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Risk-Informed Strategic Governance in Precast Concrete Production as A High-Risk Industry: Cross-Sector Evidence from The Construction and Oil & Gas Industries

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ABSTRACT - High-risk industrial production systems, particularly in the oil and gas sector, are characterized by capital-intensive operations, strict regulatory requirements, and extremely low tolerance for technical failure. In such environments, misalignment between technical risk exposure and strategic decision-making may escalate into significant operational, financial, and safety consequences. However, empirical examination of risk-informed strategic governance in oil and gas production systems remains limited due to data accessibility and confidentiality constraints. To address this gap, this study proposes an integrated risk-informed strategic governance framework using precast concrete manufacturing in Indonesia as a representative high-risk industrial production system with structural characteristics analogous to oil and gas fabrication and EPC-based operations. This study integrates the Risk Breakdown Structure (RBS) and Risk Priority Number (RPN) methods with the Quantitative Strategic Planning Matrix (QSPM) to explicitly link quantified technical risk exposure with strategic governance priorities. A descriptive–quantitative approach was employed, involving leading precast concrete companies in Indonesia to capture actual industrial production conditions. The research was conducted through three main stages: 1). Systematic identification and hierarchical classification of technical risks using the RBS method; 2). Quantitative assessment and prioritization of risks using the RPN method based on severity, occurrence, and detection parameters; and 3). Formulation and prioritization of strategic governance responses using the QSPM approach. The results indicate that the most critical technical risks are design drawing errors, lack of supervision over the implementation of production standards, and product non-compliance with quality requirements, as reflected by the highest RPN values. Integration of RPN outputs into the QSPM analysis identifies three governance priorities with the highest Total Attractiveness Score (TAS): implementation of effective management systems, conducting operational risk management, and reducing product deviations. These priorities demonstrate the strongest quantitative alignment between dominant technical risks and strategic governance responses. Overall, the proposed RBS–RPN–QSPM integration framework strengthens the linkage between technical risk assessment and strategic governance by explicitly transforming quantified operational risk into strategic decision variables. In practice, the framework provides a structured decision-support approach that can assist oil and gas fabrication managers in prioritizing governance interventions—such as strengthening design verification, improving production supervision, and enhancing quality compliance—based on quantified technical risk exposure. Although empirically grounded in precast concrete manufacturing, the governance logic and decision-support architecture are therefore transferable to oil and gas fabrication yards, modular construction facilities, and EPC-based production systems, where strategic choices must be explicitly aligned with technical risk exposure to enhance operational robustness, regulatory compliance, and long-term sustainability.

Keywords: risk-informed strategic governance; technical risk; RBS; RPN; QSPM; high-risk industrial production; oil and gas industry; precast concrete manufacturing.

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INTRODUCTION

The oil and gas industry represents one of the most prominent examples of high-risk industrial production systems, characterized by capital-intensive operations, strict regulatory oversight, and extremely low tolerance for technical failure. In fabrication yards, modular construction facilities, and engineering–procurement–construction (EPC)–based environments, relatively minor technical deviations—such as design inaccuracies, insufficient supervision, or quality non-conformance—may escalate into severe operational disruptions, financial losses, safety incidents, and environmental impacts. Consequently, effective organizational governance in oil and gas production systems depends critically on the ability to integrate technical risk management with strategic decision-making processes.

Comparable structural characteristics are also observed in construction-related industrial manufacturing systems, particularly in precast concrete production. As a capital-intensive and project-based industrial activity, construction manufacturing plays a significant role in supporting national infrastructure development and broader economic growth through employment creation, productivity enhancement, and regional development (Panjaitan et al., 2019). Government development policies strongly influence demand for industrial construction outputs, including precast concrete components. At the same time, construction production systems are widely recognized as highly complex and uncertain, particularly in terms of planning accuracy, execution reliability, cost control, and quality assurance. These characteristics generate substantial technical, financial, and operational risks that can undermine project performance and threaten organizational continuity (Ervianto 2006; Marie et al., 2020).

Within the broader category of high-risk industrial production systems, the precast concrete industry in Indonesia provides a representative empirical context for examining risk-informed strategic governance. Rapid expansion in production capacity driven by national infrastructure programs has not been matched by proportional growth in market demand, resulting in persistent oversupply. Recent data indicate that average capacity utilization in Indonesian precast concrete companies in 2024 remains below 44%, leading to declining operational efficiency, higher fixed costs per unit, and compressed profit margins (Wang et al., 2018). Under such conditions, competitive advantage is no longer determined primarily by market penetration or product differentiation, but increasingly by internal production reliability, operational discipline, and the effectiveness of governance mechanisms in managing technical risk. These pressures closely resemble those faced by oil and gas production systems, where technical inefficiencies directly translate into strategic and financial vulnerability.

Precast concrete manufacturing exhibits key characteristics that structurally align it with other high-risk industrial production systems, including oil and gas fabrication and modular construction facilities. According to BSN (2012), precast concrete components are produced off-site in controlled factory environments before being transported and assembled on-site. This industrialized approach enables improved quality consistency, shorter execution times, and higher labor productivity (Lam 2003; Vaughan & Vaughan 2003). However, these advantages are offset by substantial upfront capital investment requirements and strong dependence on design accuracy, standardized production processes, specialized equipment, and tightly coordinated logistics. As a result, precast concrete manufacturing—similar to oil and gas industrial production—operates as an integrated technical system in which failures in design control, process supervision, or quality assurance may propagate across the production chain and generate significant operational and financial consequences.

In environments characterized by intense competition and elevated technical uncertainty, many precast concrete companies in Indonesia have experienced strategic underperformance due to inadequate risk assessment and misalignment between business strategies and actual operational conditions. Risk, in this context, represents the potential deviation between expected and realized outcomes, creating both threats and opportunities for organizational sustainability (Tarantino 2008; Valena 2019). In high-risk industries such as oil and gas, risk management is widely understood as a proactive governance process that identifies uncertainty and embeds mitigation mechanisms within organizational decision structures to minimize adverse impacts while preserving strategic flexibility (Hillson & Murray-Webster 2017; PMI 2017). Similarly, in precast concrete manufacturing, technical risks emerge across all stages of production, including design completeness, material preparation, casting, curing, quality inspection, and product delivery.

Despite the recognized importance of risk management, existing studies largely treat technical risk analysis and strategic planning as separate domains. Technical risk assessment tools such as the Risk Breakdown Structure (RBS) and Risk Priority Number (RPN) are predominantly applied at the operational level for risk identification and prioritization, without being systematically embedded into strategic or governance-level decision-making processes. Consequently, strategic choices in both construction manufacturing and oil and gas industrial systems often rely on qualitative managerial judgment or market-driven considerations, rather than on explicitly quantified technical risk exposure.

A further challenge arises from the limited accessibility of operational risk data within the oil and gas industry. Due to the strategic sensitivity of fabrication processes, safety-critical operations, and proprietary engineering practices, many oil and gas companies impose strict confidentiality restrictions on technical risk information and internal governance procedures. These confidentiality constraints significantly limit opportunities for empirical academic research directly within oil and gas production environments. As a result, alternative empirical contexts that share comparable structural and operational characteristics are often required in order to examine governance mechanisms relevant to high-risk industrial systems.

Accordingly, this study proposes an integrated RBS–RPN–QSPM framework to develop a risk-informed strategic governance model, using precast concrete manufacturing as a representative empirical case under conditions of oversupply and high technical uncertainty. In the proposed framework, RPN values derived from technical risk assessment are explicitly incorporated into the Quantitative Strategic Planning Matrix (QSPM), ensuring that strategic priorities are aligned with objectively measured technical risk exposure. Rather than positioning precast concrete and oil and gas as empirically comparative sectors, this study conceptualizes precast concrete manufacturing as a structurally analogous high-risk industrial production system through which transferable governance logic can be derived.

The primary contribution of this research lies in the systematic integration of operational risk quantification and strategic governance evaluation. Unlike conventional studies that treat risk assessment and strategy formulation as separate analytical processes, this study explicitly transforms quantified technical risk priorities (RPN values) into strategic decision variables within the QSPM framework. This integration provides a structured mechanism for translating operational risk exposure into governance-level strategic priorities in high-risk industrial production systems. By linking operational risk analysis to strategic governance, the proposed framework offers a structured and replicable decision-support model applicable to oil and gas production environments as well as other capital-intensive industrial systems characterized by technical complexity, strict quality requirements, and severe consequences of operational failure.

METHODOLOGY

This study adopts a descriptive–analytical quantitative approach aimed at integrating technical risk assessment outcomes into strategic governance decision-making within high-risk industrial production systems. A quantitative approach is employed because it enables objective measurement of relationships among risk variables and supports the formulation of governance priorities based on transparent and comparable calculation results (F. R. David & David 2017). From an industrial engineering and governance perspective, this approach is particularly suitable for analyzing complex production environments characterized by high technical uncertainty, tightly interdependent processes, and severe consequences of operational failure—conditions that are typical of oil and gas fabrication and EPC-based production systems.

The empirical object of this study is the precast concrete production process at precast concrete companies in Indonesia. This production system is selected because it represents a capital-intensive, fabrication-based industrial environment in which technical risks directly influence operational reliability, product quality, and organizational competitiveness (Mehta & Monteiro 2014). Structurally, this context shares fundamental characteristics with oil and gas fabrication yards, modular construction facilities, and EPC-based production systems, particularly with respect to design dependency, process discipline, quality assurance requirements, and low tolerance for technical deviation. Due to restricted access and confidentiality constraints commonly associated with operational risk data in oil and gas production environments, precast concrete manufacturing is treated in this study as a representative high-risk industrial production system through which transferable strategic governance logic can be examined.

The data utilized in this study consist of both primary and secondary sources. Primary data were collected through Focus Group Discussions (FGD) involving core management and technical personnel from leading precast concrete companies in Indonesia. To ensure the validity of expert judgment for cross-sector analysis, the FGD participants were selected based on their professional experience in high-risk industrial operations, including large-scale infrastructure construction, industrial fabrication, and engineering –procurement–construction (EPC) project environments. Several participants possessed prior experience working in multi-sector project contexts where construction manufacturing interfaces with oil and gas–related industrial supply chains. These expert participants were therefore considered capable of providing informed judgments regarding technical risk identification and governance practices applicable across high-risk industrial production systems. The FGD sessions were conducted to elicit expert judgment regarding the identification, assessment, and prioritization of technical risks across the production process, reflecting actual governance and decision-making environments faced by industrial organizations. Secondary data were obtained from internal company reports, industry publications, and relevant scientific literature to support methodological rigor and contextual consistency (Creswell & Creswell 2018).

Technical risk assessment was conducted using the Risk Breakdown Structure (RBS) and Risk Priority Number (RPN) methods. The RBS method was applied to systematically identify and classify technical risks in a hierarchical structure based on their sources and production stages, ensuring comprehensive coverage of risk exposure throughout the production system (Hillson 2003). Subsequently, the RPN method was employed to prioritize identified risks by evaluating three parameters: severity (S), occurrence (O), and detection (D). The RPN value for each risk was calculated using the following Equation 1:

$$RPN = S \times O \times D \quad (1)$$

This calculation provides a quantitative measure of technical risk criticality, enabling objective comparison across different categories of risk within the production system and generating governance-relevant inputs for subsequent strategic evaluation.

The outputs of the RBS–RPN analysis were then integrated into the Quantitative Strategic Planning Matrix (QSPM) to support risk-informed strategic governance decisions. QSPM is a quantitative strategic evaluation tool designed to assess the relative attractiveness of alternative strategic options based on weighted internal and external factors (Gurel 2017). In the context of this study, QSPM functions as a governance mechanism that translates quantified technical risk exposure into strategic priorities, ensuring that strategic decisions are explicitly aligned with dominant operational risk profiles. The implementation of QSPM followed three main steps: 1). Compiling a set of strategic governance alternatives derived from the results of technical risk assessment; 2). Assigning weights and Attractiveness Scores (AS) to reflect the relevance of each strategy in addressing identified technical risks; and 3). Calculating the Total Attractiveness Score (TAS) to determine the priority of strategic governance responses.

The overall research procedure was conducted through a structured and sequential set of stages integrating technical risk identification, quantitative risk prioritization, and strategic governance evaluation. These stages begin with systematic risk identification using RBS, followed by RPN-based quantitative assessment, and culminate in the formulation of governance-oriented strategic priorities using QSPM. The complete research stages of the proposed framework are illustrated in Figure 1. As illustrated in Figure 1, the proposed framework establishes a coherent linkage between technical risk assessment and strategic governance decision-making. By embedding RPN values directly into the QSPM analysis, the framework ensures that governance priorities are explicitly aligned with objectively measured technical risk exposure, rather than relying solely on qualitative managerial judgment or market-driven assumptions.

This integrative approach combining RBS, RPN, and QSPM is intended to generate a risk-informed strategic governance model capable of improving the robustness and accountability of decision-making in high-risk industrial production environments. Although empirically grounded in the precast concrete industry in Indonesia, the framework is designed to be sector-neutral and transferable to other capital-intensive and highly regulated production systems, including oil and gas fabrication yards and EPC-based operations. The proposed method aligns with the principles of structured risk governance recommended by ISO 31000 (2018 and PMI (2017, particularly for engineering-oriented industries where technical risk exposure plays a decisive role in shaping strategic and organizational outcomes.

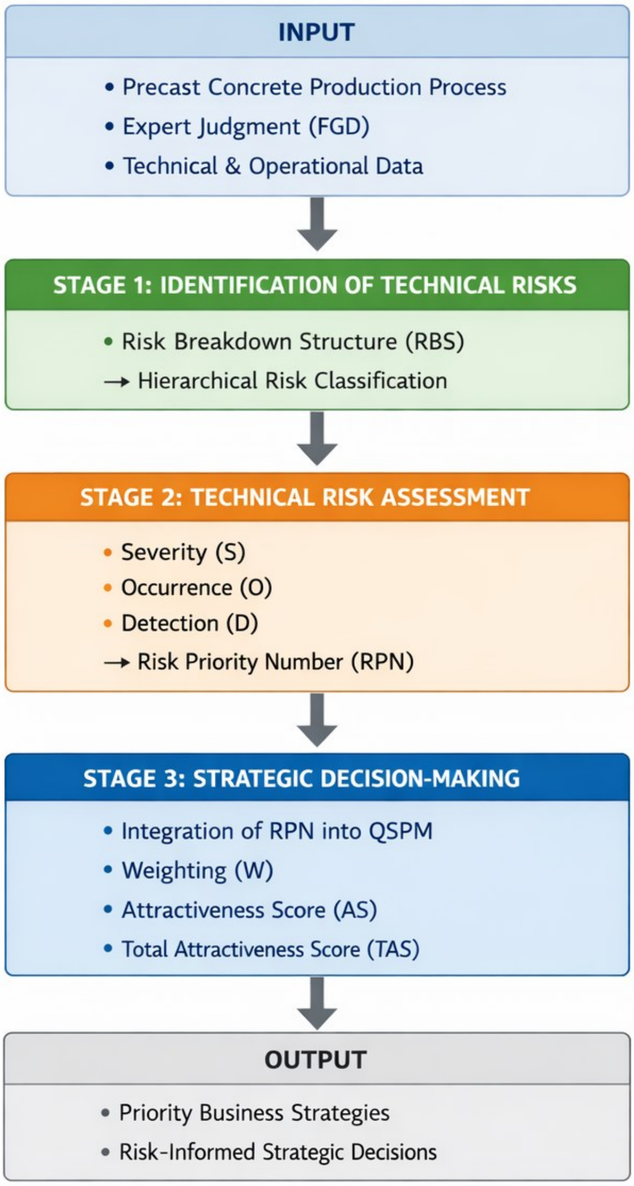

Figure 1. Research stages of the risk-informed strategic decision-making framework.

RESULT AND DISCUSSION

Precast concrete production process as a high-risk industrial governance system

High-risk industrial production systems, such as those found in oil and gas fabrication yards and EPC-based operations, are characterized by sequentially interdependent processes, capital intensity, and extremely low tolerance for technical failure. Within this category, the precast concrete production process in Indonesia provides a representative empirical setting for examining risk-informed strategic governance. The production process consists of a series of interrelated and sequential activities, beginning with design and technical completeness requirements, followed by material preparation, product molding, curing, quality inspection, and final product delivery to the project site. From an industrial engineering perspective, this configuration constitutes a technically interdependent production system in which deviations occurring at early stages may propagate downstream and significantly affect production performance, product quality, and delivery reliability.

In practice, variations in production technology, levels of factory automation, and human resource competencies substantially influence operational efficiency and process stability across precast concrete manufacturers in Indonesia. Differences in installed capacity, equipment condition, and adherence to standard operating procedures further contribute to heterogeneous technical risk exposure. As a result, precast concrete manufacturing operates as a high-risk industrial environment in which technical failures, process inefficiencies, or coordination gaps may trigger cost escalation, schedule disruption, and quality non-conformance. These characteristics are structurally consistent with conditions observed in oil and gas fabrication yards and EPC-based production systems, where tightly coupled processes and strict performance requirements amplify the strategic consequences of technical deviations.

From a strategic governance perspective, a comprehensive understanding of the production process flow is essential not merely for operational control, but for structuring effective risk-informed oversight. Detailed mapping of production activities enables the identification of critical control points at which technical risks originate, interact, and propagate across the system. This process-oriented view aligns with governance practices in complex industrial systems, including oil and gas production environments, where effective decision-making depends on visibility across interconnected technical processes rather than isolated functional silos.

Based on this logic, technical risks in the precast concrete production system were identified according to the sequence of activities illustrated in the flowchart presented in Figure 2. The flowchart provides a structured representation of the production supply chain and functions as a governance-relevant reference framework for subsequent risk identification using the Risk Breakdown Structure (RBS). By anchoring risk identification to specific production stages, the analysis ensures that technical risks are evaluated within their operational and organizational context, rather than treated as independent or abstract events.

This stage-based representation enables the translation of operational risk exposure into governance-relevant information, supporting subsequent quantitative prioritization and strategic evaluation. Although empirically derived from precast concrete manufacturing, the underlying production logic—characterized by sequential dependence, capital intensity, and low tolerance for failure—is structurally equivalent to oil and gas industrial production systems. Consequently, the process framework presented in Figure 2 provides a valid analytical foundation for examining risk-informed strategic governance across high-risk industrial sectors.

Identification of technical risks using the risk breakdown structure (RBS)

Technical risk identification in this study was conducted using the Risk Breakdown Structure (RBS) method, which systematically identifies and categorizes potential risks within complex industrial production systems. The RBS approach enables hierarchical decomposition of risks from general categories to specific sub-risks, providing a structured representation of risk sources and their interrelationships (Hillson, 2002. Such structured identification is particularly relevant for high-risk industrial environments, including oil and gas fabrication and EPC-based systems, where technical risks frequently emerge from interactions among design decisions, production processes, organizational coordination, and logistical interfaces.

The RBS developed in this study was structured according to the main stages of the precast concrete production process, including design completeness, material preparation, production operations, and product delivery. By aligning the risk structure with the actual production workflow, the RBS ensures that identified risks are directly linked to specific operational activities and decision points. From a governance perspective, this alignment allows technical risks to be traced to organizational responsibilities and control mechanisms, rather than being treated as isolated technical failures. This process-oriented structure facilitates the identification of critical risk concentration points that influence production reliability, quality performance, and strategic outcomes.

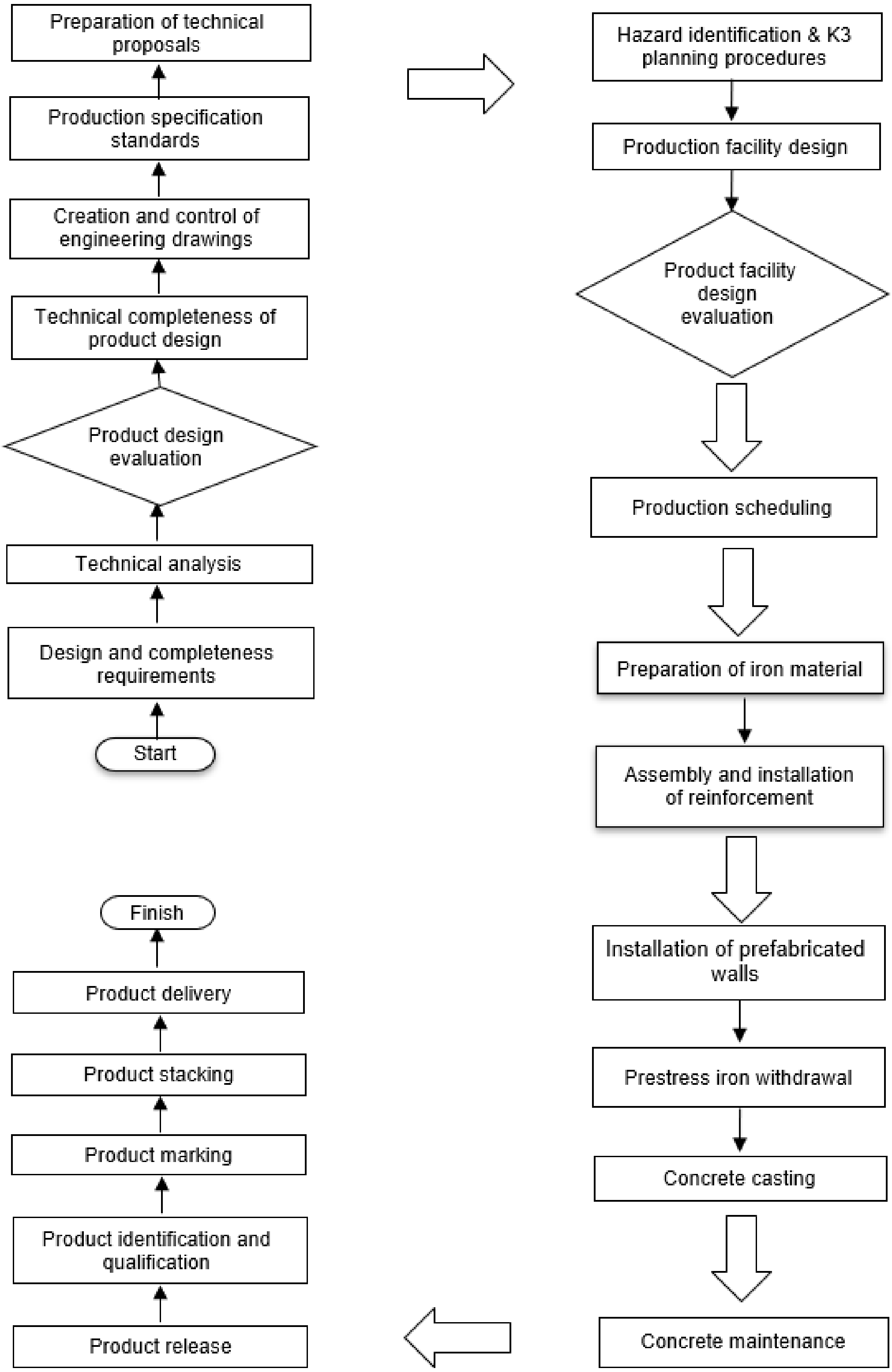

Figure 2. Flowchart of the precast concrete production supply chain in Indonesia.

Based on the identification results, technical risks were classified into 22 main risk categories at RBS Level 2, with a total of 66 sub-risks at Level 3. The distribution of risks indicates that a substantial proportion of critical technical risks originate during the design planning stage, the preparation and interpretation of technical specifications, and the coordination of production processes. These findings are consistent with Hatmoko et al. (2019), who observed that risks in precast concrete production are predominantly associated with design inaccuracies and weaknesses in technical quality control.

From a strategic governance standpoint, the concentration of high RPN values in design control, supervision mechanisms, and quality compliance highlights the critical role of early-stage decision-making and oversight structures. Similar risk patterns are widely documented in oil and gas fabrication yards and EPC-based production systems, where failures in design governance or quality assurance may escalate rapidly into safety incidents, regulatory non-compliance, and significant financial loss. In oil and gas industrial operations, deficiencies in engineering drawings and fabrication supervision are frequently associated with increases in operational safety indicators such as the Total recordable incident rate (TRIR) and lost time injury frequency (LTIF), particularly when design inconsistencies propagate into unsafe work practices or improper assembly procedures.

From an operational performance perspective, inaccurate design drawings and insufficient supervision also have direct financial implications. In fabrication yards, design errors commonly generate non-conformance reports (NCRs), rework requirements, and production stoppages during quality inspections. These disruptions increase fabrication cycle time, delay module delivery schedules, and elevate rework costs, which are often monitored through key financial performance indicators such as rework cost ratios, schedule variance, and fabrication productivity rates. Consequently, the high RPN values associated with design drawing errors and lack of supervision indicate governance weaknesses that may simultaneously affect both safety performance and project economics.

The findings therefore suggest that strengthening design verification processes and enhancing supervision of production standards are not merely operational improvements but critical governance interventions. In high-risk industrial environments such as oil and gas fabrication facilities, systematic verification of engineering drawings, strict compliance monitoring, and structured quality assurance procedures contribute directly to improved safety indicators, reduced rework rates, and greater schedule reliability. These governance mechanisms enable organizations to control technical deviations before they propagate through sequential production stages and affect broader operational performance.

Risk assessment using risk priority number (RPN)

Following risk identification using the Risk Breakdown Structure (RBS), quantitative risk assessment was conducted using the Risk Priority Number (RPN) method. The RPN approach evaluates the criticality of each identified technical risk based on Severity (S), Occurrence (O), and Detection (D). This assessment was carried out through structured surveys and Focus Group Discussions (FGD) involving technical management personnel from eight large precast concrete companies in Indonesia, ensuring that the evaluation reflected actual operational conditions and governance environments within industrial-scale production systems. The RPN value for each risk was calculated using Equation 2:

$$RPN = S \times O \times D \tag{2}$$

This formulation aggregates potential impact, likelihood of occurrence, and detectability into a single quantitative index. As such, RPN functions not only as an operational metric, but also as a governance-relevant signal that enables direct comparison of technical risk criticality across production stages and functional domains. The results of the RPN-based assessment are summarized in Table 1.

Based on the calculation results, RPN values range from 67.2 to 193.5, indicating substantial variation in technical risk criticality within the

Table 1. Risk priority number (RPN)

No	Risk Category	Average			RPN
		S	O	D	
1	Design drawing errors (Anggoro et al., 2025)	9.1	4.0	5.3	193.5
2	Technical specifications do not meet standards (Firdaus et al., 2019)	8.4	3.3	4.3	116.4
3	Dimension tolerance non-compliance (Firdaus et al., 2019; Zhang et al., 2019)	6.6	5.4	4.6	165.5
4	Errors in structural calculations (Anggoro et al., 2025)	8.4	3.3	4.6	127.8
5	Lack of verification of technical analysis results	7.6	4.4	4.3	140.4
6	Use of inaccurate analysis software	7.3	2.6	5.1	95.7
7	Discrepancy between evaluation results and technical specifications (Anggoro et al., 2025)	6.9	4.3	3.5	104.2
8	Use of non-comprehensive evaluation methods (Anggoro et al., 2025; Liu et al., 2025)	6.8	3.3	4.8	105.8
9	Lack of understanding of the product (Anggoro et al., 2025)	8.1	4.1	4.1	135.7
10	Incomplete technical documentation (Susanto & Wirawan, 2019)	8.0	4.5	3.3	118.5
11	The detailed image is unclear and leads to different interpretations	7.9	4.9	2	97.9
12	Delays in submitting technical documents to the production team (Anggoro et al., 2025; Firdaus et al., 2019)	6.8	4.5	3.4	102.1
13	Failure of document management system (Adnina et al., 2021)	6.9	4.5	3.7	112.4
14	Frequent technical drawing revisions	5.8	5.3	2.9	88.4
15	Inconsistency between technical drawings and field conditions (Anggoro et al., 2025)	7.6	4.9	4	178.8
16	Lack of supervision over the implementation of production standards (Anggoro et al., 2025; Firdaus et al., 2019)	7.3	5.2	5	189.8
17	Specifications do not meet standards (Zhang et al., 2019)	7.8	3.5	4.6	122.8
18	Changes in standards without socialization (Adnina et al., 2021)	8.3	3.3	4.5	122.3
19	Technical information in the proposal is inaccurate (Adnina et al., 2021; Anggoro et al., 2025)	7.6	4.1	4.3	133.9
20	Delays in proposal preparation (Anggoro et al., 2025)	6.5	3.8	3.4	83.7
21	Proposal does not meet the technical requirements of the project (Adnina et al., 2021; Anggoro et al., 2025)	6.8	3.8	4.9	125.8
22	Incomplete hazard identification	6.5	3.9	4.5	114.4
23	Lack of occupational safety and health training for production workers	7.1	4.2	4.1	120.5
24	Lack of periodic evaluation of OSH implementation	6.8	3.6	3.4	83.2
25	Facility layout is inefficient (Anggoro et al., 2025)	8	3.1	4.4	107.1
26	Facility capacity does not match production volume (Liu et al., 2025; Muka et al., 2023)	7.7	3.1	2.8	67.2
27	Lack of utility system planning (electricity, water, ventilation) (Anggoro et al., 2025)	7.4	2.6	3.8	73.6
28	The evaluation does not take into account occupational safety factors	7.7	2.8	4.8	100.8
29	Evaluation did not involve relevant stakeholders (Adnina et al., 2021; Firdaus et al., 2019)	7.4	3.8	3.1	84.9
30	Data limitations in the evaluation process (Anggoro et al., 2025)	7.5	4.2	4.1	127.9
31	Unrealistic schedule in terms of capacity and resources (Anggoro et al., 2025; Firdaus et al., 2019)	7.4	4.6	3	102.2
32	Sudden schedule changes without coordination (Adnina et al., 2021; Anggoro et al., 2025)	8	5.5	3.5	153.9
33	Lack of integration between production schedules and material procurement (Anggoro et al., 2025; Muka et al., 2023)	8.0	4.5	3.3	119.0
34	Delays in the delivery of iron materials from suppliers (Firdaus et al., 2019; Muka et al., 2023)	7.5	5.1	3	118.8
35	Iron material quality does not meet specifications (Firdaus et al., 2019)	8.1	3.8	4.9	149.1
36	Errors in material storage (Anggoro et al., 2025; Firdaus et al., 2019)	6.7	3.5	4	94.0
37	Detailed errors in reinforcement installation (Firdaus et al., 2019; Zhang et al., 2019)	7.8	3.9	4.8	146.0
38	Lack of supervision during assembly (Anggoro et al., 2025; Firdaus et al., 2019)	7.3	4.7	4.8	162.7
39	Deviation of reinforcement dimensions from working drawings (Firdaus et al., 2019; Zhang et al., 2019)	8	3.7	3.7	105.9
40	Mold dimensions do not match the product design (Firdaus et al., 2019)	7.5	3.5	3.8	98.0
41	Mold damage that disrupts the production process (Firdaus et al., 2019)	7.4	4.2	3	98.4
42	Failure in mold reinforcement (Anggoro et al., 2025; Firdaus et al., 2019)	7.3	3.2	4.6	106.9
43	Tensioning does not comply with technical calculations (Zhang et al., 2019)	8.1	2.6	4	82.9
44	Equipment failure during the withdrawal process (Zhang et al., 2019)	7.8	2.9	3.9	86.3
45	Procedural errors cause cracks in the product	7.9	4.6	4.5	164.4
46	Inhomogeneous concrete mixing (Firdaus et al., 2019)	7.9	4.6	4.6	167.2
47	Mix design errors (Firdaus et al., 2019)	8.1	3.1	4.3	106.6
48	Early cracking in products (Firdaus et al., 2019)	7.3	4.2	5.0	152.0
49	Treatment time does not meet technical standards (Firdaus et al., 2019)	6.0	4.3	4.4	114.6
50	Inconsistent treatment methods (Firdaus et al., 2019)	6.2	4.3	4.2	110.4
51	Limitations of care facilities (Anggoro et al., 2025; Firdaus et al., 2019)	6.2	4.4	3.8	103.5
52	Product release errors from the mold (Anggoro et al., 2025; Firdaus et al., 2019)	6.4	4.4	4.5	126.0
53	Product damage during lifting (Anggoro et al., 2025; Firdaus et al., 2019)	7.5	4.1	4.7	143.0
54	Product release procedures do not comply with standards (Anggoro et al., 2025)	7.4	3.6	3.9	101.5
55	Incomplete product quality testing (Firdaus et al., 2019)	7.4	3.4	3.3	81.8
56	Test result documentation error (Anggoro et al., 2025)	6.7	3.1	4.5	91.7
57	Product non-compliance with quality standards (Firdaus et al., 2019)	8.2	4.6	4.9	182.8
58	Product labels are unclear or missing (Adnina et al., 2021; Anggoro et al., 2025)	6.9	2.6	4.4	77.6
59	Product code assignment error (Anggoro et al., 2025)	7.0	3.1	3.9	85.2
60	Inconsistency in marking format between batches (Anggoro et al., 2025)	7	3.4	3.8	90.4
61	Storage procedures not in accordance with standards (Anggoro et al., 2025)	7	3.6	4	98.5
62	Excessive accumulation causes product deformation (Anggoro et al., 2025)	7.6	3.7	3.3	92.4
63	Lack of inventory control systems (Adnina et al., 2021; Anggoro et al., 2025)	7.1	4	4.5	125.1
64	Product damage due to improper transportation (Anggoro et al., 2025; Firdaus et al., 2019)	7.5	4.5	5.3	179.5
65	Delays in product delivery to the project site (Firdaus et al., 2019; Muka et al., 2023)	7.5	3.9	3.1	91.1
66	Incomplete shipping documentation (Anggoro et al., 2025)	6.8	3.6	3.7	89.6

production system. This range reflects the heterogeneous nature of risks associated with design control, production operations, quality assurance, and logistics in complex industrial manufacturing environments.

The three technical risks with the highest RPN values are design drawing errors (RPN = 193.5), lack of supervision over the implementation of production standards (RPN = 189.8), and product non-compliance with quality standards (RPN = 182.8). These high-priority risks are closely associated with deficiencies in design accuracy, process discipline, and quality assurance effectiveness. From an industrial engineering perspective, weaknesses in these areas represent systemic vulnerabilities that may propagate throughout the production chain, resulting in rework, material waste, schedule delays, and increased operational costs.

From a strategic governance standpoint, the concentration of high RPN values in design control, supervision mechanisms, and quality compliance highlights the critical role of early-stage decision-making and oversight structures. Similar risk patterns are widely documented in oil and gas fabrication and EPC-based production systems, where failures in design governance or quality assurance may escalate rapidly into safety incidents, regulatory non-compliance, and significant financial loss.

Conversely, risks with relatively low RPN values—such as facility capacity not matching production volume—suggest that certain infrastructure-related aspects are currently under comparatively better control. Nevertheless, in dynamic industrial environments, lower-priority risks should not be disregarded entirely, as changes in demand patterns, regulatory requirements, or production configurations may cause latent risks to escalate. Continuous monitoring is therefore required to maintain governance effectiveness over time.

Determining business strategy using the quantitative strategic planning matrix (QSPM)

Following the quantitative prioritization of technical risks, this study employed the Quantitative Strategic Planning Matrix (QSPM) to determine strategic governance priorities aligned with the dominant risk profile. QSPM enables systematic comparison of alternative strategies based on their relative attractiveness to key decision factors (David et al., 2009), making it particularly suitable for high-risk industrial production systems characterized by competing priorities and constrained organizational resources.

In capital-intensive and highly regulated industries, including oil and gas production, QSPM provides a structured mechanism for translating quantified technical risk exposure into actionable governance-level strategic priorities. By integrating risk-informed inputs with strategic evaluation, QSPM supports transparent, auditable, and accountable decision-making, reducing reliance on purely qualitative judgment or market-driven assumptions.

The total attractiveness score (TAS) serves as a governance-relevant indicator of strategic priority. Strategies with higher TAS values are interpreted as more effective in addressing dominant technical risks, while those with lower TAS values are considered less aligned with the organization's current risk exposure. Through this evaluation, QSPM establishes a direct linkage between operational risk analysis and strategic governance capacity.

Integration of technical risk data into QSPM

The integration of technical risk data into the Quantitative Strategic Planning Matrix (QSPM) is performed by employing Risk Priority Number (RPN) values as a quantitative linkage between technical risk criticality and strategic governance priorities in high-risk industrial production systems. Within this framework, a higher RPN value represents a more critical and urgent technical risk, which correspondingly demands a higher level of strategic and governance attention. This approach is particularly relevant for capital-intensive and tightly regulated industries—such as oil and gas fabrication and EPC-based production systems—where strategic decisions must be explicitly aligned with quantified technical risk exposure. By embedding RPN values into QSPM, strategic decision-making is informed by measurable operational risk rather than relying primarily on qualitative judgment or managerial intuition.

Based on the RPN results, technical risk factors are classified as organizational weaknesses or strengths and subsequently assigned a weight (W) that reflects their relative significance within the overall technical risk profile. The weighting process follows a normalization procedure, in which the weight of each risk factor is calculated as the proportion of its RPN value relative to the total RPN of all identified risks. The normalization is defined as:

$$W_i = \frac{RPN_i}{\sum_{i=1}^{66} RPN_i} \tag{3}$$

with the total weight Equation 1 This normalization ensures proportional representation of each technical risk based on its contribution to cumulative operational risk, thereby embedding objective risk exposure directly into the strategic governance evaluation process. Such proportional weighting mirrors governance practices in oil and gas risk management frameworks, where resource allocation and strategic oversight are prioritized according to quantified risk criticality.

Subsequently, each strategic alternative is evaluated using an Attractiveness Score (AS), which reflects the extent to which a given strategy addresses or mitigates a particular technical risk. The AS values are defined on a four-point scale:

- 4 = very attractive / very relevant,
- 3 = moderately relevant,
- 2 = less relevant,
- 1 = not relevant.

The AS values are assigned based on the suitability of each strategic option in responding to the identified technical risks within the precast concrete production system. From a strategic governance perspective, the AS represents the perceived effectiveness of a strategic response in controlling, mitigating, or absorbing technical risk at the organizational level. The Total Attractiveness Score (TAS) for each strategy–risk combination is then calculated as:

$$TAS_{ij} = W_i \times AS_{ij} \tag{4}$$

Through this formulation, QSPM transforms quantified technical risk exposure into a structured and comparable set of strategic governance priorities, enabling transparent ranking of alternative strategies based on their alignment with dominant technical risks.

The integration results indicate that, out of the 23 evaluated strategic alternatives, three strategies exhibit the highest Total Attractiveness Score (TAS), as summarized in Table 2. These strategies represent the most effective governance responses to the dominant technical risks identified in the production system.

Based on the results presented in Table 2, the three strategies with the highest TAS values are the implementation of an effective management system (TAS = 0.50), conducting operational risk management (TAS = 0.43), and reducing product deviations (TAS = 0.32). These strategies demonstrate the strongest alignment with critical technical risks identified in the precast concrete production process. The implementation of an effective management system enhances process consistency and organizational control (F. R. David & David, 2017, while operational risk management strengthens production stability and organizational resilience against disruption (Arviana & Suseno, 2024. Strategies aimed at reducing product deviations focus on improving quality control mechanisms and design standardization, thereby minimizing defects and non-conformities (Gamil & Cwirzen, 2022.

From a strategic governance perspective, the dominance of management system implementation and operational risk management among the top-ranked strategies indicates that the most effective responses to high technical risk are governance-oriented rather than market-driven. Similar patterns are widely observed in oil and gas industrial production systems, where robust management systems, formalized risk governance structures, and strict quality control regimes constitute foundational mechanisms for managing technical uncertainty, regulatory compliance, and safety-critical operations.

Overall, the integration of RPN-based technical risk prioritization with QSPM-based strategic evaluation confirms that strategies associated with higher cumulative technical risk exposure should receive greater governance priority. This finding substantiates the effectiveness of the proposed risk-informed strategic governance framework, demonstrating how quantified operational risk can be systematically translated into defensible and transparent strategic decisions. Although empirically grounded in precast concrete manufacturing, the governance logic of the framework is transferable to other high-risk industrial production environments, particularly oil and gas fabrication yards and EPC-based systems, where strategic choices must be explicitly aligned with technical risk exposure to ensure operational robustness and long-term sustainability.

CONCLUSION

Based on the results of the Quantitative Strategic Planning Matrix (QSPM), developed through the integration of technical risk assessment outcomes derived from the Risk Breakdown Structure (RBS) and Risk Priority Number (RPN) methods, this study demonstrates that strategic alternatives exhibit significantly different levels of effectiveness in addressing organizational challenges under conditions of high technical risk. The findings confirm that strategic effectiveness in high-risk industrial production systems is strongly determined by the degree of alignment between quantified technical risk exposure and strategic focus, rather than by market-oriented considerations alone.

The QSPM results indicate that strategies with the highest Total Attractiveness Score (TAS) should be prioritized as governance-level responses to dominant technical risks. In the empirical context of precast concrete manufacturing, the three highest-priority strategies are the implementation of effective management systems, conducting operational risk management, and reducing product deviations. These strategies exhibit the strongest quantitative alignment with critical technical risks identified in the production system, particularly those associated with design

Table 2. Total attractiveness score (TAS) values

No	Business Strategy	RPN	W	AS	TAS	Rank
1	Implementation of management systems	1,624.1	0.138	3.63	0.50	1
2	Conducting operational risk management	1,301.1	0.110	3.88	0.43	2
3	Reducing product deviation	975.9	0.083	3.88	0.32	3
4	Human resource competency development	891.9	0.076	4.00	0.30	4
5	Differentiating products	1,170.7	0.099	3.00	0.30	5
6	Digital technology utilization	583.1	0.050	3.88	0.19	6
7	Product innovation	731.2	0.062	2.50	0.16	7
8	Improving customer satisfaction	560.3	0.048	3.13	0.15	8
9	Collaborating and forming business partnerships	433.5	0.037	3.38	0.12	9
10	Practicing sound financial management and investment	521.9	0.044	2.75	0.12	10
11	Creating competitive advantage	629.9	0.053	2.25	0.12	11
12	Implementing operational efficiency	381.5	0.032	3.25	0.11	12
13	Business adaptation and resilience	502.6	0.043	2.38	0.10	13
14	Expanding networking	466.1	0.040	1.63	0.06	14
15	Strengthening the financial balance sheet	213.1	0.018	3.00	0.05	15
16	Marketing effectiveness	266.7	0.023	1.25	0.03	16
17	Performing effective supply chain performance	153.4	0.013	2.00	0.03	17
18	Market and customer penetration	266.7	0.023	1.13	0.03	18
19	Strategic performance monitoring	104.9	0.009	2.63	0.02	19
20	Compliance with regulations and environmental standards	–	–	1.13	–	–
21	Making a commitment to sustainability	–	–	1.13	–	–
22	Driving company growth	–	–	1.25	–	–
23	Increasing social awareness	–	–	1.38	–	–
	Total	**11,778.6**				

drawing errors, insufficient supervision over production standard implementation, and product non-compliance with quality requirements.

The prioritization of these strategies underscores the central role of governance mechanisms—such as formalized management systems, structured risk management processes, and robust quality assurance regimes—in controlling the propagation of technical risk across industrial production systems. In high-risk sectors such as oil and gas fabrication and EPC-based production environments, deficiencies in these governance mechanisms are widely recognized as root causes of operational disruption, regulatory non-compliance, and safety-critical incidents. Addressing dominant technical risks through governance-oriented interventions is therefore essential for improving operational reliability, reducing systemic vulnerability, and maintaining consistent performance under conditions of elevated technical uncertainty.

Overall, this study confirms that the integration of RBS–RPN-based technical risk assessment with QSPM-based strategic evaluation constitutes a coherent and effective risk-informed strategic governance framework, rather than a conventional approach to risk analysis or strategy selection in isolation. The principal contribution and novelty of this research lie in the explicit use of quantified technical risk priorities (RPN values) as direct inputs for strategic weighting and evaluation within the QSPM framework, enabling a systematic, transparent, and auditable linkage between operational risk exposure and strategic governance decisions.

By transforming technical risk assessment outputs into strategic decision variables, the proposed framework advances existing governance practices that often rely primarily on qualitative judgment or market-driven reasoning. Although empirically grounded in precast concrete manufacturing, the governance logic and decision architecture developed in this study are applicable to a broader class of high-risk industrial production systems. In particular, the framework offers direct relevance for oil and gas fabrication yards, modular construction facilities, and EPC-based production systems, where technical complexity, strict quality and safety requirements, and severe consequences of operational failure necessitate explicit alignment between quantified risk exposure and strategic governance to achieve long-term operational robustness and sustainability.

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GLOSSARY OF TERMS AND SYMBOLS

Terms & Symbols	Definition	Unit
AS	Attractiveness score used in qspm to indicate the degree to which a strategy responds to a specific risk factor	–
D	Detection rating indicating the ability to detect a technical risk before it occurs	–
EPC	Engineering–procurement–construction production system commonly used in large-scale industrial and oil & gas projects	–
FGD	Focus group discussion used to collect expert judgment from technical and managerial personnel	–
High-Risk Industrial Production	Industrial production systems characterized by capital intensity, technical complexity, and low tolerance for failure (e.g., construction manufacturing, oil & gas)	–
O	Occurrence rating indicating the likelihood of a technical risk occurring	–
Operational Risk	Risk arising from failures in processes, systems, human factors, or organizational control during production	–

QSPM	Quantitative strategic planning matrix used to evaluate and prioritize strategic alternatives based on weighted factors	–
RBS	Risk breakdown structure used to hierarchically identify and classify technical risks	–
RPN	Risk priority number calculated as the product of severity, occurrence, and detection (rpn = s × o × d)	–
Risk-Informed Strategic Governance	Governance approach in which strategic priorities are explicitly derived from quantified technical risk exposure	–
S	Severity rating indicating the potential impact of a technical risk on operations and performance	–
Strategic Governance	Organizational decision-making framework that aligns strategy, risk control, and accountability	–
TAS	Total attractiveness score representing the overall priority of a strategy in qspm	–
Technical Risk	Risk associated with design, production processes, quality control, and technical coordination	–
W	Weight assigned to a risk factor in qspm, derived from normalized rpn values	–

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