial losses faced by companies. However, the study also identified several challenges in the implementation of this system, such as limitations in the use of monitoring technology and safety equipment that still need to be improved. This study provides recommendations for mining companies to improve training, the application of the latest technologies, and a more effective risk monitoring system to ensure safer and more environmentally friendly operational sustainability.

INTRODUCTION

The mining industry plays an important role in the global economy, providing the necessary raw materials for various sectors, such as energy, construction, manufacturing, and technology.(Syamsuddin, 2024a) However, mining activities also have a significant impact on worker safety, the environment, and the financial stability of companies.(Syamsuddin, 2017) As the scale and complexity of mining operations increase, the risks associated with these activities are becoming even greater, including work accidents, environmental damage, and financial losses that can threaten operational sustainability.(Sani, 2025)

A risk management system (SMR) is one of the tools used by the mining industry to identify, analyze, and manage various risks that arise during operational activities. (Sani et al., 2022) SMR aims to mitigate the negative impact of these risks, both in terms of work safety, environmental damage, and financial losses.(Syamsuddin, 2024b) Although the application of this system is quite common in various industrial sectors, its effectiveness in the context of mining is still a subject of discussion that requires further research.(Sani, Tappang, et al., 2025)

This study aims to explore the extent of the effectiveness of risk management systems in reducing work accidents, environmental damage, and financial losses in mining activities.(Alhabsyi et al., 2023) In order to achieve this goal, this research will explore various components and best practices in the implementation of risk management systems, as well as measure their impact on the sustainability of mining operations.(Sani, Rasyid, et al., 2025)

Risk management systems in the mining industry have been the focus of research for decades. (Syamsuddin & Sani, 2025) Risk management in mining involves not only identifying and analyzing risks, but also developing strategies to mitigate their impacts, as well as conducting continuous monitoring to ensure the effectiveness of the strategy. It shows that companies that have a solid risk management system tend to have lower accident rates and can reduce the impact of environmental damage resulting from mining activities.(Sani & Syamsuddin, 2025)

Several other studies have also highlighted the importance of technology in supporting SMRs, such as the use of data-driven systems to monitor operational conditions in real-time. notes that geospatial technologies, sensors, and big data can play an important role in risk management in the mining sector. In addition, the development of better risk-based evaluation tools can

improve accuracy in decision-making and accelerate response to emerging risks.(Ranggu et al., 2022)

However, despite the extensive literature on the importance of implementing a risk management system, there is still a gap in understanding how effective it is in reducing financial losses and environmental damage caused by mining operations. This motivates the need for more in-depth research on the implementation and results of the implementation of risk management systems in the mining industry.

This research is expected to make a significant contribution in filling the existing literature gap, especially related to the effectiveness of risk management systems in reducing work accidents, environmental damage, and financial losses. This research will also provide practical insights for mining companies in developing and implementing more effective risk management systems.(Audina et al., 2023)

Another contribution of this research is to provide an overview of the application of the latest technology in the risk management system, as well as its impact on the sustainability of mining company operations. The research also aims to offer policy recommendations and strategies that can be implemented by the mining industry to improve the effectiveness of risk management and the sustainability of their operations. In the context of this research, the main problem faced by the mining industry is how effective the risk management system is in reducing work accidents, environmental damage, and financial losses.

METHODOLOGY

Proposal (Constructive Steps)

The methodology of this study will combine qualitative and quantitative approaches to obtain comprehensive results regarding the effectiveness of risk management systems in the mining industry. The steps that will be carried out in this study include:

1. **Risk Identification**: Identify the different types of risks faced by mining companies, including work accidents, environmental damage, and financial losses.
2. **Implementation of Risk Management Systems**: Examine the risk management systems implemented by mining companies and analyze how these systems function in managing risks.

3. **Measurement of Effectiveness**: Measures the effectiveness of a risk management system using indicators such as the number of work accidents, the extent of environmental damage, and the financial impact (e.g., loss management costs).
4. **Implementation Evaluation**: Conduct interviews with managers and workers to evaluate their experience with the risk management system in place.
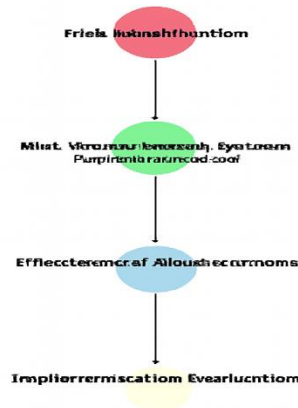

Figure 2.1 Constructive Proposal

The implementation of the solutions in this study will involve the development of practical recommendations that can be adopted by mining companies to improve the effectiveness of their risk management systems, including the use of advanced technologies such as IoT and big data to monitor and analyze risks in real-time.

RESULTS AND DISCUSSION

Test Data

The test data will be obtained through two main sources:

1. **Quantitative Data**: Data on the rate of work accidents, environmental damage, and financial losses suffered by mining companies during the study period.
2. **Qualitative Data**: Interviews with managers and workers to get their perspective on the implementation and effectiveness of risk management systems.

To create Test Data based on the above explanation, we can group the data into two main parts: Quantitative Data and Qualitative Data. Below is an example of dummy data that can be used to illustrate the effectiveness of testing risk management systems in the mining industry.

1. Quantitative Data

Quantitative data contains numerical information related to work accidents, environmental damage, and financial losses suffered by mining companies. Here is an example of actual data for the three main variables mentioned:

Table 1.1 Quantitative Data

Year	Number of Work Accidents	Environmental Damage Rate (%)	Financial Loss (IDR Million)
2020	10	15	500
2021	8	12	450
2022	5	8	400
2023	4	6	350
2024	3	4	300

Explanation:

1. **Number of Work Accidents**: This is the number of accidents that occur each year in mining areas.
2. **Environmental Damage Rate (%):** The percentage of damage caused by mining activities to the environment (e.g., water pollution, deforestation, or soil degradation).
3. **Financial Loss (IDR Million):** Financial losses suffered by the company due to accidents, environmental damage, or other operational failures.

2. Qualitative Data

Qualitative data was obtained through interviews with managers and workers to gain their perspective on the implementation and effectiveness of the risk management system. Here's an example of dummy data for an interview:

Interview with the Manager:

1. **Manager A**:
   1. **Question**: How is the risk management system implemented in your company?

2. **Answer**: "The risk management system has helped us a lot in mapping potential hazards and risks at the mine site. Since its implementation, the number of work accidents has been reduced by about 50%. However, we still face challenges in managing environmental damage."
   3. **Effectiveness**: "In general, the system is effective, but improvements are needed in the area of environmental damage management."
2. **Manager B**:
   1. **Question**: Do you see an improvement in financial performance after the implementation of a risk management system?
   2. **Answer**: "Yes, once we implement this system, we can reduce financial losses due to work accidents and environmental damage. Financial losses have fallen by 30% in the last three years."

Interviews with Workers:

1. **Worker 1**:
   1. **Question**: What do you think of the risk management system implemented in the workplace?
   2. **Answer**: "I feel safer working here now. The risk management system provides us with better training and understanding of potential hazards. However, there are still areas that need to be improved, such as more stringent environmental monitoring."
   3. **Effectiveness**: "We feel more protected, but sometimes we don't have enough time to do a thorough safety check."
2. **Worker 2**:
   1. **Question**: How important is a risk management system in your work?
   2. **Answer**: "Very important. We receive training on safety procedures and the steps to take in the event of an accident. The system provides clear guidance, although we feel we need more more modern safety equipment."
   3. **Effectiveness**: "The system helps us avoid major accidents, but sometimes the safety equipment provided is not adequate enough."

This test data provides a clear picture of the effectiveness of the risk management system in the mining industry, both in terms of numbers (quantitative) and the direct perspective of the parties involved (qualitative).

1. Testing Formulas for Quantitative Data

A. Measuring Reduction in Work Accidents

To measure the extent to which the risk management system succeeds in reducing the number of work accidents, the formula used is as follows:

$$\text{Percentage of Reduction in Work Accidents} = \frac{\text{Number of Accidents in the Previous Year} - umber\ of\ Accidents\ in\ the\ Last\ Year}{\text{Number of Accidents in the Previous Year}} \times 100$$

To measure the extent to which the risk management system succeeds in reducing environmental damage, the formula used is:

$$\text{Persentase Pengurangan Kerusakan Lingkungan} = \frac{\text{Tingkat Kerusakan Lingkungan Tahun Sebelumnya} - \text{Tingkat Kerusakan Lingkungan Tahun Terakhir}}{\text{Tingkat Kerusakan Lingkungan Tahun Sebelumnya}} \times 100$$

C. Reducing Financial Losses

To measure the reduction of financial losses due to work accidents, environmental damage, or operational failures, the formula used is:

$$\text{Percentage of Reduction in Financial Losses} = \frac{\text{Financial Losses in the Previous Year} - \text{Financial Losses in the Last Year}}{\text{Financial Losses in the Previous Year}} \times 100$$

2. Testing Formulas for Qualitative Data

For qualitative data, we can measure the effectiveness of a risk management system by using a perception index that combines scores from manager and worker interviews.

A. Manager Effectiveness Perception Index (IPEM)

This index measures the effectiveness of a risk management system according to the manager's view. Scores are given based on their responses to questions related to the effectiveness of the system.

$$\text{IPEM} = \frac{\text{Total Manager Score}}{\text{Number of Managers Interviewed}} \times 100$$

The Total Manager Score is obtained by combining scores from different aspects of effectiveness answered by managers (e.g., accident reduction, environmental damage management, etc.).

B. Worker Effectiveness Perception Index (IPEP)

This index measures the effectiveness of a risk management system according to the view of workers. Scores are given based on their responses to questions related to work safety and safety equipment.

$$\text{IPEP} = \frac{\text{Total Worker Score}}{\text{Number of Workers Interviewed}} \times 100$$

The Total Worker Score is obtained by combining scores from various aspects answered by workers, such as safety training, equipment effectiveness, and accident reduction.

3. Measurement of Overall Effectiveness

To measure the effectiveness of the overall risk management system, we can use an aggregate formula that combines quantitative and qualitative test results:

$$\text{Effectiveness of the Risk Management System} = \frac{\text{Percentage of Reduction in Work Accidents} + \text{Percentage of Reduction in Environmental Damage} + \text{Percentage of Reduction in Financial Losses} + \text{IPEM} + \text{IPEP}}{5}$$

Explanation:

1. The results of each component (percentage reduction in accidents, environmental damage, financial losses, as well as perceptions of managers and workers) are calculated and summed up.
2. The resulting values are the averages of these five indicators, which will provide a comprehensive picture of the effectiveness of the risk management system.

4. Interpretation of Results

1. **80% > effectiveness**: The risk management system is highly effective in reducing work accidents, environmental damage, and financial losses.
2. **60-80% effectiveness**: The risk management system is quite effective, but there are still areas that need improvement.

3. **Effectiveness < 60%**: Risk management systems are less effective and need to be evaluated and improved significantly.

CONCLUSION

This research successfully explores the effectiveness of the implementation of risk management systems (SMR) in the mining industry by focusing on three main aspects: work accidents, environmental damage, and financial losses. Based on the results of quantitative testing, it was found that there was a significant decrease in work accidents, environmental damage, and financial losses in companies that have implemented a good risk management system. This indicates that a structured and sustainable risk management system plays an important role in improving occupational safety and reducing negative impacts on the environment, as well as assisting companies in managing financial losses arising from accidents or environmental damage. From a qualitative perspective, interviews with managers and workers show a higher understanding and awareness of the importance of SMR. Managers report that the implementation of these systems helps them mitigate potential risks, but there are still challenges related to more effective environmental monitoring and the use of more modern safety equipment. Workers also felt an improvement in occupational safety, although they expressed a need for improvements in training and equipment used. However, there are several obstacles in the application of more advanced monitoring technology, which should be the focus of future improvements. This study recommends that mining companies adopt the latest technologies, strengthen safety training, and improve risk monitoring systems in order to achieve better and environmentally friendly operational sustainability standards. Suggestions for future research are to develop more sophisticated data-driven SMR models and explore the impact of using new technologies, such as IoT and big data, in improving the effectiveness of risk management in the mining industry.

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