



# Research on a Homogeneous Closed-loop Governance Architecture for Work Safety Based on Process Digitalization

## Closed-loop Safety Governance via Process Digitalization

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**Abstract.** Homogeneous work safety management is a core strategy for power enterprises to address the challenges of increasing organizational integration and management complexity. However, its implementation often becomes trapped in the “disconnection between institutions and execution.” This study proposes a triadic integration approach of “institution–process–data” and demonstrates that process digitalization is the key technological pathway for transforming formal consistency into substantive consistency. Accordingly, the study first constructs a quality-and-effectiveness evaluation system driven by management needs to guide homogeneous work safety practices, and then elaborates on process digitalization as the foundational enabler for operating this system and empowering it with data. Finally, a three-dimensional closed-loop governance architecture is integrated and constructed, featuring three vertical levels, three horizontal lines, and five process segments. The findings not only provide an actionable methodology for homogeneous management, but also offer an empirical example for organizational governance theory in the digital era.

**Keywords:** Work Safety, Homogeneous Management, Process Digitalization, Quality and Effectiveness Evaluation

## 1 Introduction

Large, group-based power enterprises face a unique management dilemma characterized by dispersed organizations, diverse conditions, and high mobility. This is manifested in three major symptoms: first, a broken transformation chain from strategic intent to on-site execution, whereby written rules and regulations fail to ensure consistent implementation; second, conflicting objectives among different functional departments (such as safety, operations, and finance); and third, management’s difficulty in grasping the actual state of execution. Management complexity significantly increases work safety risks. To address these challenges, State Grid Corporation of China has proposed a “homogeneous work safety management” strategy. Its core objective is to achieve a

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H. Li et al. (eds.), *Proceedings of the 2026 5th International Conference on Big Data Economy and Digital Management (BDEDM 2026)*, Advances in Economics, Business and Management Research 383,

[https://doi.org/10.2991/978-94-6239-640-1\\_16](https://doi.org/10.2991/978-94-6239-640-1_16)

reduction in management complexity—an “entropy reduction” effect—through strategic focus, organizational alignment, end-to-end process integration, information transparency, and risk controllability.

The key to solving the above problems lies in understanding the triadic integration of “institution–process–data”: institutions define what to do, processes stipulate how to do it, and data answer how well it is done. The integration of these three elements forms a closed loop from strategic intent to execution verification. This study further argues that process digitalization is the crucial technological lever that links this triad. By embedding strategic requirements into digitalized processes, process execution can automatically generate objective data, thereby forming a new governance mechanism of “rigidified execution → automatic data generation → intelligent feedback.”

This study unfolds around three progressively deepening questions:

- How can evaluation dimensions and indicators be systematically defined based on strategic needs?
- How can process digitalization bridge the triadic relationship of “institution → process → data”?
- How can an adaptive closed-loop governance framework be constructed so that strategic intent penetrates and is implemented at all organizational levels?

## 2 Literature Review

This chapter focuses on the two core concepts of “homogeneous work safety management” and “process digitalization,” systematically reviewing existing studies to clarify the theoretical entry point and innovative contributions of this research.

### 2.1 Research on Work Safety Management

Work safety management is a major focus in both academia and practice, with theoretical studies extensively covering influencing factors, mechanisms of action, and technological applications[1-3]. With the deepening of the Industry 4.0 era, theoretical innovation and model optimization in work safety management (WSM) have increasingly come to the forefront. The core definition of WSM is: a normalized management activity that is embedded in production processes and systematically achieves safety objectives. This definition reveals the essence of work safety management—it is both the direct foundation for ensuring orderly production and operation, and an important bridge to research on risk management and emergency management[4][5]. At the theoretical development level, existing studies exhibit two trends. The first is innovation in fundamental theories. Lei Xiaofeng et al.[6] systematically elaborate the basic assumptions of work safety and construct a transaction management system based on the principle of safety domain maintenance. Aven[7] integrates and proposes the system framework of Safety-III. The second is the diffusion of emerging paradigms. New research paradigms and management models such as safety intelligence and evidence-based safety are gradually receiving increasing attention[8].

Despite the many theoretical frameworks proposed by scholars in the fields of safety science, risk management, and emergency management, systematic theoretical understanding and universally applicable model construction remain insufficient for the specific domain of WSM. In particular, dedicated studies on homogeneous work safety management are extremely rare—that is, how to achieve substantive consistency in safety management within large, dispersed organizations through strategic alignment, end-to-end process integration, and data-driven approaches has not yet been fully discussed in the existing literature.

## **2.2 Research on Process Digitalization**

Digitalization and process digitalization are progressive rather than simply inclusive concepts[9]. Process digitalization refers to enterprises leveraging digital technologies to empower production and business operations as well as routine management activities, thereby enhancing organizational agility and responsiveness to demand[10]. In terms of implementation mechanisms, enterprises use digital technologies to transform new or existing business processes, enabling digital empowerment across multiple domains such as production, operations, and supply chain management[11]. Its core value lies in reducing information and communication costs through data closed loops and end-to-end process integration, strengthening collaboration within organizations and between upstream and downstream firms, and improving organizational adaptability and rapid response capabilities[12][13]. Although research on process digitalization has seen some development, the existing literature remains insufficient in both depth and breadth on the key question of “how process digitalization supports the multi-level transmission and realization of strategic objectives,” especially regarding its application in “management homogenization scenarios in high-risk, high-complexity industries (such as electric power).”

This study, at the theoretical level, integrates the three elements of “institution–process–data” to construct a framework for homogeneous work safety management. Focusing on the dispersed characteristics of large, group-based power enterprises, it achieves homogeneous management through holistic alignment along five dimensions: strategic focus, organizational alignment, end-to-end process integration, information transparency, and risk controllability, thereby filling the current gaps in both theory and practice.

## **3 Homogeneous Work Safety Management: Needs and Pathways**

### **3.1 Constructing a Quality-and-Effectiveness Evaluation System Based on Management Needs**

Through analysis of the organizational characteristics and practical requirements of large-scale power groups, this research identifies five hierarchical requirements for homogenized safety production management: (1) strategic alignment—coordinating

mechanisms among multi-level organizations around the principle of "managing business means managing safety"; (2) organizational alignment—goal coordination mechanisms among different functional lines such as safety, business, and finance; (3) process integration—complete transformation chains from strategic intent to field execution; (4) information transparency—real-time visibility of execution status across organizational levels by corporate management; and (5) risk controllability—mechanisms for risk prevention and rapid response within business objective constraints. These five hierarchical requirements reflect the essence of homogenized management, which is not simply copying management texts but rather achieving multi-dimensional strategic collaboration and shared risk governance.

Through analysis of management practices at State Grid Corporation and similar enterprises, this research identifies four hierarchical levels of processes in homogenized management:

1. **First Level: Responsibility Implementation Process.** This level primarily encompasses process nodes for establishing and cascading safety targets, deciding and allocating safety investments, and pursuing and assessing safety accountability. These processes embody the concretization of strategic intent within the organization, corresponding to the two core requirements of "strategic alignment" and "organizational alignment."

2. **Second Level: Functional Collaboration Process.** This level primarily encompasses process nodes for inter-departmental approval coordination, integration of business management and safety management, and risk assessment and professional guidance. These processes embody the organic integration of different functional lines, corresponding to the two core requirements of "organizational alignment" and "process integration."

3. **Third Level: Capability Building Process.** This level primarily encompasses process nodes for personnel and organizational structure configuration, assurance of safety investments and resource allocation, implementation of education and training, and organization of emergency drills. These processes embody the transformation of management systems into execution capabilities, corresponding to the two core requirements of "process integration" and "information transparency."

4. **Fourth Level: Operational Site Risk Control Process.** This level primarily encompasses process nodes for work plan approval, issuance of work permits, inspection of field safety measures, and management of safety equipment and tools. These processes embody the concrete implementation of management systems at operational sites, corresponding to the two core requirements of "information transparency" and "risk controllability."

This research adopts an assessment indicator system design paradigm rooted in management processes, wherein indicators are quantitative variables extracted from critical process nodes that effectively reflect final outcomes. Accordingly, based on the aforementioned process framework, this research constructs a corresponding assessment indicator system. The core characteristic of this indicator system is that each evaluation dimension directly originates from a specific category of management process, and each indicator can be mapped to the execution status of one or multiple process nodes. The specific structure of this system is presented in Table 1.

**Table 1.** Evaluation Index System for the Quality and Effectiveness of Homogeneous Work Safety Management

Evaluation Dimension	Corresponding Processes	Secondary Indicators
Implementation of safety management responsibilities	Safety target establishment and cascading processes; safety investment decision-making processes; safety accountability pursuit and assessment processes.	<ol style="list-style-type: none"> <li>1. Status of responsibility system establishment</li> <li>2. Status of safety investment and budgeting</li> <li>3. Status of accountability and performance appraisal</li> <li>4. Status of safety emergency response system development</li> <li>5. Status of education, training, and safety culture development</li> </ol>
Coordination among professional management departments	Inter-departmental approval coordination processes; integration of business management and safety management processes; risk assessment and professional guidance processes.	<ol style="list-style-type: none"> <li>1. Clarity of division of responsibilities</li> <li>2. Degree of integration into business management</li> <li>3. Status of professional inspections and guidance</li> <li>4. Risk assessment and control</li> <li>5. Access and qualification management</li> </ol>
Work safety management capability	Personnel and organizational structure configuration processes; safety investment and resource allocation processes; education and training implementation processes; emergency drill organization processes.	<ol style="list-style-type: none"> <li>1. Status of organizational structure and staffing</li> <li>2. Status of assurance for safety investment</li> <li>3. Subcontractor management</li> <li>4. Implementation of education and training</li> <li>5. Implementation of emergency drills</li> </ol>
Safety risk control at work sites	Hazard identification and inspection processes; corrective action tracking and verification processes; work permit issuance processes; incident response processes.	<ol style="list-style-type: none"> <li>1. Work planning and control</li> <li>2. Pre-job preparation</li> <li>3. Compliance of on-site safety measures</li> <li>4. Safety tools and equipment management</li> <li>5. Construction tools and equipment management</li> </ol>

Such an indicator system design ensures an inherent correspondence between indicators and processes. The data source for each indicator derives from concrete process execution records, and the calculation logic for each indicator is directly associated with the degree of process standardization. This transforms the indicator system from a theoretical framework into a practical, traceable, and verifiable management tool.

### 3.2 Process Digitalization: The Path from Evaluation to Governance

The aforementioned evaluation system requires real-time, process-based, and objective data support. However, traditional manual reporting is inefficient, error-prone, and more likely to have its fairness questioned. By embedding institutional rules and evaluation indicators into executable and traceable business processes, process digitalization enables a paradigm shift from merely supporting evaluation to achieving a closed governance loop.

### 1. Paradigm Shift in Data: From Reporting to Generating

Process digitalization changes the mechanism of data generation, realizing a shift from relying on manual reporting to automatic generation within business processes:

#### (1) Objectivity at the data source

Indicator data no longer comes from manual aggregation by lower levels, but is automatically generated as the natural by-product of business process execution. For example, the “emergency drill execution rate” is derived from the automatic issuing and completion confirmation of online drill plans; the “hidden danger rectification closure rate” is automatically calculated based on the status of each node in the process. This fundamentally eliminates information distortion and delay, and ensures the originality and traceability of the data.

#### (2) Process-embedded indicators

Each evaluation indicator can be mapped to the output of one or more digitalized processes. For example, the “degree of integration into business management” is directly reflected in the activation rate of safety approval nodes in business workflows; the “compliance of on-site safety measures” is achieved by mandating the upload of on-site evidence via mobile devices in the work-permit approval process. This embedding turns evaluation into an imperceptible, real-time, and accompanying measurement.

### 2. Governance Paradigm Shift: From Ex-post Evaluation to Proactive Regulation

On the basis of high-quality data, process digitalization can build a data-driven, adaptive governance closed loop, upgrading evaluation into a forward-looking, dynamic system regulation mechanism. Its operation follows an iterative cycle of “Perception–Diagnosis–Intervention–Learning”:

#### (1) Perception and diagnosis

Digitalized processes run continuously and generate streams of process data. The system performs real-time computation and pattern recognition on these data, quantifying process execution status into performance indicators and automatically diagnosing deviations. For example, when multiple projects experience delays at the same node in the “subcontractor admission process,” the system automatically flags this as a signal of a process bottleneck or ambiguous standards.

#### (2) Intervention and feedback

Diagnosis results trigger predefined governance rules, enabling automated management interventions. When the “overdue rate of hidden danger inspection and rectification” exceeds a threshold, the system automatically issues warning work orders to responsible parties and upper-level regulators, and locks advanced approval permissions for related projects, thus achieving instantaneous penetration of management directives and rigid constraints. At the same time, the system conducts root-cause analysis on process performance, driving continuous optimization of institutional standards, resource allocation, and even the processes themselves.

#### (3) Learning and evolution

Historical process data and corresponding evaluation results form a “management event repository.” Through data analysis and machine learning, risks can be predicted

and process parameters can be optimized, enabling standardized (homogenized) management to evolve from static institutional compliance into a dynamic, data-driven core capability.

In summary, by realizing rigid enforcement of execution, integrated governance, and intelligent decision-making, process digitalization fundamentally reshapes the way standardized safety production is achieved. It transforms standardized management from merely a set of institutional documents and assessment indicators into a governance system endowed with self-regulation capabilities.

## 4 Closed-Loop Governance Architecture for Homogenized Work Safety Based on Process Digitalization

### 4.1 Overall Logical Architecture

The closed-loop governance framework for homogenized work safety constructed in this study is a three-dimensional management system spanning multiple levels, multiple dimensions, and multiple links. The framework is designed along three dimensions—vertical hierarchy, horizontal functions, and process stages—forming an integrated whole in which all components are interconnected and mutually reinforcing, as shown in the Fig. 1.

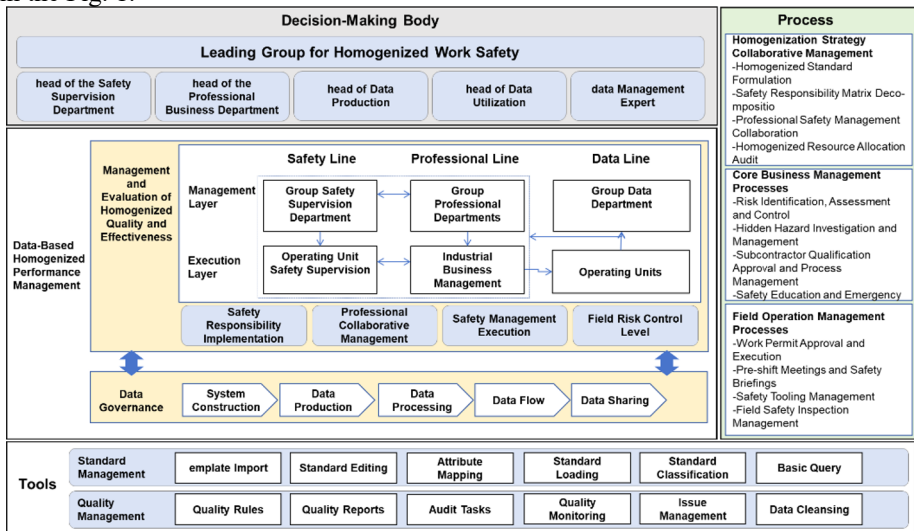


Fig. 1. Design of a Closed-Loop Governance Framework for Homogenized Work Safety Based on Process Digitalization

#### 1. Vertical Dimension: Three Progressive Governance Levels

The framework is vertically divided into three levels, reflecting a progressive governance chain from strategic decision-making → middle management → frontline execution.

(1) Decision-making level is composed of the Leading Group for Homogenized Work Safety, which includes five key roles: head of the Safety Supervision Department (representing safety interests); head of the Professional Business Department (representing business interests); head of Data Production (in charge of data sources); head of Data Utilization (in charge of data application); data Management Expert (providing technical support). The composition of these five roles embodies the integration of three management lines—safety line, business line, and data line—at the decision-making level, thereby enabling collaborative decision-making from multiple perspectives.

(2) Management level consists of the group's functional departments and industry-specific professional departments, representing the parallel expansion of the three lines. The safety line is responsible for formulating safety policies and standards and carrying out safety supervision. The business line is responsible for establishing business specifications and process standards and for optimizing business processes. The data line is responsible for developing the data standards system and monitoring data quality.

(3) Execution level is composed of the various industrial entities and frontline operating units and serves as the common executor of the three lines. The execution level is characterized by "one matter, three perspectives", which is safety departments focus on risk control, business departments focus on efficiency improvement, data departments focus on data accuracy.

## 2. Horizontal Dimension: Tri-line Collaborative Functional System

The core innovation of the framework lies in the organic collaboration among the safety line, business line, and data line. These three lines form a structure of deep coordination and mutual checks and balances centered on "Homogeneous Work Safety Quality and Effectiveness."

The functions of the safety line include establishing safety standards, conducting risk management, performing safety supervision, and generating safety data. The business line is responsible for designing business processes, managing operational efficiency, controlling production costs, and generating operational data. The data line focuses on building a data standard system, ensuring data quality, facilitating data flow, and supporting decision-making applications.

The key mechanism for tri-line collaboration is data-driven cross-functional dialogue. When conflicts arise between safety and efficiency, the data line intervenes by extracting historical data for analysis: assessing the true effectiveness of certain safety measures and identifying the optimal efficiency solutions. Based on data-driven justification, the decision-making team can develop Pareto-optimal solutions that meet safety requirements without excessively compromising efficiency.

## 3. Process Dimension: Five-Segment Closed-Loop Data Value Chain

The framework designs a five-segment closed-loop process of "System Construction → Data Production → Data Processing → Data Flow → Data Sharing," which constitutes the operational mechanism of the entire framework.

System Construction is the infrastructure phase, responsible for establishing the physical and digital foundations for data collection, including sensor networks, information systems, data warehouses, etc. Data Production is the stage where business processes are transformed into data information, encompassing various methods such as

automatic collection, manual input, system recording, and event-driven triggers. Data Processing converts raw data into high-quality data through procedures like cleansing, validation, transformation, and standardization. Data Flow involves the vertical aggregation (from grassroots → business units → group level) and horizontal correlation (integrating safety, operational, and financial data) of processed data, establishing a comprehensive group-level data view. Data Sharing opens data to business departments for utilization, supporting safety management decisions, business optimization decisions, and collaborative decision-making.

These five segments form a complete closed loop, with each segment having explicit quality requirements and feedback mechanisms to ensure that the quality of the preceding segment directly influences the effectiveness of the subsequent one.

## 4.2 Technical Implementation Pathway for Process Digitalization

The process digitalization system comprises four technical dimensions that form a progressive support structure: microservices architecture serves as the technical foundation, supporting the independent operation of various functional modules; BPMN process reengineering crystallizes management standards into structured workflows; multi-system integration extends data sources; and end-to-end data governance ensures data quality. These four dimensions are tightly coupled and jointly support the effective operation of the quality and efficiency evaluation system.

### 1. Microservices Architecture Design

A cloud-native microservices architecture is adopted to support system operations. The system functionality is decomposed into eight independent microservices: objective management, responsibility matrix, hazard management, remediation tracking, data analytics, report generation, permission management, and message notification. Each microservice communicates through OpenAPI 3.0 standard interfaces, and Kafka message queues are utilized to achieve asynchronous decoupling.

Key Implementation Considerations: Kubernetes is employed for container orchestration; a service mesh (Istio) is implemented to achieve service governance and chain tracing; and a CI/CD pipeline is established to enable automated deployment. Risk Mitigation: Prometheus and Grafana are utilized to achieve end-to-end observability; for operations with stringent data consistency requirements, distributed transaction processing (Saga pattern) is adopted to ensure consistency.

### 2. BPMN Process Reengineering

BPMN 2.0 standard is adopted to optimize homogenized management processes. Objective Management Process Optimization: The original process comprised nine steps with a 30-day cycle, characterized by non-scientific objective decomposition and arbitrary objective adjustments. The optimized process is simplified to five steps with a 7-day cycle: the system automatically calculates recommended objective ranges based on project risk levels, scale, and historical performance → municipal companies submit proposals (with the system automatically validating scientific soundness) → group approval → system generates implementation plans → real-time monitoring is initiated. An "automated objective scientific soundness validation" mechanism is introduced to prevent unsound objectives from being adopted.

**Departmental Collaboration Process Optimization:** The original process involved dispersed email-based approvals with uncertain timelines (2-14 days) and lack of traceability. The optimized process is as follows: engineering department submits in the system → system automatically routes → each department completes review within 3 working days → review comments are structured and recorded → automated escalation alerts for overdue items. Departmental collaboration transforms from "ambiguous email exchanges" to a "traceable, time-constrained, evidence-documented" collaboration model.

**Key Implementation Considerations:** A Business Process Management (BPM) engine is employed to execute workflows; a process rule repository is established to support dynamic configuration; and mobile applications are developed to enable online workflow processing. **Risk Mitigation:** Human confirmation mechanisms are retained for "gray-area" decisions; a phased implementation approach ("pilot first, then rollout") is adopted.

### 3. Multi-System Integration Architecture

Integration with ERP, OA, and identity authentication systems is achieved. The ERP system provides project basic information and resource configuration data; the OA system provides meeting records and safety inspection reports; the identity authentication system provides organizational structure and permission control, serving as the foundation for automatic workflow routing based on personnel information.

**Interface Governance:** Documentation complies with OpenAPI 3.0 standards; version management norms are enforced (with 3-month parallel operation of old and new versions); and a monitoring and alerting mechanism is established (automatic alerts when response times or error rates exceed thresholds). **Risk Mitigation:** Compatibility adapters are developed for non-standard interfaces; daily reconciliation mechanisms are implemented to identify data inconsistencies; and a phased integration strategy is adopted to reduce risk.

### 4. End-to-End Data Governance

A five-layer data governance architecture ("collection-storage-processing-management-application") is constructed, using hazard data management as an example.

**Collection Layer:** The system enforces mandatory entry of hazard location, description, category, and discoverer, with automated completeness validation. **Storage Layer:** Real-time data is stored in relational databases, while historical data is archived in a data lake. **Processing Layer:** Data cleansing (deduplication, anomaly removal) → data transformation (text to standard encoding) → data aggregation (summarization by project and municipality) → key performance indicator (KPI) calculation. **Management Layer:** Following DLT 860 standards, field specifications, completeness norms, and accuracy specifications are established; a "data lineage map" is created to trace data origins; and data security norms are established (encryption, access control, audit logs). **Application Layer:** Quality and efficiency evaluation computes risk management KPIs based on standardized data; hazard monitoring dashboards are developed; and trend prediction models are established.

**Implementation Steps:** (1) Data standards definition (months 0-1); (2) Data cleansing tool deployment (months 1-2); (3) Storage infrastructure development (months 2-3);

(4) Processing engine and KPI model development (months 3-4); (5) Visualization application development (months 4-6). Risk Mitigation: A "data quality scoring" system is established for regular assessment; data security is ensured through encrypted channels, data masking, and audit logging; and phased investment reduces hardware cost pressures.

The four technical dimensions form a synergistic system: microservices architecture provides flexible execution capability, BPMN process reengineering ensures normalized execution, multi-system integration breaks down data silos, and end-to-end data governance assures data quality. Through this system, the "disconnect between policy and execution" problem in homogenized management is systematically resolved.

## 5 Conclusion and Perspectives

This study constructs a three-dimensionally integrated "institution-process-data" closed-loop governance framework, providing a systematic solution for homogeneous safety management in power production. The main innovative contributions include three aspects: First, it proposes a novel framework that clarifies the progressive relationships among institutions, processes, and data, thereby enriching the theoretical foundation of homogeneous safety management. Second, it designs a homogeneous management system framework comprising vertically progressive three-level structures, horizontally collaborative three-line mechanisms, and a five-stage closed-loop process. Third, it outlines the technical implementation pathway from perspectives of information architecture, process re-engineering methods, information system collaboration, and data chain integration.

It should be noted that this research presents a comprehensive theoretical framework and methodological architecture for homogenized safety management in power enterprises. The framework was developed through systematic analysis of industry best practices, regulatory requirements, and management theory, representing a product of theoretical deduction and empirical practice analysis. While the framework has not yet undergone large-scale empirical validation in operational enterprises, its design foundation is robust and reflects cutting-edge industry management practice.

This framework holds practical engineering value for safety management practices in power enterprises. While this research is grounded in the management practices of large-scale power enterprises, the underlying logic of homogenized safety management—integrating multi-level organizational alignment, process standardization, and risk governance—may have broader applicability across other high-risk industries. Industries such as chemical manufacturing, transportation, water conservancy, and mining share similar organizational characteristics with the power sector, including dispersed operations, diverse operational conditions, and high safety criticality. However, the direct transferability of this framework requires careful consideration of industry-specific contexts. Future research should investigate the adaptability of this homogenized management model to other sectors, examining how industry-specific operational features, regulatory requirements, and hazard profiles necessitate modifications to the core process framework.

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