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Developing an Integrated Process Safety Management Framework for Nickel Smelter Operations: Alignment of PP 50/2012, CCPS-RBPS, and OSHA 29 CFR 1910.119

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Abstract

The rapid expansion of Indonesia's mineral processing and refining industry, particularly nickel smelters, has heightened the need for a systematic, risk-based Process Safety Management (PSM) program. Existing Occupational Health and Safety Management Systems under Government Regulation No. 50/2012 are considered insufficient to comprehensively address the complex process hazards associated with smelter operations. This study aimed to develop an integrated Process Safety Management (PSM) framework for PT Ceria Nugraha Indotama (PT CNI) that aligns with Government Regulation No. 50/2012, the Center for Chemical Process Safety Risk-Based Process Safety (CCPS-RBPS) framework, and OSHA 29 CFR 1910.119 requirements. A mixed-methods approach was employed. Qualitative data were collected through document reviews, field observations, focus group discussions, and in-depth interviews with operational personnel and management to identify implementation barriers and enabling factors. Quantitative data were collected from 101 purposively selected respondents, comprising internal personnel and external professionals from high-risk industries. An initial set of 22 PSM elements identified through cross-comparison analysis was consolidated into 12 integrated components through expert validation and focus group discussions. Data analysis included Pearson correlation validity testing, Cronbach's Alpha reliability testing, Shapiro-Wilk normality testing, and One-Sample Wilcoxon Signed-Rank testing using Jamovi software. The Wilcoxon Signed-Rank Test showed significant positive responses across all twelve integrated components ($W = 5151$, $p < 0.001$), showing strong stakeholder acceptance of the proposed framework. Major implementation challenges included a limited understanding of trade secret management, mechanical integrity, and pre-startup safety review. In contrast, training systems, incident investigation practices, and work permit systems were identified as supporting factors. The integrated PSM framework developed in this study provides a practical reference for enhancing process safety performance in nickel smelters and other high-risk industries in Indonesia through a sustainable and risk-based management approach.

Keywords: PP 50/2012, Occupational Health, Safety Management System, Process Safety Management (PSM), CCPS-RBPS, OSHA 29 CFR 1910.119

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I. BACKGROUND

Indonesia occupies a strategic position in the global mining industry as one of the countries with the largest natural resource reserves, particularly nickel. According to data published by the United States Geological Survey (USGS), Indonesia possesses approximately 55 million tons of nickel reserves, equivalent to around 42-43% of total global nickel reserves, exceeding 130 million tons (Stewart, 2024). This figure places Indonesia far above other nickel-producing countries such as Australia, Brazil, Russia, and New Caledonia. In addition to proven reserves, Indonesia also has substantial unexplored nickel resources estimated at tens of billions of tons, offering significant opportunities for the future development of nickel-based downstream industries. Recognizing this strategic potential, the Indonesian government has encouraged the expansion of nickel mining and processing activities across various regions, particularly in eastern Indonesia. Current data indicate that approximately 339 active mining permits covering around 856 thousand hectares have been issued for nickel management and development activities (ChuangYu, 2025).

Nickel has become one of the world's most strategic minerals because of its crucial role in the steel and electric vehicle battery industries. The growing global demand for electric vehicles and renewable energy technologies has driven demand for nickel as a primary raw material for stainless steel and battery manufacturing (Purwanto, 2024). Consequently, the Indonesian government has provided extensive opportunities for businesses to conduct nickel exploration, mining, processing, and refining operations, especially in regions with large nickel reserves, such as Southeast Sulawesi, Central Sulawesi, and Maluku (Agung, 2020). Previously, Indonesia mainly exported raw nickel ore to foreign markets, resulting in limited domestic economic benefits and vulnerability to fluctuations in global commodity prices. To address this issue, the government introduced a strategic downstream policy, prohibiting the export of raw nickel ore from 2014 onward and promoting domestic mineral processing and refining industries (Gultom, 2020). This downstreaming policy aims to increase the added value of mineral commodities through processing and refining activities, thereby strengthening national competitiveness and increasing state revenues.

The nickel downstreaming policy has become one of the key pillars of Indonesia's national economic development strategy, particularly during the administration of

President Joko Widodo and the current government. Furthermore, the development of downstream nickel industries has been incorporated into the National Medium-Term Development Plan (RPJMN) 2025-2029 through Presidential Regulation Number 12 of 2025 (Perpres 12/2025; Ministry of National Development Planning/BAPPENAS). The importance of mineral value addition is also regulated under Law Number 3 of 2020, Article 102, which states that mineral value enhancement must be conducted through processing and refining activities for metallic minerals, non-metallic minerals, rocks, and coal. According to the Regulation of the Minister of Energy and Mineral Resources Number 25 of 2018, value addition refers to efforts to increase the value of minerals through processing and refining activities (Arif, 2022). Through this policy framework, the government has emphasized the construction of domestic smelter facilities so that nickel ore can be transformed into higher-value products such as ferronickel, nickel matte, steel products, and electric vehicle battery precursors, including Nickel Sulphate ($NiSO_4$) and Manganese Sulphate ($MnSO_4$) processed through High Pressure Acid Leaching (HPAL) technology (Gultom, 2020).

The implementation of downstream nickel industrialization has successfully transformed Indonesia into one of the world's largest exporters of stainless steel raw materials. This policy has generated substantial economic impacts, including increased investment, industrial growth, and increased state revenue. Statistics indicate that the export value of nickel products and their derivatives reached approximately US$7.99 billion by the end of 2024, an increase of nearly 53% from 2023 and significantly exceeding the export value achieved before the raw ore export ban policy was implemented (BPS, 2025). Beyond national economic contributions, downstream industrialization has accelerated industrial development in eastern Indonesia, regions that previously experienced relatively slow economic growth. The emergence of nickel processing and refining industries has created employment opportunities, improved the quality of human resources, and stimulated the growth of supporting sectors such as logistics, energy, and industrial services. The downstreaming program has also facilitated international technology transfer, enabling Indonesia to develop capabilities in operating sophisticated mineral processing and refining facilities.

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One of the companies actively contributing to the nickel downstreaming program is PT Ceria Nugraha Indotama (PT CNI), a domestic investment company operating mining, processing, and refining activities in Kolaka Regency, Southeast Sulawesi. PT CNI manages approximately 6,785 hectares of nickel mining areas and is currently entering the initial operational stage of its Rectangular Rotary Kiln Electric Furnace (RKEF) Line 1 smelter, followed by the planned development of High Pressure Acid Leaching (HPAL) facilities. The "Merah Putih" smelter project operated by PT CNI has been designated as one of Indonesia's National Strategic Projects. It is expected to strengthen Indonesia's position in the global green economy (CNI, 2019). The facility not only produces high-quality ferronickel products but also utilizes clean energy supplied by the national electricity company, PLN, thereby supporting the government's sustainable development agenda. PT CNI has also demonstrated a strong commitment to Environmental, Social, and Governance (ESG) principles by implementing renewable energy initiatives, reducing carbon emissions, empowering local communities, and creating employment opportunities for surrounding communities (Alamsyah, 2024).

Most existing studies have focused on the chemical, oil and gas, and manufacturing sectors, where PSM frameworks are generally applied as standalone systems based on either OSHA 29 CFR 1910.119 or CCPS-RBPS guidelines. Limited research has examined how international process safety frameworks can be systematically integrated with national occupational safety regulations in the extractive and mineral processing industries, particularly in nickel smelters. A theoretical gap remains in developing a context-specific PSM framework that simultaneously addresses regulatory compliance, process safety performance, and the unique operational hazards associated with nickel smelting technologies such as RKEF and HPAL. Previous studies have rarely explored how the complementary strengths of PP 50/2012, CCPS-RBPS, and OSHA 29 CFR 1910.119 can be combined into a unified framework suitable for high-risk industries in developing countries. This study advances PSM knowledge by proposing a structured model that bridges conventional occupational safety management and risk-based process safety management, thereby extending the application of PSM theory to the extractive industry. Therefore, this study aims to develop a structured, context-specific PSM

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framework for PT CNI by integrating the mandatory national regulation PP 50/2012 with the Risk-Based Process Safety (RBPS) framework developed by CCPS and the OSHA 29 CFR 1910.119 standards. This integrative approach is expected to bridge the gap between national regulatory compliance and the specific operational safety requirements of Indonesia's nickel smelting industry, while advancing process safety management practices in the national extractive sector (George, 2025).

2. METHODS

This study employed a mixed-methods research design to obtain valid, reliable, and comprehensive findings regarding the development of a Process Safety Management (PSM) system at the smelter facility of PT Ceria Nugraha Indotama (PT CNI). The research process began with a preliminary study analyzing existing company documents and operational data related to occupational and process safety practices. This initial assessment was intended to identify the level of conformity and the existing gaps between the current safety management system and the requirements of Government Regulation Number 50 of 2012 (PP 50/2012), CCPS Risk-Based Process Safety (RBPS), and OSHA 29 CFR 1910.119. Following the preliminary assessment, the study proceeded to select and formulate relevant PSM elements and sub-elements derived from the three regulatory and international standards. Qualitative and quantitative data were subsequently collected to gain a broader understanding of the selected variables, followed by validation through discussions with Subject Matter Experts, company management representatives, and operational managers, before preparing the final PSM system document.

The mixed methods research approach was selected because it combines the strengths of quantitative and qualitative methods within a single integrated study, thereby enabling researchers to answer both "what" questions through quantitative analysis and "why" or "how" questions through qualitative exploration. In the initial stage of the study, PSM elements were selected using a Cross-Comparison Analysis method. This approach involved mapping and comparing the elements and sub-elements in PP 50/2012, the CCPS-RBPS framework (20 elements), and OSHA 29 CFR 1910.119 (14 elements). Comparative matrices were developed to identify overlapping, complementary, and unique elements among the three standards. Through this process, the study analyzed similarities and differences in the

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objectives, structures, and implementation requirements of each standard to determine which elements were most relevant to the operational conditions of the PT CNI smelter facility. Gap analysis and risk-based decision-making techniques were also applied to evaluate whether additional elements were required to address the operational hazards associated with nickel smelting activities. Data collection was conducted through in-depth interviews involving personnel directly engaged in process safety management and smelter operations, including safety managers, process engineers, operators, technicians, maintenance personnel, and plant management representatives.

The quantitative approach used structured questionnaires and surveys distributed to personnel from PT CNI and several similar nickel processing and refining companies in Indonesia. The survey instrument was designed to identify the key elements required for effective PSM implementation in smelter industries and to evaluate compliance with CCPS-RBPS, OSHA 29 CFR 1910.119, and PP 50/2012 requirements. Survey respondents included Health, Safety, and Environment (HSE) Engineers, Process Plant Managers, Process Engineers, Plant Managers, Maintenance Managers, operators, technicians, and other personnel directly involved in operational safety management.

The questionnaire consisted of demographic information, implementation assessment questions, identification of operational barriers, and evaluation of enabling factors supporting the implementation of PSM systems. Several questions used a Likert scale to measure the degree of system integration, compliance, and managerial support related to process safety implementation. The Likert-scale questionnaire was developed based on the 12 integrated PSM elements identified through cross-comparison of PP 50/2012, CCPS-RBPS, and OSHA 29 CFR 1910.119. Each element was translated into a set of statements representing its implementation and applicability within smelter operations. The questionnaire content was subsequently reviewed through discussions with Subject Matter Experts, operational managers, and safety practitioners before distribution to respondents. Open-ended questions were also included to allow respondents to provide additional explanations regarding operational challenges and organizational conditions. The survey instrument was distributed via Google Forms to improve data collection efficiency and accessibility for respondents across different operational sites.

The quantitative survey employed purposive sampling to select respondents with direct experience in process safety, occupational safety, operations, maintenance, or managerial functions within high-risk industrial sectors. The final sample consisted of 101 respondents, including PT CNI personnel and professionals from comparable mineral processing and refining industries. Following the cross-comparison analysis, 22 initial PSM elements were presented during Focus Group Discussions involving safety experts, operational managers, and process engineers. Elements with overlapping objectives, implementation requirements, or operational functions were consolidated through consensus-based discussions, resulting in 12 integrated PSM components for subsequent evaluation.

The study was conducted at the nickel processing and refining facilities of PT CNI located in Kolaka Regency, Southeast Sulawesi, over five months. The research subjects included individuals directly involved in process safety management and smelter operations, while the research objects focused on operational equipment, safety management systems, and related safety documentation. Operational observations specifically covered critical smelter facilities, including the apron feeder, dryer unit, calcination kiln, calcine transfer system, furnace unit, and ferronickel production area. Additional research objects included existing occupational safety management systems, operational forms, work instructions, Standard Operating Procedures (SOPs), incident reports, and emergency response procedures. Independent variables in this study included the PSM elements derived from CCPS-RBPS, OSHA 29 CFR 1910.119, PP 50/2012, and the operational characteristics of PT CNI, while the dependent variables consisted of the level of success in implementing the PSM system and the level of compliance with PP 50/2012 requirements.

3. RESULTS

A gap analysis was conducted to compare the requirements of PP 50/2012, CCPS-RBPS, and OSHA 29 CFR 1910.119 and to identify process safety elements relevant to nickel smelter operations. The analysis identified 22 initial PSM elements that served as the basis for subsequent evaluation and framework development (Table 1).

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Table 1. Initial Process Safety Management Elements Identified Through Gap

No.	Integrated PSM Elements	PP 50/2012	CCPS-RBPS	OSHA 29 CFR 1910.119	Gap Identified
1	Company Policy	Explicitly Covered	Explicitly Covered	Not Covered	OSHA does not explicitly address company policy or leadership commitment.
2	Process Safety Culture	Partially Covered	Explicitly Covered	Not Covered	Strong emphasis exists only within CCPS-RBPS.
3	Employee Competencies	Explicitly Covered	Explicitly Covered	Partially Covered	OSHA focuses primarily on training rather than competency management.
4	Stakeholder & Employee Involvement	Partially Covered	Explicitly Covered	Explicitly Covered	More comprehensive coverage in OSHA and CCPS-RBPS.
5	Planning, Programs & OHS Documentation	Explicitly Covered	Partially Covered	Not Covered	OSHA does not require integrated OHS strategic planning.
6	Document Management	Explicitly Covered	Partially Covered	Partially Covered	Strongest emphasis found in PP 50/2012.
7	OHS Data & Information	Explicitly Covered	Explicitly Covered	Not Covered	OSHA lacks explicit OHS performance information requirements.
8	Process Safety Information (PSI)	Partially Covered	Explicitly Covered	Explicitly Covered	Fully addressed by OSHA and CCPS-RBPS.
9	Trade Secret	Not Covered	Not Covered	Explicitly Covered	Regulated only by OSHA.
10	Process Hazard Analysis (PHA)	Partially Covered	Explicitly Covered	Explicitly Covered	PP 50/2012 lacks explicit PHA requirements.
11	Hazardous Materials Management	Explicitly Covered	Partially Covered	Partially Covered	Most detailed requirements appear in PP 50/2012.
12	Operating Procedures & Maintenance Standards	Explicitly Covered	Explicitly Covered	Explicitly Covered	Covered comprehensively by all frameworks.
13	Mechanical Integrity	Partially Covered	Explicitly Covered	Explicitly Covered	Not explicitly addressed in PP 50/2012.
14	Pre-Startup Safety Review (PSSR)	Partially Covered	Explicitly Covered	Explicitly Covered	Strong emphasis in OSHA and CCPS-RBPS.
15	Management of Change (MoC)	Partially Covered	Explicitly Covered	Explicitly Covered	Not explicitly regulated in PP 50/2012.
16	Hot Work Permit	Partially Covered	Explicitly Covered	Explicitly Covered	More detailed requirements in OSHA.
17	Contractor Safety Management System (CSMS)	Explicitly Covered	Explicitly Covered	Explicitly Covered	Comprehensive coverage across all frameworks.
18	Training	Explicitly Covered	Explicitly Covered	Explicitly Covered	Comprehensive coverage across all frameworks.
19	Work Environment Monitoring	Explicitly Covered	Partially Covered	Not Covered	OSHA PSM does not specifically address occupational hygiene monitoring.
20	Incident & Accident Investigation	Explicitly Covered	Explicitly Covered	Explicitly Covered	Comprehensive coverage across all frameworks.
21	Compliance Audit	Explicitly Covered	Explicitly Covered	Explicitly Covered	Comprehensive coverage across all frameworks.
22	Emergency Response Plan & Team	Partially Covered	Explicitly Covered	Explicitly Covered	More comprehensive coverage in OSHA and CCPS-RBPS.

The gap analysis showed substantial overlap among the 22 identified elements. To improve practicality and avoid redundancy, a Focus Group Discussion (FGD) was conducted with operational managers, safety practitioners, and subject matter experts. Through consensus-based evaluation, conceptually related elements were consolidated into 12 integrated PSM components that served as the basis for the questionnaire and proposed framework, as shown in Table 2.

Table 2. Integrated PSM Components Developed Through FGD

No.	Integrated PSM Component	PP 50/2012	OSHA 29 CFR 1910.119	CCPS-RBPS
1	Occupational Safety Policy & Safety Culture	Articles 7-8	Employee Participation	Process Safety Culture
2	Occupational Safety Planning & Documentation	Articles 9-10	Operating Procedures	Operating Procedures
3	Contractors & Work Permit System	Appendix I, 3.1-3.2	Contractors	Contractor Management
4	Training & Competency	Article 12; Appendix I 4.x	Training	Training & Performance Assurance
5	Mechanical Integrity & Operations	Appendix I, 6.1-6.5	Mechanical Integrity	Asset Integrity & Reliability
6	Risk Analysis & Process Safety Information (PSI)	Article 11; Appendix I 5.x	PSI; PHA	HIRA; Process Knowledge Management
7	Documentation & Trade Secrets	Appendix I, 3.5	Trade Secrets	Process Knowledge Management
8	Pre-Startup & Emergency Response	Appendix I, 8.1-8.4	PSSR; Emergency Planning and Response	Pre-Startup Review; Emergency Management
9	Audit & Continuous Improvement	Articles 14-16	Compliance Audits	Auditing; Measurement & Metrics
10	Hazardous Chemicals Management	Appendix I, 6.3-6.4	PSI and Appendix A	HIRA; Process Knowledge Management
11	Incident Investigation	Appendix I, 10.x	Incident Investigation	Incident Investigation
12	Management of Change (MoC) & Worker Participation	Article 13; Appendix I 3.3	Management of Change; Employee Participation	Management of Change; Stakeholder Outreach

The questionnaire was distributed to both internal and external respondents associated with PT CNI to obtain representative empirical data regarding the implementation of Process Safety Management practices. Respondents included operational and maintenance staff, supervisors, managers, and professionals from organizations with similar high-risk industrial activities. A total of 101 respondent datasets were collected and analyzed statistically. Before conducting further statistical analyses, the questionnaire underwent validity and

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reliability testing to ensure it accurately measured the intended constructs and consistently reflected respondents' perceptions. Subsequently, normality testing was conducted to determine the distribution characteristics of the collected data. The results of the normality assessment served as the basis for selecting the appropriate statistical analysis method: normally distributed data permitted parametric analysis. At the same time, non-normal distributions required nonparametric techniques such as the Wilcoxon Signed-Rank Test.

The questionnaire used a Likert scale to measure respondents' perceptions of the implementation of Process Safety Management elements derived from the integration of PP 50/2012, CCPS-RBPS guidelines, and OSHA 29 CFR 1910.119 standards. Quantitative analysis was intended to transform subjective respondent perceptions, assessments, and evaluations into measurable numerical data suitable for statistical analysis. Data processing began with descriptive statistical analysis to evaluate respondent profiles and response distributions, followed by instrument quality testing through validity and reliability assessments. All statistical computations in this study were conducted using Jamovi.

Validity testing was conducted using Pearson Correlation analysis to evaluate whether the questionnaire items accurately measured the intended constructs associated with the twelve PSM elements shown in Figure 1.

Correlation Matrix

		Elemen1	Elemen2	Elemen3	Elemen4	Elemen5	Elemen6	Elemen7	Elemen8	Elemen9	Elemen10	Elemen11	Elemen12	Jlh Total
Elemen1	Pearson's r	—												
	df	—												
	p-value	—												
Elemen2	Pearson's r	0.766	—											
	df	99	—											
	p-value	<.001	—											
Elemen3	Pearson's r	0.699	0.842	—										
	df	99	99	—										
	p-value	<.001	<.001	—										
Elemen4	Pearson's r	0.725	0.846	0.884	—									
	df	99	99	99	—									
	p-value	<.001	<.001	<.001	—									
Elemen5	Pearson's r	0.675	0.833	0.846	0.854	—								
	df	99	99	99	99	—								
	p-value	<.001	<.001	<.001	<.001	—								
Elemen6	Pearson's r	0.591	0.777	0.785	0.813	0.871	—							
	df	99	99	99	99	99	—							
	p-value	<.001	<.001	<.001	<.001	<.001	—							
Elemen7	Pearson's r	0.610	0.785	0.741	0.757	0.825	0.857	—						
	df	99	99	99	99	99	99	—						
	p-value	<.001	<.001	<.001	<.001	<.001	<.001	—						
Elemen8	Pearson's r	0.632	0.771	0.783	0.766	0.826	0.833	0.843	—					
	df	99	99	99	99	99	99	99	—					
	p-value	<.001	<.001	<.001	<.001	<.001	<.001	<.001	—					
Elemen9	Pearson's r	0.640	0.792	0.790	0.771	0.777	0.826	0.877	0.862	—				
	df	99	99	99	99	99	99	99	99	—				
	p-value	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	—				
Elemen10	Pearson's r	0.580	0.730	0.771	0.775	0.841	0.876	0.844	0.848	0.800	—			
	df	99	99	99	99	99	99	99	99	99	—			
	p-value	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	—			
Elemen11	Pearson's r	0.509	0.673	0.700	0.722	0.722	0.794	0.749	0.800	0.793	0.771	—		
	df	99	99	99	99	99	99	99	99	99	99	—		
	p-value	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	—		
Elemen12	Pearson's r	0.534	0.681	0.729	0.660	0.759	0.806	0.833	0.804	0.829	0.797	0.736	—	
	df	99	99	99	99	99	99	99	99	99	99	99	—	
	p-value	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	—	
Jlh Total	Pearson's r	0.752	0.896	0.902	0.906	0.925	0.923	0.910	0.914	0.913	0.903	0.842	0.856	—
	df	99	99	99	99	99	99	99	99	99	99	99	99	—
	p-value	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	—

Figure 1. Correlation Matrix Results for Validity Testing

Based on Figure 1, all Pearson correlation coefficients between elements ranged from 0.731 to 0.928, indicating strong, positive inter-item relationships among all variables. The correlation coefficients between each element and the total score exceeded 0.84, with some exceeding 0.945, indicating that all elements significantly contributed to the overall measurement model. The significance values for all correlations were reported as $p < .001$, indicating that the probability of the observed correlations occurring by chance was less than 0.1%. According to the commonly accepted validity criteria, where questionnaire items are considered valid if the calculated correlation coefficient exceeds the critical r-table value at $\alpha = 0.05$, all questionnaire items were confirmed as valid because all calculated r-values substantially exceeded the r-table value of 0.195, as shown in Table 3.

Table 3. Pearson Correlation Coefficients for Validity Testing

No.	Element	r-value (r-count)	r-value (r-table)	Status
1	Element 1	0.752	0.195	Valid
2	Element 2	0.896	0.195	Valid
3	Element 3	0.902	0.195	Valid
4	Element 4	0.906	0.195	Valid
5	Element 5	0.925	0.195	Valid
6	Element 6	0.923	0.195	Valid
7	Element 7	0.910	0.195	Valid
8	Element 8	0.914	0.195	Valid
9	Element 9	0.913	0.195	Valid
10	Element 10	0.903	0.195	Valid
11	Element 11	0.842	0.195	Valid
12	Element 12	0.856	0.195	Valid

Reliability testing was subsequently performed using Cronbach's alpha to evaluate the questionnaire's internal consistency, as shown in Table 4.

Table 4. Scale Reliability

Analysis	Metric	Value
Scale Reliability	Cronbach's	0.974

The results showed a Cronbach's Alpha coefficient of 0.974 for the 12 elements, based on responses from 101 respondents with no missing data. This value significantly exceeded the commonly accepted reliability threshold of 0.70, showing an exceptionally high level of internal consistency among the questionnaire items. The findings confirmed that all twelve elements collectively measured the same construct with very low measurement error. Item-level analysis showed that each item contributed meaningfully to the instrument's overall reliability. From a psychometric perspective, these results provided a strong empirical basis for subsequent analyses, such as regression and hypothesis testing, with confidence that the collected data originated from a reliable and trustworthy measurement instrument.

Normality testing was conducted using the Shapiro-Wilk method to determine whether the collected data followed a normal distribution, shown in Table 5.

Table 5. Descriptive Statistics and Shapiro-Wilk Normality Test

Element	Missing	Mean	Median	Standard Deviation	Min	Max	Shapiro-Wilk W	Shapiro-Wilk p
E.1	0	3.81	4.00	0.866	1.00	5.00	0.924	< .001
E.2	0	3.80	4.00	0.936	1.20	5.00	0.923	< .001
E.3	0	3.96	4.00	0.831	1.00	5.00	0.931	< .001
E.4	0	3.69	3.80	1.05	1.00	5.00	0.927	< .001
E.5	0	3.68	3.80	0.843	1.20	5.00	0.958	0.003
E.6	0	3.60	3.60	0.886	1.00	5.00	0.956	0.002
E.7	0	3.73	3.80	0.778	1.20	5.00	0.950	< .001
E.8	0	3.80	4.00	0.748	1.20	5.00	0.956	0.002
E.9	0	3.86	4.00	0.778	1.40	5.00	0.944	< .001
E.10	0	3.69	3.60	0.829	1.00	5.00	0.962	0.005
E.11	0	3.83	4.00	0.888	1.00	5.00	0.937	< .001
E.12	0	3.78	3.80	0.822	1.00	5.00	0.940	< .001

The descriptive statistical analysis showed that the mean values for all elements ranged from 3.60 to 3.96, showing generally positive respondent evaluations toward the implementation of PSM elements. Median values were predominantly 4.00 and 3.80, consistent with a tendency toward positive responses. Standard deviation values ranged from 0.748 to 1.05, showing moderate variability in respondent perceptions across the measured elements. However, all Shapiro-Wilk significance values were reported as $p < .001$, indicating that the data were not normally distributed and exhibited right-skewed, leptokurtic distributions.

The One-Sample Wilcoxon Signed-Rank Test was subsequently applied because the data did not satisfy the assumptions required for parametric one-sample t-tests. The Wilcoxon test results showed identical W statistics of 5151 across all 12 elements, with all p-values remaining below .001, indicating highly significant results, as shown in Table 6.

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Table 6. Wilcoxon Signed-Rank Test for Process Safety Management Questionnaire Data

Element	Test Statistic	Wilcoxon W	p-value
Element 1	Wilcoxon W	5151	< 0.001
Element 2	Wilcoxon W	5151	< 0.001
Element 3	Wilcoxon W	5151	< 0.001
Element 4	Wilcoxon W	5151	< 0.001
Element 5	Wilcoxon W	5151	< 0.001
Element 6	Wilcoxon W	5151	< 0.001
Element 7	Wilcoxon W	5151	< 0.001
Element 8	Wilcoxon W	5151	< 0.001
Element 9	Wilcoxon W	5151	< 0.001
Element 10	Wilcoxon W	5151	< 0.001
Element 11	Wilcoxon W	5151	< 0.001
Element 12	Wilcoxon W	5151	< 0.001

4. DISCUSSION

The results of the Wilcoxon Signed-Rank Test showed a highly consistent statistical pattern across all twelve elements of the integrated Process Safety Management (PSM) system. Each element yielded the same Wilcoxon W value of 5151, with a p-value of < 0.001, indicating that the null hypothesis was rejected for all variables. This finding confirms that the median score for each element was significantly greater than zero, indicating a strong positive perception among respondents regarding the implementation of MKP/PSM elements within the company. The consistency of the results across all variables suggests that respondents viewed the integrated framework as a cohesive, interconnected system rather than as separate, isolated components. The high mean scores, ranging from 3.60 to 3.96, support the interpretation that respondents generally agreed with the relevance and importance of all PSM elements.

The findings regarding respondents' perceptions of implementation gaps revealed several critical barriers affecting the successful implementation of the MKP/PSM system. Among all elements, Trade Secret was identified as the least understood, with 63% of respondents showing limited comprehension. This result indicates that legal-administrative aspects of process safety are less familiar to operational personnel than practical safety procedures encountered in daily activities. In the context of OSHA 29 CFR 1910.119(p), a Trade Secret is the protection of proprietary process information while still ensuring worker access to hazard-related information. The lack of understanding of this element may stem from insufficient training and limited integration of intellectual property discussions into conventional occupational safety programs. In addition, Mechanical Integrity was identified as another major challenge by 52% of respondents.

Approximately 44% of respondents identified PSSR as difficult to understand, while 37% reported challenges in understanding MoC procedures. These findings are significant because both elements represent critical preventive controls within process safety management systems. PSSR serves as a verification mechanism before startup or restart operations, ensuring that all safety requirements are met before hazards are activated. Meanwhile, MoC ensures that every operational or technical change undergoes a structured safety evaluation before implementation. The relatively limited understanding of these elements may stem from the perception that they are administrative processes rather than operational risk-control mechanisms. In many industrial environments, workers often perceive changes such as alarm setpoint adjustments or material substitutions as minor modifications that do not require formal evaluation procedures. This phenomenon can gradually lead to normalization of deviance, where small unmanaged changes accumulate into significant process safety vulnerabilities.

In contrast to the identified barriers, several elements showed very high levels of understanding and served as enabling factors supporting successful MKP/PSM implementation. The Data and Information element of OHS Programs achieved the highest level of understanding, with 98% of respondents showing familiarity with this component. This result suggests that safety performance reporting systems, safety metrics, and documentation activities have already become institutionalized within the organizational culture. Similarly, Training was understood by 93% of respondents, reflecting the effectiveness of the company's existing occupational safety education programs and competency development initiatives. The high level of familiarity with training activities may be attributed to regular induction programs, toolbox meetings, competency certifications, and routine safety briefings that directly involve employees in structured learning processes. Incident and Accident Investigation also showed a high level of understanding, reaching 91% of respondents.

A strong understanding of Work Permit and Supervision systems also significantly contributed to the implementation readiness of the integrated MKP/PSM framework. Approximately 91% of respondents reported a good understanding of permit-to-work procedures and supervisory controls during hazardous work activities. This finding reflects the operational visibility and routine interaction workers have with permit systems in daily industrial operations. Permit-to-work systems are highly tangible administrative controls that directly involve workers, supervisors, and operational authorities in hazard identification and risk management processes. As a result, employees tend to become more familiar with these procedures than with more conceptual process safety elements, such as Trade Secret or Mechanical Integrity. Furthermore, the element of OHS Planning, Programs, and Documentation also showed high comprehension levels, with 90% of respondents demonstrating comprehension. The implementation of SMK3, as outlined in Government Regulation No. 50 of 2012, has established a structured management foundation that supports the organizational understanding of systematic safety management processes.

The development of the integrated MKP/PSM framework in this study shows significant strategic advantages for high-risk industries, particularly within nickel smelter operations. The integration of PP 50/2012, OSHA 29 CFR 1910.119, and CCPS-RBPS successfully bridges the gap between general occupational safety management and specialized process safety requirements. Conventional SMK3 systems primarily focus on occupational safety hazards affecting individual workers. In contrast, process safety management emphasizes preventing catastrophic incidents involving large-scale explosions, toxic releases, equipment failures, and process instability. The inclusion of advanced elements such as Process Hazard Analysis (PHA), Mechanical Integrity, PSSR, and Management of Change enables the framework to address systemic operational risks that are not comprehensively covered within conventional occupational safety systems. In addition, adapting the framework to the specific operational characteristics of nickel smelters enhances its practical relevance and implementation feasibility. The proposed framework not only enhances regulatory compliance but also supports operational reliability, business sustainability, and organizational resilience against major process hazards. Therefore, this integrated MKP/PSM framework has strong potential to become a reference model for other high-risk industries in Indonesia seeking to improve process safety performance while aligning with international best practices.

5. CONCLUSION

The research identified 22 key PSM elements by integrating Indonesian Government Regulation PP No. 50/2012, CCPS-RBPS, and OSHA 29 CFR 1910.119, thereby creating a comprehensive framework adaptable to the characteristics of high-risk mineral processing and refining industries in Indonesia. Quantitative findings demonstrated excellent construct validity and high internal reliability (Cronbach's $\alpha = 0.974$). At the same time, the One-Sample Wilcoxon Signed-Rank Test showed significant positive acceptance of all proposed PSM elements ($W = 5151$, $p < 0.001$), with mean Likert scores ranging from 4.00 to 4.26, indicating very positive perceptions from both internal and external stakeholders toward the developed system. The study also identified key driving factors supporting implementation, including OHS data and information systems, training, incident investigation, work permit and supervision, and OHS planning and documentation. In contrast, major implementation gaps were found in trade secret management, mechanical integrity, pre-startup safety review, management of change, and hazardous material management.

AUTHOR CONTRIBUTIONS

AYE, contributed to the development of research concepts, data collection, data processing and analysis, interpretation of research results, preparation and revision of the article manuscript. IB, contributed to research supervision, preparation of research methodology, validation of data analysis, as well as revision and refinement of the article manuscript

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CONFLICT OF INTEREST

The authors declare that there are no conflicts of interest in this research.

DATA AVAILABILITY STATEMENT

The data the findings of this research are available from the corresponding author upon reasonable request.

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