

Evaluation of Big Data Integration in Monitoring the Performance of the OHS Management System in the Energy Sector

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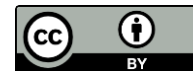
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Keywords

Occupational Safety and Health Management System (SMK3), OHS Performance Monitoring, Digital Transformation of Occupational Safety

ABSTRACT

This study evaluates the integration of Big Data in monitoring the performance of the Occupational Health and Safety Management System (OHSMS/SMK3) in the energy sector in Indonesia. A quantitative approach with an evaluative and explanatory design was employed, involving 210 respondents from oil and gas, power generation, and renewable energy companies. Data were collected through structured questionnaires and analyzed using descriptive and inferential statistical techniques. The findings indicate that Big Data integration significantly enhances OHSMS monitoring performance by improving the timeliness of information, risk visibility, and decision-making effectiveness. Organizations with higher levels of data integration demonstrate stronger capabilities in identifying hazards, responding to incidents, and supporting evidence-based safety management. However, the utilization of advanced data analytics remains comparatively lower than other dimensions, indicating uneven maturity in digital adoption. These results confirm that Big Data integration is not merely a technological upgrade but a strategic transformation toward predictive and preventive safety management. The effectiveness of this integration is influenced by data quality, system interoperability, workforce digital competence, and organizational commitment to data-driven practices. Implications: This study provides specific implications for policy, emphasizing the need for regulatory frameworks that standardize data integration and interoperability in OHS systems, as well as national strategies for strengthening digital competencies in high-risk industries. Organizational policies should also prioritize data governance, cybersecurity, and the alignment of analytics capabilities with operational safety processes to ensure optimal system performance.



INTRODUCTION

Occupational Safety and Health (OHS) is a crucial component of the dynamics of industrial operations, particularly in high-risk sectors such as energy. The Occupational Safety and Health Management System (OHSMS) is recognized as a systematic framework for controlling occupational risks, preventing accidents, and improving workforce productivity and well-being. Effective OHS implementation reduces the number of occupational accidents and illnesses, as well as other negative effects that can occur in the workplace. International studies show that safety management systems are a crucial component of contemporary business practices to ensure a healthy and safe work environment (Najwa Hanni et al., 2025).

The energy sector generates massive datasets from operations like drilling, pipelines, and power plants, where safety risks are high due to hazardous environments (Tan et al., 2016). Big Data integration allows processing of structured and unstructured data from sensors, incidents, and personnel records to predict and mitigate OHS risks (Haroun and Ghomari, 2023). This is essential as traditional OHSMS monitoring struggles with data volume and silos in high-stakes energy operations (Hussain et al., 2023).

The energy sector, which encompasses oil and gas, power generation, and renewable energy sources, presents a high level of risk complexity due to its work characteristics involving hazardous materials, extreme pressures and temperatures conditions, and complex industrial operations. Without adequate risk mitigation and oversight systems, accidents frequently occur in such workplaces. A data-driven, proactive, and reactive approach to safety and health (OHS) is needed to address these issues. However, OHSMSs often face limitations in handling the significant volume and speed of safety data when used in practice. Conventional methods that rely on handwritten records or periodic reports tend to be overly sensitive and less responsive to changes in workplace risk dynamics. This shortcoming disconnects management decision-making processes from actual safety situations.

Digital advancements have opened up new opportunities for environmental safety and health management, particularly through the integration of digital technologies such as IoT (Internet of Things) sensors, digital reporting platforms, and advanced data analytics that enable real-time monitoring and prediction. These data-driven systems not only accelerate data flow but also improve clarity and accuracy in safety decision-making (Najwa Hanni et al., 2025).

Thus, Big Data, characterized by its high volume, velocity, variety, and value, can be used to explore risk patterns, predict incidents, and evaluate safety performance comprehensively. In the international literature, the use of Big Data in safety management has been described as a crucial part of evidence-based decision-making in the context of industrial safety. Conceptually, Big Data analytics can expand monitoring capacity by integrating various data sources, such as operational logs, IoT sensors, incident reports, and worker health data. This method enables the recognition of high-risk situations before an incident occurs and provides the basis for faster and more precise mitigation actions (Wang & Wang, 2021).

OHSMS performance is typically measured through leading and lagging indicators, with leading indicators reflecting preventative efforts (e.g., training, inspections), and lagging indicators reflecting historical data such as the number of accidents or lost work hours. Traditionally, these



performance evaluations have been retrospective and do not always provide sufficient information for anticipatory action planning in a dynamic system (Tri Atmojo et al., 2025).

Therefore, integrating Big Data analytics into SMK3 performance monitoring offers a more adaptive and responsive approach. Big Data enables long-term trend analysis, automated anomaly detection, and risk modeling that considers complex variables—something that is impossible to achieve through conventional evaluation approaches alone (Wang & Wang, 2021).

System interoperability is a major issue because the diversity of data formats (structured, semi-structured, and unstructured) complicates integration between platforms. Varying data quality often leads to issues such as false or inaccurate data, while the need for robust and secure infrastructure requires significant investment and large-scale encryption to prevent leaks (Judijanto et al., 2025).

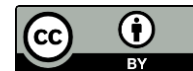
Human resource readiness is low due to a lack of technical skills among workers, particularly in occupational health and safety (OHS) sectors such as construction and oil and gas. A strong safety culture is difficult to build without digital training, compounded by resistance to change and literacy gaps. Top management commitment is crucial for budget allocation and regulatory compliance, often hampered by initial costs and inconsistent regulations (Wahyudi, 2024).

Law No. 27 of 2022 concerning Personal Data Protection (PDP) regulates Big Data processing, including OHS security and privacy, and establishes penalties for violations. Ministerial Regulation No. 5/1996 now combines OHSMS for risk monitoring with Big Data digitization. A literature review shows that there is still little empirical research specifically evaluating the relationship between Big Data integration and the effectiveness of OHSMS performance monitoring, particularly in the energy sector. Many OHSMS studies focus on evaluating OHS cultural or technical implementation, but do not address the role of Big Data technology in performance monitoring (Aulia & Susilawati, 2024; Najwa Hanni et al., 2025).

Global research on Big Data security management shows a shift from a reactive approach to a predictive one through intensive analysis, enabling more proactive risk detection. However, research in high-risk areas like energy is still limited, requiring further development for meaningful applications. Real-time data processing, machine learning, and models such as predictive maintenance, which reduce downtime and industrial accidents, enable Big Data analytics for incident prediction. As shown in the literature review, these methods are used in security management to identify early threats by combining historical data, the Internet of Things (IoT), and artificial intelligence (Barker, 2020; Ezerins et al., 2022).

Furthermore, there is a gap between Big Data theory and operational practices in the field, requiring a comprehensive evaluation model that measures data output and influences safety policies and operational efficiency. This requires more contextual and empirical research on the energy industry, especially in developing countries like Indonesia, which face distinct challenges with human resources and infrastructure.

Given the need for energy companies to improve safety system performance, this research is increasingly important. Incorporating Big Data into the OHSMS framework promises improved safety performance, productivity, reduced costs due to workplace accidents, and a company's reputation for implementing best safety practices. Therefore, this research is important to systematically evaluate the level of Big Data integration in OHSMS performance monitoring and to



understand the relationship between Big Data utilization and decision-making efficiency rather than decision-making using Big Data.

METHODS

This study uses a quantitative approach with an evaluative and explanatory design to analyze the integration of Big Data in monitoring the performance of the Occupational Safety and Health Management System (SMK3) in the energy sector. The quantitative approach was chosen because the study focuses on objectively measuring the level of Big Data integration and testing the relationship between Big Data utilization and the effectiveness of OHS performance monitoring based on empirical data. The evaluative design is used to assess the condition of Big Data implementation in the OHS monitoring system, while the explanatory design aims to explain the effect of Big Data integration on the performance of SMK3 monitoring.

This research was conducted at companies operating in the energy sector, including the oil and gas, power generation, and renewable energy subsectors, which are characterized by high occupational risks and complex operational systems. The research object was the SMK3 performance monitoring system, specifically the mechanism for collecting, processing, and utilizing OHS data based on digital technology and Big Data. The research subjects included personnel directly involved in OHS management and implementation, such as OHS managers, safety supervisors, HSE staff, and information system or data analytics support personnel.

Respondents were selected using purposive sampling, with the criteria being that respondents had at least one year of work experience in the field of occupational safety and health or occupational health and safety information systems, were involved in the monitoring and evaluation of occupational health and safety performance, and understood the use of digital systems in occupational safety management. This approach was chosen to ensure that the data obtained came from individuals with relevant knowledge and experience related to the research object.

The research variables consist of two main variables, namely Big Data integration in OHSMS monitoring as the independent variable and OHSMS monitoring performance as the dependent variable. Big Data integration is defined as the level of utilization of large data characterized by the diversity of OHS data sources, processing speed, data quality, and the use of data analytics for safety risk identification and prediction. Meanwhile, OHSMS monitoring performance is measured based on the effectiveness of the system in supporting OHS risk control and decision-making, which includes leading and lagging safety indicators, timeliness of information, and the quality of the safety information produced.

Data collection was conducted through a structured questionnaire as the primary research instrument. The questionnaire was constructed using a five-point Likert scale to measure respondents' perceptions of the level of Big Data integration and the effectiveness of OHSMS performance monitoring. Furthermore, a documentation study was conducted on OHS reports, safety monitoring dashboards, OHSMS policies, and incident reports to strengthen the quantitative findings and provide context for the implementation of the data-driven monitoring system.

Prior to data analysis, the research instruments were tested for validity and reliability. Validity was tested using Pearson Product Moment correlation to ensure each question item



adequately measures the construct being studied. Reliability was tested using Cronbach's Alpha coefficient, with a minimum value of 0.70 as an indicator of acceptable reliability.

Data analysis was conducted through descriptive and inferential statistical analysis. Descriptive analysis was used to describe the characteristics of respondents and the level of Big Data integration and SMK3 monitoring performance based on the average value and data distribution. Furthermore, inferential analysis was conducted to examine the relationship and influence of Big Data integration on SMK3 monitoring performance using correlation tests and linear regression analysis. The results of the statistical analysis were then interpreted evaluatively to assess the role of Big Data in improving the effectiveness of OHS performance monitoring in the energy sector.

RESULTS

This study involved 210 respondents from energy sector companies, covering the oil and gas, power generation, and renewable energy subsectors. Respondents were personnel directly involved in the management and monitoring of the Occupational Safety and Health Management System (SMK3). Based on the data processing results, the majority of respondents were male and in the productive age range (30–50 years), with a dominant job background as OHS staff and supervisors, HSE managers, and OHS information system personnel.

In terms of work experience, most respondents have worked for more than five years in the field of OHS, which indicates that the data obtained comes from individuals with adequate understanding of the implementation of OHSMS and the use of digital systems in high-risk work environments.

Table 1. Descriptive Statistics of Research Variables (n = 210)

Variables	Dimensions	Mean	Standard Deviation
Big Data Integration	Diversity of K3 data sources	4.18	0.52
	Data processing speed	4.11	0.55
	Data quality and accuracy	3.87	0.61
	Utilization of data analytics	3.79	0.64
Average of Variable X		3.99	0.58
SMK3 Monitoring Performance	Timeliness of information	4.22	0.50
	Visibility of work risks	4.15	0.53
	Integration of leading-lagging indicators	3.76	0.62
	Decision-making support	4.09	0.56
Average of Variable Y		4.06	0.55

Descriptive statistics show that Big Data integration in OHSMS monitoring is in the high category with an average score of 3.99. The highest-scoring dimension is the diversity of OHS data sources, reflecting the energy company's ability to integrate data from various channels such as incident reports, safety inspections, and operational digital systems.

SMK3 monitoring performance also showed a high average score (4.06), particularly in terms of timeliness of information and visibility of occupational risks. This indicates that a Big Data-based

monitoring system can improve the transparency and responsiveness of occupational safety oversight.

Table 2. Results of Instrument Validity and Reliability Tests

Variables	Number of Items	Range of r-value	Cronbach's Alpha
Big Data Integration (X)	12	0.46 – 0.78	0.89
SMK3 Monitoring Performance (Y)	10	0.49 – 0.81	0.91

All items in both variables had calculated r-values above the table r-value ($\alpha = 0.05$), thus declared valid. A Cronbach's Alpha value > 0.80 indicates that the instrument has excellent internal consistency, making it suitable for further inferential analysis.

Table 3. Pearson Correlation Test Results

Variables	Big Data Integration (X)	SMK3 Monitoring Performance (Y)
Big Data Integration (X)	1	0.683
SMK3 Monitoring Performance (Y)	0.683	1

Information:

$p < 0.01$

The Pearson correlation test results show a positive and significant relationship between Big Data integration and OHSMS monitoring performance, with a correlation coefficient of 0.683. This value is in the strong relationship category, meaning that increased Big Data integration is followed by improved occupational safety and health monitoring performance.

Table 4. Linear Regression Analysis Results

Independent Variables	β	t-value	Sig.
Big Data Integration	0.657	12.84	0.000
Model Statistics			Value
R			0.683
R ²			0.467
Adjusted R ²			0.464
F-value			164.9
Sig. F			0.000

The linear regression results show that Big Data integration has a positive and significant effect on SMK3 monitoring performance ($\beta = 0.657$; $p < 0.001$). The coefficient of determination ($R^2 = 0.467$) indicates that 46.7% of the variation in SMK3 monitoring performance can be explained by Big Data integration, while the remainder is influenced by other factors such as safety culture, HR competency, and management policies.

These findings emphasize the role of Big Data as a strategic factor in supporting a more adaptive, evidence-based, and risk-prevention-oriented OHS monitoring system. Overall, the statistical results show that:



1. The level of integration of Big Data and SMK3 monitoring performance is in the high category.
2. There is a strong and significant relationship between the two variables.
3. Big Data integration makes a substantial contribution to increasing the effectiveness of SMK3 monitoring in the energy sector.

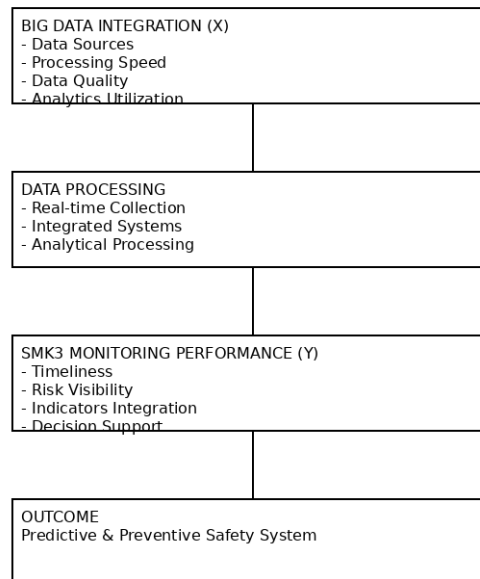


Figure 1. Framework of Big Data Integration in SMK3 Monitoring

The diagram shows that the integration of Big Data serves as the primary input influencing data processing mechanisms within digital systems. However, the effectiveness of the transition towards a predictive safety system is highly dependent on the extent to which data analytics are utilised, which remains a weak point in this study. This underscores that without adequate analytical capabilities, the advantages of Big Data cannot be fully translated into improved SMK3 monitoring performance.

DISCUSSION

The Pearson correlation test results in Table 3 indicate a strong positive relationship ($r = 0.683$; $p < 0.01$) between Big Data integration and OHSMS monitoring performance in the energy sector. This means that the higher the level of Big Data integration through diverse data sources, processing speed, and the use of data analytics, the more effective the occupational safety monitoring system will be. The linear regression analysis in Table 4 confirms this with a value of $\beta = 0.657$ and $R^2 = 0.467$, indicating that 46.7% of the variation in OHSMS monitoring performance can be explained by the Big Data integration factor.

These findings demonstrate that Big Data analytics technology has significantly contributed to accelerating risk identification, reducing incident reactions, and improving evidence-based decision-making. This aligns with the findings of Dos Santos et al. (2025) who have stated that the application of Industry 4.0 technology, including Big Data and artificial intelligence, boosts the

efficiency of OHS systems through adaptive monitoring and predictive analysis (Dos Santos et al., 2025). Similarly, Ramadhan et al. (2025) confirmed that the integration of IoT with Big Data analytics in the oil and gas industry increases the speed of potential hazard detection and the effectiveness of safety responses (Ramadhan et al., 2025).

From a theoretical perspective, these findings reinforce the “data-driven safety management” model, which emphasizes the role of real-time information and systemic learning in supporting a proactive safety culture (C. Mahammedi et al., 2025). The improved performance of the OSHMS monitoring on indicators of information timeliness and risk visibility indicates that the company has shifted from a reactive to a preventive approach—aligning with the Occupational Safety and Health (OSH) 5.0 paradigm that integrates Big Data and AI for multi-level prevention (Ávila-Gutiérrez & Suárez-Fernandez, 2022).

In addition, the results of this study are consistent with the findings of Hadi et al. (2025) which proves that the use of IoT wearable devices and AI-based analytics improves the accuracy of OHS data and minimizes delays in incident reporting (Hadi et al., 2025). Thus, Big Data integration not only impacts operational efficiency but also strengthens compliance and regulatory oversight aspects, as explained by (O. Demikhov et al., 2023) in their study of the digital transformation of OHS systems in Europe.

This study suggests that improving SMK3 monitoring performance through Big Data is influenced by three key factors:

1. Data quality and digital infrastructure. System performance will be maximized if the data is standardized, accurate, and integrated across platforms.
2. Human resource readiness and digital safety culture The workforce's ability to understand and use analytical systems determines the effectiveness of implementation.
3. Management commitment to data-driven policies Organizations that place data as the foundation for decision-making will be more adaptive to the dynamics of work risks.

Empirical results show that the implementation of Big Data in the energy sector is not merely a system modernization, but a transformational step towards predictive and preventative safety management. Thus, this study supports recent literature such as AlMarri et al., (2025) which highlights the importance of integrating digital systems and ERP in safety management to ensure cross-divisional compliance and efficiency (AlMarri et al., 2025).

Although the overall level of Big Data integration is high, the research findings indicate that the ‘data analysis utilization’ dimension received the lowest score (mean = 3.79) compared to the other dimensions. This phenomenon suggests a gap between the availability of data and the organization’s ability to extract strategic value from it. Critically, this low score can be explained by several structural and operational barriers. Firstly, limited analytical competencies among the workforce mean that available data is not yet being utilised optimally for predictive analytics or risk modelling. Secondly, immature analytical infrastructure—such as a lack of integration between data platforms and machine learning-based analytical tools—limits the organization’s ability to conduct advanced analysis. Thirdly, an organizational culture that remains focused on descriptive reporting rather than predictive analysis further hinders the strategic use of data. Furthermore, issues regarding data quality and interoperability also contribute to low confidence in analytical results, meaning that decision-making still tends to rely on experience rather than data-driven insights.



Thus, a low score in this dimension does not merely reflect technical shortcomings, but indicates that the transition towards data-driven safety management is still in its early stages. This underscores that the successful integration of Big Data depends not only on the volume and speed of data, but on the organization's ability to convert data into actionable insights (*actionable insights*).

CONCLUSIONS

Based on the research results and discussion, it can be concluded that Big Data integration has been proven to have a positive and significant effect on the monitoring performance of the Occupational Safety and Health Management System (SMK3) in the energy sector. Empirical findings show a strong relationship between the two variables ($r = 0.683$; $p < 0.01$) and a substantial influence value ($\beta = 0.657$; $R^2 = 0.467$), which indicates that almost half of the variation in SMK3 monitoring performance can be explained by the level of Big Data integration in the organizational system. This condition shows that the higher the level of Big Data technology adoption including the diversity of data sources, processing speed, information accuracy, and the application of predictive analytics, the more effective the occupational safety monitoring system is in detecting risks and supporting data-based decision making. Conceptually, these results strengthen the theory of data-driven safety management which places Big Data and artificial intelligence as the main foundation in building an adaptive, predictive, and preventive safety system. The application of Big Data has been proven to strengthen the effectiveness of the safety system by increasing risk visibility and timeliness of reporting in high-risk industries such as energy. Therefore, this study confirms that the success of Big Data integration into the OHSMS system is strongly influenced by three key factors: data quality and interoperability, human resource readiness in operating analytical technology, and top management commitment to driving digital transformation of occupational safety. Therefore, Big Data integration is not merely a technological innovation, but rather a transformative strategy towards a more agile, evidence-based, and prevention-oriented occupational safety culture.

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