

Operational Risk Control Through OSHMS Implementation in Biosilica Manufacturing

Noveria SJAFRINA¹, Jonathan PRABOWO², Eko BHAKTI SUSETYO³, Lukman JUNAIDI³, Irpan BADRUL JAMAL¹, Nyimas DEWI SARTIKA⁴, Christine Cecylia MUNTHE⁵, Arief ARIANTO^{6,9}, ARIFIN², SAHLAN³, Sigit SETIADI⁴, SUDONO⁷, Ali ASGAR¹, Muhammad RAFI DHIA⁸

¹ Research Center for Horticulture, National Research and Innovation Agency (BRIN), Indonesia

² Research Center for Manufacturing Technology and Production Machinery, Research Organization for Energy and Manufacturing, National Research and Innovation Agency (BRIN), Indonesia

³ Research Center for Industrial Systems and Sustainable Manufacturing, National Research and Innovation Agency (BRIN), Indonesia

⁴ Research Center for Process Technology, Research Organization for Energy and Manufacturing, National Research and Innovation Agency (BRIN), Indonesia

⁵ Research Center for Data and Information Sciences, Research Organization for Electronics and Informatics, National Research and Innovation Agency (BRIN), Indonesia

⁶ Research Center for Behavioral and Circular Economics, Research Organization for Governance, Economy, and Public Welfare, National Research and Innovation Agency (BRIN), Indonesia

⁷ Research Center for Public Policy, Research Organization for Governance, Economy, and Public Welfare, National Research and Innovation Agency (BRIN), Indonesia

⁸ Department of Management, Faculty of Economics and Business, University of Muhammadiyah Jakarta, Indonesia

⁹ Telkom University, Indonesia

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Abstract

This study examines the impact of Occupational Safety and Health Management System (OSHMS) implementation on operational risk control in biosilica production. Using a quantitative survey of 200 employees exposed to operational risks, four components management policy and commitment, hazard identification and risk assessment, operational control, and OSH training and competence were analyzed as reflective indicators of OSHMS. Data were evaluated using Partial Least Squares Structural Equation Modeling (PLS-SEM). Results show all components significantly affect operational risk control, with OSH training and competence having the strongest influence. Findings align with High Reliability Organization (HRO) theory, highlighting the integration of managerial, technical, and behavioral aspects in safety practices. The study concludes that effective OSHMS implementation is essential for proactive and sustainable risk management in high-hazard industries. Future research should consider moderating factors and longitudinal designs to assess long-term safety outcomes.

Keywords

Occupational Safety and Health Management System, Management Policy and Commitment, Hazard Identification, Operational Control, OSH Training and Competence, Operational Risk Control.

Introduction

Industrial progress is often accompanied by increasing complexity in operational processes, especially in sectors involving chemical and mineral-based produc-

tion, such as biosilica. As the demand for biosilica grows due to its diverse applications from agriculture and cosmetics to pharmaceuticals and environmental technologies companies are under greater pressure to ensure not only productivity but also the safety and reliability of their operations. In this context, managing operational risks becomes a critical priority that cannot be overlooked (Reason, 2016; Leveson, 2016). Biosilica, also known as biogenic silica, is a naturally occurring form of silica produced by various organisms such as sponges, radiolarians, and diatoms. These organisms precipitate silica from dissolved silicic acid

Corresponding author: Noveria Sjafrina Noveria – Research Center for Horticulture, National Research and Innovation Agency (BRIN), Indonesia, e-mail: nove002@brin.go.id

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to form intricate nanostructures that serve various biological functions, including structural support and protection (Suman et al., 2024).

For a variety of sectors to control operational hazards, the Occupational Safety and Health Management System (OSHMS) must be implemented. By using organized risk control procedures to avoid accidents and occupational illnesses, OSHMS aims to provide a safe, effective, and productive workplace (Suhartina et al., 2020). Operational risks ranging from equipment malfunctions, chemical hazards, production errors, to unsafe work environments can result in serious consequences, including financial losses, damage to company reputation, environmental degradation, and most critically, the loss of human lives. These risks are often interconnected and may escalate if not addressed through systematic control measures. Many incidents in industrial sectors have demonstrated that the absence of a well-established safety culture and risk management framework contributes significantly to operational failures.

To address these challenges, companies are increasingly adopting structured safety and health management systems that prioritize prevention over reaction. One of the most recognized frameworks in Indonesia is the Occupational Safety and Health Management System (OSHMS). More than just a regulatory requirement, OSHMS is designed to promote a culture of safety by emphasizing risk identification, hazard control, continuous training, and employee involvement at all levels of the organization. The proper implementation of OSHMS is believed to reduce the frequency and severity of incidents, improve compliance, and enhance operational sustainability. Integrating the Occupational Safety and Health Management System (OSHMS) with other management systems can enhance risk management by providing a holistic approach to occupational health and safety. This integration helps organizations to more effectively identify, assess, and mitigate risks (Pacaiova et al., 2020; Filimonov & Gorina, 2019).

However, the reality in the field often shows that the level of OSHMS implementation differs across organizations, depending on leadership commitment, workforce awareness, organizational structure, and industry type. The overall implementation of OSHMS in Indonesia is not optimal, primarily due to a lack of ingrained safety culture among the workforce (Sutawijaya & Nawangsari, 2018). There is often a lack of understanding and application of government regulations related to OSHMS. This is evident in both service users and providers, including planners, supervisors, and implementers (Lamba et al., 2019). Ensuring compliance with these regulations is crucial but challenging due to varying levels of awareness and commitment.

In newer or growing sectors like biosilica production, where rapid expansion may sometimes outpace internal capacity for risk management, the role of OSHMS becomes even more crucial. Specific to biosilica production, managing exposure to respirable crystalline silica (RCS) is crucial due to its health risks, including silicosis (Moredock et al., 2023). Biosilica production involves complex technological processes that require robust safety management systems to handle potential hazards. Ensuring that safety protocols are integrated into the production process is critical to prevent accidents and ensure worker safety (Kontogiannis, 2019). Proper training and adherence to Standard Operating Procedures (SOPs) are critical for managing occupational health and safety risks. In biosilica production, specialized training tailored to the unique hazards of the industry is necessary but often insufficiently provided (Astuti & Ramdhan, 2024). Understanding how effectively OSHMS is being implemented and how it contributes to controlling operational risks becomes a matter of strategic importance. Adequate training and knowledge dissemination are essential for successful OSHMS implementation (Van Zyl et al., 2018). Organizations need to invest in training programs to ensure that employees are well-versed in safety protocols and procedures (Hobscheidt et al., 2021).

Compliance with national and international standards is a significant driver for OSHMS implementation. For instance, the Indonesian government's regulation on OSHMS mandates its implementation across various sectors, influencing organizations to adopt these safety management systems (Lestari et al., 2020). This research seeks to explore the extent to which OSHMS implementation influences operational risk control in the biosilica industry. By examining this relationship in depth, the study aims to provide evidence-based insights that can help companies strengthen their safety culture, reduce incidents, and foster long-term operational excellence.

Previous studies have extensively examined the implementation of Occupational Safety and Health Management Systems (OSHMS) across various industrial and organizational contexts. For instance, (Murad et al., 2020) identified critical success factors for OSHMS implementation in petrochemical manufacturing companies, while (Fitrijaningsih et al., 2023) analyzed OSHMS practices within the education sector. Similarly, (Septiana et al., 2024) evaluated the effectiveness of OSHMS implementation in pine resin harvesting, and (Bochkovskyi and Sapozhnikova, 2021) focused on the development of automated OSH management systems in enterprise settings. More recently, (Mandowa et al., 2025) investigated organizational and managerial factors influencing OSHMS implementation in the manufacturing industry in Zimbabwe.

Despite these valuable contributions, existing studies predominantly emphasize implementation factors, system effectiveness, or sector-specific applications of OSHMS, rather than empirically examining its direct impact on operational risk control. Moreover, the majority of prior research has been conducted in sectors such as petrochemical manufacturing, education, forestry, and general manufacturing, leaving limited empirical evidence in emerging and high-risk production contexts such as biosilica manufacturing. Consequently, there remains a clear research gap regarding how specific OSHMS components namely management policy and commitment, hazard identification, operational control, and OSH training and competence collectively influence operational risk control. Addressing this gap, the present study extends prior research by empirically testing the relationship between OSHMS implementation and operational risk control within the biosilica production environment.

This paper is structured to systematically examine the relationship between the implementation of the Occupational Safety and Health Management System (OSHMS) and operational risk control in the biosilica production environment. The discussion begins with a literature review that outlines the theoretical foundations of High Reliability Organization (HRO), OSHMS, and key variables related to operational risk control. The subsequent section explains the research methodology, including the research design, sampling strategy, measurement instruments, and the application of PLS-SEM. The results section presents respondent characteristics and the findings of the measurement and structural model evaluations. This is followed by a discussion that interprets the results in relation to existing theories and previous studies, highlighting both theoretical and practical implications. The paper concludes by summarizing the main findings, acknowledging research limitations, and proposing directions for future research.

Literature review

High Reliability Organization

High Reliability Organization (HRO) theory focuses on organizations that operate in high-risk, high-consequence environments and manage to maintain error-free operations over extended periods. Introduced in the 1980s, HRO theory has since been applied across various industries, including healthcare, aviation, nuclear power, and more (Dwyer et al., 2023). Measuring the extent to which an organization is highly reliable and tracking progress over time remains a challenge. Developing reliable metrics and evaluation tools is

crucial for advancing HRO practices (Cartland et al., 2022). HRO theory provides a valuable framework for organizations operating in high-risk environments to achieve high reliability and safety. By focusing on key characteristics such as preoccupation with failure and commitment to resilience, organizations can better manage risks and avoid catastrophic failures.

Occupational Safety and Health Management System

An Occupational Safety and Health Management System is a structured framework designed to manage and continuously improve occupational health and safety performance within an organization (Génesis, Stefania, Karen, Claudia, Sukier Harold, et al., 2022). OSHMS is designed to be dynamic, involving continuous monitoring, evaluation, and improvement of safety practices. This iterative process ensures that safety measures evolve in response to new risks and changing workplace conditions (Génesis, Stefania, Karen, Claudia, & Yulineth, 2022). The primary goal is to prevent work-related injuries, diseases, and accidents, thereby promoting the health and well-being of employees (Vranješ & Todić, 2019). Organizations are often required by law to implement OSHMS to meet regulatory standards and ensure the safety of their employees. Additionally, ethical considerations play a crucial role in fostering a proactive safety culture beyond mere compliance (Mixafenti et al., 2025). A structured and systematic approach is essential for the successful implementation and continuous improvement of OSHMS (Ramzi & Abdulwahid, 2021).

Biosilica Production

The biosilica production industry is gaining significant attention due to its potential for sustainable and cost-effective manufacturing processes. Biosilica, primarily derived from diatoms and agricultural residues, offers several advantages over synthetic silica, including environmental benefits and lower production costs. The production of biosilica is environmentally friendly, generating minimal toxic waste and requiring less energy compared to synthetic silica production (Tessema et al., 2023). Biosilica is a cheap and renewable resource since it can be generated in huge amounts with little material and energy investment (Saoud et al., 2022). The industry is moving towards more sustainable production methods, utilizing renewable resources and waste materials to produce high-value silica products (Bazzi et al., 2023). Biosilica production in Indonesia is primarily derived from agricultural waste, particularly rice husk (RH), which constitutes 20–22% of the

by-products of rice production (Cahyani & Purwanto, 2024). The process of converting RH into biosilica involves acid leaching, which optimizes the quality of the silica produced. Using organic acids like CH_3COOH and $\text{C}_4\text{H}_6\text{O}_6$ under specific conditions (temperature and duration) can yield high-purity green silica with significant amorphous content and enhanced surface area and pore volume (Cahyani & Purwanto, 2024). This method is environmentally friendly and promotes safer chemical processes.

Management Policy and Commitment

Management policy and commitment are critical components of an effective Occupational Safety and Health Management System. Top management's strategic commitment is essential for setting values, goals, and providing visible support for OHS initiatives (Akinbode, 2022). This commitment includes defining OHS responsibilities and tasks at different organizational levels, ensuring that middle and frontline managers are also engaged in OHS management (Tappura et al., 2017). A well-defined safety policy is crucial. It should include clear action plans, continuous monitoring, and assessment of workplace safety (Mohammadfam et al., 2017). Policies should align with standards which provide comprehensive guidelines for implementing safety management systems (Manuele, 2019).

Hazard Identification

Hazard identification (HI) is a critical component of any Occupational Safety and Health Management System (OSHMS). It involves detecting, recognizing, and evaluating hazardous conditions in the workplace to ensure risks are minimized (Gonzalez et al., 2015). Effective hazard identification in OSHMS requires a combination of robust methodologies, comprehensive tools, and active employee engagement (Nenonen et al., 2021). Addressing challenges such as psychosocial hazards and improving communication and safety culture are essential for minimizing risks and ensuring workplace safety (Agarwalla et al., 2025).

Operational Control

Operational control within an Occupational Safety and Health Management System (OSHMS) is crucial for ensuring workplace safety and minimizing risks. Operational control involves identifying, assessing, and controlling risks to prevent workplace accidents and health issues (Karkoszka, 2017). By systematically managing risks, operational control helps in preventing accidents and ensuring the safety of employees (Kapadia & Elliott, 2018). Adhering to operational

control standards ensures compliance with legal and regulatory requirements, avoiding penalties and legal issues (Hale et al., 2015). Operational control fosters a culture of continuous improvement, leading to better safety performance and reduced incident rates.

OSH Training and Competence

Different training methods, such as active group discussions and expository methods, have been shown to improve OSH knowledge, though their impact on safety behaviors may be limited (Barros et al., 2019). Continuous learning through professional organizations, conferences, and technical courses is encouraged to maintain and enhance OSH competences (Fuller, 2019). Despite having appropriate qualifications, many OSH service employees lack sufficient knowledge and skills to meet employers' expectations, highlighting the need for improved training and competence development. Effective OSH training and competence development are vital for the successful implementation of OSHMS. This involves a combination of validated training programs, continuous professional development, and organizational support to ensure that employees are equipped with the necessary skills and knowledge to manage workplace safety effectively. The integration of Human Factors and adherence to regulatory guidelines further enhance the effectiveness of these systems (Kwegyir-Afful et al., 2018).

Operational Risk

The danger of suffering a loss as a result of insufficient or unsuccessful internal procedures, personnel, or systems, or from outside circumstances, is known as operational risk (Setiawan & Yulianto, 2019). This type of risk is distinct from market and credit risk, as it does not offer the potential for higher returns when assumed; instead, it solely destroys value for all stakeholders (Peña et al., 2018). The first step in operational risk control is to identify potential risks that could adversely affect an organization. This includes recognizing hazards in the operational environment and understanding the sources of potential losses (Akgün, 2017). Risks must be evaluated once they have been identified in order to determine their likelihood and possible effect. Accurate risk measurement requires both quantitative and qualitative approaches. Continuous monitoring of identified risks is essential to ensure that they are managed effectively. This includes tracking risk indicators and reviewing risk management processes regularly (Kummer & Mendling, 2021).

Based on the theoretical perspectives and empirical evidence discussed in the preceding literature re-

view, it is evident that the implementation of the Occupational Safety and Health Management System (OSHMS) plays a crucial role in strengthening operational risk control in high-risk industrial settings. The key dimensions of OSHMS, including management policy and commitment, hazard identification, operational control, and OSH training and competence, are widely recognized as essential mechanisms for preventing incidents and mitigating operational risks. Therefore, to empirically examine the relationships between these OSHMS components and operational risk control in the biosilica production environment, the following hypotheses are formulated:

H1 Management Policy and Commitment has a positive effect on Operational Risk Control.

H2 Hazard Identification has a positive effect on Operational Risk Control.

H3 Operational Control has a positive effect on Operational Risk Control.

H4 OSH Training and Competence has a positive effect on Operational Risk Control.

Methods

The impact of implementing the Occupational Safety and Health Management System (OSHMS) on operational risk control in the biosilica production environment is investigated in this study utilizing a quantitative research technique and survey method. The implementation of OSHMS is reflected through four variables: management policy and commitment (X1), hazard identification (X2), operational control (X3), and OSH training and competence (X4). The dependent variable (Y) is operational risk control, which reflects the organization's capacity to proactively mitigate and manage operational risks. The population of this study includes employees directly involved in biosilica production processes, particularly those exposed to occupational hazards. Respondents with enough knowledge and expertise of occupational safety and health procedures in their workplace were chosen using a purposive sample approach. The determination of the sample size follows the recommendation by (Hair et al., 2022), which states that the minimum sample size should be 10 times the number of indicators used in the research model. With a total of 20 indicators, the required minimum sample size is 200 respondents. This ensures adequate statistical power for structural equation modeling using PLS. With the aid of Smart-PLS software, the data were examined using Partial Least Squares Structural Equation Modeling (PLS-SEM). This approach was selected due to its strong

suitability for predictive-oriented research, exploratory model development, and the analysis of complex relationships among latent variables, particularly when theoretical frameworks are still evolving (Chua, 2023). Partial Least Squares Structural Equation Modeling (PLS-SEM) is especially appropriate for handling multiple constructs measured by several indicators and for estimating models with intricate structural paths (Hair et al., 2022).

In the context of structural equation modeling, the constructs examined in this study are treated as latent variables, meaning that they cannot be observed directly and are therefore measured through multiple observed indicators. The measurement model (outer model) specifies the relationships between each latent variable and its indicators and was assessed to ensure indicator reliability, internal consistency, convergent validity, and discriminant validity. Subsequently, the structural model (inner model) represents the hypothesized causal relationships among the latent variables and was evaluated by examining path coefficients, t-statistics, and p-values to determine the significance and strength of the relationships. This two-stage analytical procedure is consistent with established guidelines for PLS-SEM and provides a robust framework for evaluating both measurement quality and structural relationships within the proposed research model (Hair et al., 2022; Kline, 2023).

To further enhance methodological transparency, the data collection instrument was developed based on established OSHMS and operational risk management literature, ensuring content validity of all measurement items. Each construct was measured using multiple indicators adapted from prior empirical studies and adjusted to the biosilica production context. Responses were captured using a five-point Likert scale ranging from 1 ("strongly disagree") to 5 ("strongly agree"), allowing respondents to express the extent of their agreement with each statement. Prior to the main data collection, the questionnaire was reviewed by occupational safety experts to ensure clarity, relevance, and contextual appropriateness. Data screening procedures were conducted to assess completeness and consistency of responses before analysis, ensuring that all cases met the requirements for PLS-SEM estimation. Bootstrapping with 5,000 resamples was applied to assess the significance of path coefficients, following recommended practices for robust hypothesis testing in PLS-SEM. This methodological approach strengthens the reliability of the findings and ensures that the estimated relationships between OSHMS components and operational risk control are statistically sound and theoretically meaningful.

Results

It is essential to describe the demographic and occupational characteristics of the respondents. This information provides context for understanding the perspectives of individuals involved in biosilica production, particularly those exposed to operational risks. The following table outlines the general profile of the respondents who participated in this study.

Table 1 summarizes the general profile of 200 respondents involved in biosilica production. The majority were male (69.0%) and primarily aged 30–39 years (43.0%), followed by 27.0% aged 20–29 years, 21.0% aged 40–49 years, and 9.0% aged 50 years or older. Regarding work experience, 36.0% of the respondents had 3–5 years of experience, 32.0% had 6–10 years, 18.0% had less than 3 years, and 14.0% had more than 10 years. Most respondents worked in the production department (55.0%), followed by maintenance/engineering (19.0%), health, safety, and environment (17.0%), and quality assurance/control (9.0%). In terms of exposure to occupational risk, 60.0% of respondents reported high exposure through direct contact with hazards, 30.0% experienced moderate or intermittent exposure, and 10.0% reported low or indirect exposure. These results suggest that the sample is well-distributed across rele-

vant operational domains and reflects a workforce with significant engagement in risk-prone processes, thereby providing a suitable basis for assessing operational risk control in biosilica production (Fig. 1).

The measurement model assessment aims to ensure that the research instrument meets the criteria for validity and reliability. This process is essential to confirm that the indicators accurately and consistently reflect the latent constructs. Based on the ideas of structural equation modeling (SEM), the evaluation analyzes average variance extracted (AVE), cronbach alpha, composite reliability, and discriminant validity.

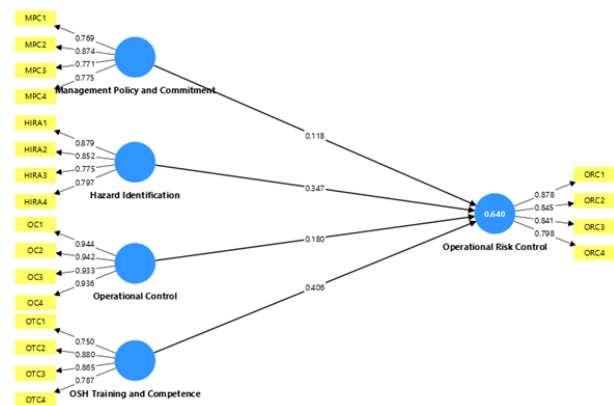


Fig. 1. Measurement Model

Table 1
Demographic Respondents

Category	Sub-category	Frequency (n)	Percentage (%)
Gender	Male	138	69.0
	Female	62	31.0
Age	20–29 years	54	27.0
	30–39 years	86	43.0
	40–49 years	42	21.0
	≥ 50 years	18	9.0
Work Experience	< 3 years	36	18.0
	3–5 years	72	36.0
	6–10 years	64	32.0
	> 10 years	28	14.0
Department	Production	110	55.0
	Maintenance/Engineering	38	19.0
	Health, Safety, and Environment	34	17.0
	Quality Assurance/Control	18	9.0
Exposure to Risk	High (Direct contact with hazards)	120	60.0
	Moderate (Intermittent exposure)	60	30.0
	Low (Indirect exposure)	20	10.0

Table 2 presents the construct reliability and validity results, demonstrating that all measurement constructs meet the required thresholds for internal consistency and convergent validity. Cronbach's alpha values range from 0.813 to 0.955, and composite reliability (ρ_c) scores range from 0.875 to 0.967, all exceeding the minimum standard of 0.70. Similarly, the Average Variance Extracted (AVE) for each construct is above the 0.50 threshold, ranging from 0.637 to 0.881, indicating adequate convergent validity. The highest reliability and validity values are observed in the Operational Control construct (Cronbach's alpha = 0.955, AVE = 0.881), confirming the robustness of the measurement model and the consistency of the indicators used to assess each latent variable.

The green-highlighted values in Table 2 indicate that all constructs meet the required reliability and convergent validity thresholds. Specifically, Cronbach's alpha and composite reliability values exceed 0.70, while the AVE values are above 0.50, confirming that the measurement model is reliable and valid.

Table 3 presents the Heterotrait-Monotrait (HTMT) ratios used to assess discriminant validity among the constructs. All HTMT values are below the recommended threshold of 0.90, indicating that each con-

struct is empirically distinct and does not overlap excessively with others. Specifically, the HTMT values range from 0.162 to 0.788, demonstrating clear differentiation between constructs such as Hazard Identification, Management Policy and Commitment, OSH Training and Competence, Operational Control, and Operational Risk Control. These results confirm that the measurement model satisfies the criterion for discriminant validity, thereby supporting the structural integrity of the construct relationships.

In Table 3, the values highlighted in green indicate that all HTMT ratios are below the recommended threshold of 0.90, confirming adequate discriminant validity. The green font is used to visually show that each construct is sufficiently distinct from the others, with no problematic overlap between latent variables.

The evaluation of the proposed connections between latent components is done through the structural model assessment. To ascertain the importance of each link, path coefficients, t-statistics, and p-values are analyzed. Furthermore, the model's explanatory power is evaluated using the coefficient of determination (R^2), and its capacity to forecast endogenous variables is assessed using the predictive relevance (Q^2) (Fig. 2).

Table 2
Construct Reliability and Validity

	Cronbach's alpha	Composite reliability (ρ_a)	Composite reliability (ρ_c)	Average variance extracted (AVE)
Hazard Identification	0.846	0.862	0.896	0.684
Management Policy and Commitment	0.813	0.860	0.875	0.637
OSH Training and Competence	0.845	0.884	0.893	0.676
Operational Control	0.955	0.956	0.967	0.881
Operational Risk Control	0.862	0.862	0.906	0.707

Table 3
Discriminant Validity

	Hazard Identification	Management Policy and Commitment	OSH Training and Competence	Operational Control	Operational Risk Control
Hazard Identification	–	0.249	0.690	0.364	0.783
Management Policy and Commitment	0.249	–	0.350	0.162	0.390
OSH Training and Competence	0.690	0.350	–	0.304	0.788
Operational Control	0.364	0.162	0.304	–	0.474
Operational Risk Control	0.783	0.390	0.788	0.474	–

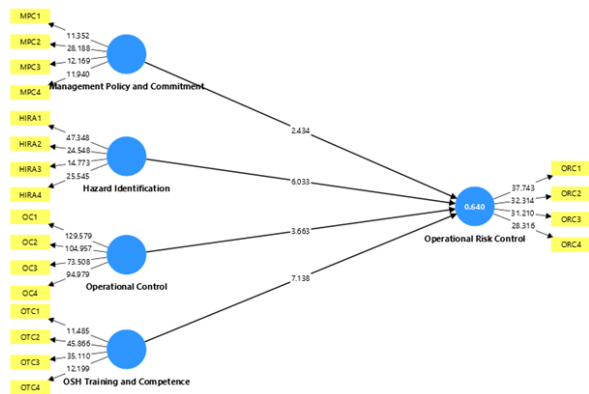


Fig. 2. Structural Model

Table 4 shows that the R^2 value for Operational Risk Control is 0.640, indicating that the exogenous variables in the model collectively explain 64% of the variance in this construct. The adjusted R^2 value of 0.633 further supports the model's explanatory strength by accounting for the complexity and number of predictors used. In addition, the Q^2 value of 0.624 reflects strong predictive relevance, suggesting that the model has a high level of accuracy in predicting the endogenous variable. These values collectively confirm that the structural model possesses substantial explanatory and predictive power in assessing operational risk control.

Table 4
 R Square and Q Square

	R -square	R -square adjusted
Operational Risk Control	0.640	0.633
	Q^2 predict	
Operational Risk Control	0.624	

Table 5 presents the results of the path coefficient analysis, indicating that all hypothesized relationships toward Operational Risk Control are statistically significant. Among the predictors, OSH Training and Competence exhibits the strongest influence ($\beta = 0.406$, $t = 7.138$, $p < 0.001$), followed by Hazard Identification ($\beta = 0.347$, $t = 6.033$, $p < 0.001$), Operational Control ($\beta = 0.180$, $t = 3.663$, $p < 0.001$), and Management Policy and Commitment ($\beta = 0.118$, $t = 2.434$, $p = 0.015$). These results confirm that each of the four exogenous variables makes a meaningful and statistically significant contribution to enhancing operational risk control within the biosilica production context.

In Table 5, only the p -values are highlighted in green to indicate that all hypothesized relationships are statistically significant. The green color shows that each

p -value is below the 0.05 significance level, confirming that the corresponding path coefficients have a meaningful effect on Operational Risk Control.

Table 5
Path Coefficient

	Original sample	T statistics	P values
Management Policy and Commitment $\rightarrow$ Operational Risk Control	0.118	2.434	0.015
Hazard Identification $\rightarrow$ Operational Risk Control	0.347	6.033	0.000
Operational Control $\rightarrow$ Operational Risk Control	0.180	3.663	0.000
OSH Training and Competence $\rightarrow$ Operational Risk Control	0.406	7.138	0.000

Discussion

Theoretically, these findings are consistent with the High Reliability Organization (HRO) framework, which highlights the need for ongoing training, a preoccupation with failure, and decentralized decision-making in maintaining safety in high-risk environments (Weick & Sutcliffe, 2015). In the context of operational risk control, HRO provides a conceptual foundation that underscores the importance of proactive risk identification, structured management policies, and competence-based interventions. Biosilica production involves intricate biological and chemical processes that are susceptible to a wide range of operational hazards, thereby demanding robust safety mechanisms. The application of HRO principles to this industry represents a promising pathway for enhancing operational safety and organizational reliability (Cantu et al., 2021).

In addition to the theory-driven interpretation, practical insights emerged during data collection that help explain how OSHMS is enacted in daily operations. Beyond the statistical results, the authors' observations suggest that OSHMS implementation in biosilica manufacturing is often uneven across operational units.

While policies, procedures, and formal documentation are generally available, their execution at the shop-floor level tends to depend heavily on frontline competence, situational awareness, and immediate supervisory reinforcement. This practical reality reflects a common gap highlighted in safety management literature: system design and formal compliance do not automatically translate into high reliability unless safety routines are embedded in everyday operational decisions. In the biosilica context, where process variability and exposure risks require rapid responses, operational risk control effectiveness is strongly shaped by how consistently workers apply hazard recognition and control procedures in real time, rather than by the existence of written standards alone.

From a practical standpoint, the strong effect of OSH Training and Competence highlights the importance of continuous investment in employee capacity building to ensure that personnel possess the necessary knowledge and skills to operate safely and respond effectively to potential hazards. This is particularly critical in the biosilica production industry, where complex processes and chemical exposures pose elevated safety risks. Regular training, risk awareness programs, and adherence to safety protocols are essential and can be supported through detailed safety instructions and process mapping (Tsopa et al., 2022). Continuous development of competencies in hazardous material handling and safety management further strengthens risk control effectiveness (Afroh & Basaria, 2023).

The significant influence of Hazard Identification confirms that proactive detection and assessment of potential risks form the foundation of an effective OSHMS framework. Proactive hazard identification enables organizations to shift from reactive to preventive safety strategies (Hopkin, 2018). In biosilica production, where chemical exposure and operational complexity are high, early detection of hazards is a critical control point. An effective Occupational Safety and Health Management System should therefore incorporate comprehensive hazard identification processes, including risks related to respirable crystalline silica (RCS) exposure (Moredock et al., 2023).

Operational Control also demonstrates a significant impact, supporting the assertion that standard operating procedures, work instructions, and continuous monitoring constitute the backbone of risk mitigation strategies (Goetsch & Ozon, 2019). Robust operational controls ensure consistency in safe work practices and reduce the impact of operational disruptions on organizational risk exposure and performance (Schmidt & Raman, 2022).

Although Management Policy and Commitment exhibits the smallest coefficient, its significance confirms that leadership support remains a critical enabler for the effective implementation of all other OSHMS components. Strong managerial commitment fosters a safety-oriented culture, ensures resource allocation, and establishes clear expectations for organizational behavior (Murray, 2015).

All findings align with the core principles of OSHMS as stipulated in ISO 45001:2018 and Indonesia's Government Regulation No. 50 of 2012. The results reinforce the necessity of integrating technical, behavioral, and managerial safety efforts to achieve comprehensive operational risk control. In biosilica production an industry characterized by emerging technologies and process-specific hazards such integration becomes particularly vital for sustaining safe and reliable operations (Ratar et al., 2019).

In comparison with previous studies, this research reveals several distinctive features of the biosilica production sector. While studies in financial and service industries emphasize governance-level controls and board oversight (Lawrence et al., 2018; Mandel & Parija, 2024), this study demonstrates that operational-level factors – particularly OSH Training and Competence and Hazard Identification – play a more dominant role in biosilica manufacturing. This reflects the sector's process-intensive and hazard-sensitive nature, where frontline workers' ability to recognize and respond to risks is critical (Nenonen et al., 2019; Si Mohammed & Rahmouni, 2025).

From the authors' perspective, this sector-specific pattern reflects the operational reality of biosilica manufacturing, where risk control effectiveness is determined by workers' real-time decision-making and competence under dynamic production conditions. This observation strengthens the HRO argument that reliability is sustained when safety principles are translated into routine behaviors and continuous learning at the operational level. Thus, confronting practice with theory, OSHMS effectiveness in biosilica manufacturing is best understood as an enacted capability rather than merely a documented management system.

Despite the valuable insights generated by this study, several limitations should be acknowledged. First, the cross-sectional research design limits the ability to establish strong causal relationships between OSHMS implementation and operational risk control, as the analysis reflects organizational conditions at a single point in time. Second, the study relies on self-reported questionnaire data, which may be subject to response bias and common method variance, despite the application of established reliability and validity assessments. Third,

the empirical context is restricted to biosilica manufacturing, which may limit the generalizability of the findings to other high-risk industries with different technological and organizational characteristics. In addition, the analytical model focuses on direct relationships and does not incorporate potential mediating or moderating variables such as safety culture, organizational learning, or digital safety systems. These limitations provide important opportunities for future research to further refine and extend the proposed framework.

Conclusions

By employing the Structural Equation Modeling (SEM) technique, this study examined how the introduction of the OSHMS (Occupational Health and Safety Management System) affected the operational risk control in the biosilica manufacturing process. The results demonstrate that OSH Training and Competence, Hazard Identification, Operational Control, and Management Policy and Commitment each have a statistically significant impact on enhancing operational risk control. Among these factors, OSH Training and Competence showed the strongest effect, emphasizing the importance of equipping workers with adequate knowledge and skills to manage risks effectively. These findings highlight the need for consistent and integrated implementation of OSHMS components to ensure a safer and more controlled production environment.

Based on the empirical findings of this study, it is strongly recommended that companies operating in biosilica production strengthen their implementation of the Occupational Safety and Health Management System (OSHMS) in a more structured and integrated manner. Specifically, organizations should prioritize the continuous development of OSH training and competence programs tailored to the specific hazards and operational conditions of biosilica production. This involves not only providing technical safety training but also fostering behavioral safety competencies, simulation-based learning, and periodic refresher courses to ensure sustained knowledge retention and hazard response readiness. Moreover, effective hazard identification should be institutionalized through the adoption of systematic risk assessment tools such as Job Safety Analysis (JSA), Failure Mode and Effects Analysis (FMEA), and predictive analytics.

These tools should be supported by real-time data collection and reporting mechanisms to ensure early detection and mitigation of operational risks. Operational controls must also be regularly evaluated and upgraded

in alignment with changes in production technology, regulatory requirements, and incident learning. This requires cross-departmental collaboration, standardized operating procedures, and integration with digital monitoring systems to enhance control effectiveness and responsiveness. In addition, top management must demonstrate a visible and sustained commitment to occupational safety by embedding OSH goals into strategic business planning, allocating adequate resources, and participating actively in safety audits and leadership walk-arounds. Cultivating a culture of safety leadership and shared accountability is crucial to ensuring that OSHMS implementation is not merely a compliance requirement but a core organizational value.

Future research avenues should extend the current findings by incorporating additional methodological and contextual dimensions. Subsequent studies may employ longitudinal research designs to capture the dynamic effects of OSHMS implementation on operational risk control over time, thereby enabling a more robust assessment of causality beyond cross-sectional SEM analysis. Future research is also encouraged to integrate mediating and moderating variables such as safety culture, digital safety maturity, organizational learning, and leadership style to refine the explanatory power of the SEM model. Furthermore, expanding the research scope to include multi-site biosilica manufacturing facilities or cross-industry comparisons would enhance the generalizability of the findings. The integration of advanced SEM techniques, such as multi-group analysis and higher-order construct modeling, may provide deeper insights into structural relationships among OSHMS components. Finally, future studies could explore the role of digital technologies, including Industry 4.0-based safety monitoring systems and predictive risk analytics, in strengthening the effectiveness of OSHMS and advancing proactive operational risk management.

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