Journal of Business and Audit Information Systems (JBASE) *Vol. 8 (No.2): 32-51, 2025*
Online Version: http://journal.ubm.ac.id/index.php/jbase *p-ISSN: 2615-6431*
DOI: dx.doi.org/ 10.23893/jbase.v8i2.9003 *e-ISSN: 2620-7907*

Comprehensive HIRARC Implementation for Port Operations: A Multi-Zone Risk Management Framework

Filscha Nurprihatin[1)*], Faridah Hanum Br. Tampubolon[1)], Yayang Nadistya Ayu[1)], Ali Vaezi[2)]

[1)]Department of Industrial Engineering, Sampoerna University, L'Avenue Building, Jl. Raya Pasar Minggu No. Kav. 16, Pancoran, South Jakarta 12780, Indonesia
[2)]Department of Logistics and Supply Chain Management, Trent University, L1J 5Y1, Canada

15 Mei 2025 / 29 Septemberi 2025

Abstract

Ensuring occupational safety in port operations is critical due to the inherently high-risk nature of maritime activities. This study presents an integrated application of the Hazard Identification, Risk Assessment, and Risk Control (HIRARC) methodology across eight operational zones within a major container terminal. Using structured field observations, qualitative risk matrices, and industry-aligned compliance standards, hazards were systematically identified and categorized into low (5%), medium (87%), and high (8%) risk priorities. Key findings indicate recurrent hazards such as electrical shocks, slips, and container-handling incidents, with control strategies emphasizing administrative protocols, engineering measures, and personal protective equipment (PPE). The findings reaffirm that durable HIRARC implementation necessitates both engineering solutions and the active involvement of personnel, alongside an ongoing reinforcement of the safety culture. In this regard, the present study expands the occupational safety and health (OSH) knowledge by articulating a governance model for risk that is simultaneously generalizable and directly applicable to maritime terminals and comparably dense operational settings, effectively narrowing the distance between normative theory and tangible safety measures.

Keywords: *Occupational Safety and Health, Hazard Identification, Risk Assessment, Risk Control, Maritime Safety, HIRARC Framework*

Introduction

Terminal operations situated in port environments are widely acknowledged as some of the most intricate and risk-laden spheres within the worldwide logistics network, typified by extensive cargo handling, heterogeneous and mutually influencing hazard sources, and continuously negotiable human-machine contact. Given that maritime routes now underpin the movement of over 85% of global trade (Mollaoğlu et al., 2019), pressing traffic demands on container facilities have multiplied, concurrently heightening susceptibility to occupational hazards of an essentially mechanical, electrical, kinetic, and chemical nature. Manifest hazards such as crane malfunctions, electrical arching, working at height, unintended material transfer, and hazardous cargo spillage, if left inadequately treated, threaten worker safety, compromise environmental stewardship, and disrupt operational viability.

Occupational Safety and Health (OSH) governance serves as the first line of defense against risks in settings typified by the simultaneous presence of labor, heavy machinery, and toxic substances. The Hazard Identification, Risk Assessment, and Risk Control (HIRARC) paradigm has, therefore, become foundational in the systematic management of these risks within industrial domains (Kabul & Yafi, 2022). The framework directs practitioners to catalogue hazards, appraise the potential severity and frequency, and refine controls under a structured hierarchy. Despite its methodical soundness, field observations indicate that the adoption of HIRARC is spatially and administratively uneven; certain operational matrices escape rigorous scrutiny, giving rise to persistent, already residual vulnerabilities (Priyanka & Basaria, 2023).

[*]Corresponding Author:
Email: filscha.nurprihatin@sampoernauniversity.ac.id

Contemporary literature urges the augmentation of HIRARC by converging behavioral, psychological, and computational vectors. Empirical work, for example, has documented that coupling HIRARC with the PreSiM behavioral lens materially heightens adherence to safe practices and cultivates constructive risk orientations within the workforce (Masuri et al., 2020). Such behavioral reframing is of particular salience within maritime transport corridors, where human misjudgment is systematically acknowledged as the preeminent etiological agent in recorded accidents. Another research reported that over 65% of shipboard accidents, especially in engine room operations, are attributable to human actions, underscoring the urgency of embedding psychological and ergonomic considerations into OSH frameworks (Chowdhury et al., 2024).

Concurrently, advances in fuzzy logic and multi-criteria decision-making (MCDM) methodologies have augmented the analytical capability of contemporary risk assessment frameworks. A recent contribution, for instance, delineated a fuzzy-integrated structure that amalgamates fuzzy analytic hierarchy process (FAHP) with fuzzy VIKOR, effectively ameliorating the known deficiencies of exper) d t bias in risk ranking and the inflexibility of static weighting schemas (Gul, 2020). This model confers superior adaptability across intricate operational settings, at the same time quantifying uncertainty and facilitating participative, compromise-directed control protocols. Another paper renovated the paradigm through the elaboration of a holistic *Z*-number-based risk management framework (HZRMF) designed for environmentally sustainable construction (Zhang & Mohandes, 2020). The construction interlaces the Z-numbers-based Best Worst Method (ZBWM), Z-based weighted minimum-maximum (ZBWM) and the fuzzy technique for ordered preference by similarity to the ideal solution (TOPSIS) families, embedding expert confidence metrics and dynamic parameter weighting to rectify the ingrained deficiencies of prescribed risk matrices (Zhang & Mohandes, 2020). While principally contextualized to the construction of green edifices, the HZRMF's resolute commitment to expert-anchored modeling and comprehensive multi-parameter scrutiny portends substantial crossover utility, particularly for port domains, where operational variability and infrastructural complexity resemble, in essential dimensions, those of the referenced building projects.

The conventional HIRARC methodology lacks standardized risk-acceptance criteria, which serve as a vital deficiency. A previous research conducted a systematic review of RACs in occupational health and safety, categorizing them into individual, societal, cost-benefit, and environmental dimensions (Marhavilas & Koulouriotis, 2021). The proposed flowchart-based algorithm for RAC integration offers a replicable structure for embedding tolerability thresholds into risk assessment workflows (Marhavilas & Koulouriotis, 2021). The question “How safe is safe enough?” remains central to risk governance, particularly in high-risk, high-throughput domains such as maritime terminals (Marhavilas & Koulouriotis, 2021). Without clear RACs, safety decisions may be inconsistent, subjective, or misaligned with organizational risk appetite and regulatory standards.

This study responds to these theoretical and practical gaps by implementing a comprehensive HIRARC framework across eight operational zones within a major container terminal. Unlike prior research that often focuses on single-site or generic applications, this investigation adopts a multi-zone perspective to capture the spatial and functional heterogeneity of port operations. Through structured field observations, qualitative risk matrices, and compliance benchmarking, hazards are systematically identified, assessed, and controlled. The analysis categorizes risk exposure into low (5%), medium (87%), and high (8%) priority levels, with control strategies encompassing administrative protocols, engineering interventions, and personal protective equipment (PPE).

The research is guided by two central questions:

1. What are the predominant hazards across distinct operational areas in port environments?

2. How can a structured, multi-zone HIRARC framework enhance safety, governance, and risk prioritization?

By addressing these questions, the study contributes to both academic discourse and industry practice. Theoretically, it reinforces the role of systematic hazard assessment in sustaining safety culture and operational resilience. Practically, it offers a replicable governance model for port operators seeking to implement HIRARC in a context-sensitive and behaviorally informed manner. Moreover, the integration of insights from fuzzy logic, Z-numbers modeling, and RAC formation algorithms positions this framework at the intersection of traditional safety engineering and emerging computational risk analytics.

The research advances occupational risk management through HIRARC application, which includes behavioral and computational elements for hazard reduction in complex port settings. The research results impact maritime terminals along with other industrial environments that operate multiple zones at high risk because they must integrate the safety protocols with current operational needs and regulatory standards.

Literature Review

Occupational Safety and Health: Scope and Global Relevance

Occupational Safety and Health (OSH) functions as an essential foundation of industrial governance, which protects the physical and psychological, and social wellness of workers in various industries (Jain et al., 2021). The main goal of OSH frameworks involves reshaping workplace conditions to match human requirements, which leads to enduring productivity and reduced occupational danger exposure. The global workplace safety issue persists even though regulations have evolved along with technological development over the past decades. The International Labour Organization reported that yearly work-related incidents number 313 million, which cause 2.78 million deaths and more than 160 million occupational disease cases (Dodoo & Al-Samarraie, 2023). The reported data demonstrates that organizations must prioritize creating safety systems beyond basic compliance because they need to build resilience directly into the organizational culture.

OSH challenges in high-throughput environments like ports become intensified due to the integration of human workers with mechanized operations and dangerous substances. Ports operate as essential nodes throughout worldwide supply chains since they process more than 85% of international trade (Mollaoğlu et al., 2019). The wide range of operational tasks from container handling and fuel transfer to maintenance and inspection puts workers at risk of mechanical injuries and chemical exposure as well as ergonomic strain and psychosocial stressors (Sanni-Anibire et al., 2020). The absence of proper safety protocols, together with disjointed safety management systems and inadequate worker education, creates amplified risks that lead to both avoidable accidents and permanent health problems.

A strong OSH implementation produces various advantages for organizations. The implementation of safety measures brings economic benefits through decreased downtime and reduced compensation claims, and lower employee turnover (Jain et al., 2021). The implementation of safety measures supports sustainability objectives because it advances fair working conditions while boosting the organization's public image. A complete OSH strategy requires the incorporation of hazard assessment processes together with behavior monitoring systems and adaptable control systems for regulatory compliance and operational success.

Conceptual Distinction Between Safety and Health

The term "Occupational Safety and Health" contains two essential domains that work together yet operate separately. The term safety focuses on conditions that cause injuries and usually occur abruptly through mechanical events, yet health refers to long-term disease exposures linked to chemical and ergonomic, and psychological stressors (Binti Ramli et al., 2020). The distinction becomes essential when working in port environments because both domains converge.

The continuous exposure to loud noise from power terminal generators can create psychological stress, together with auditory fatigue, which constitutes a health matter. The same stress situation causes decreased cognitive alertness, which leads to increased chances of procedural errors and physical accidents that represent safety issues. The necessary OSH framework requires both immediate and latent risk assessment to enable proactive safety-health interventions across the entire continuum.

Knowledge about the two main hazard profile elements improves hazard analysis and creates better methods for controlled intervention plans. The approach enables the creation of combined evaluation tools that link together compliance auditing with behavioral diagnosis of OSH performance.

OSH Challenges in Port Operations

The combination of a diverse workforce and intense temporal activity and spatial variability in port operations makes them highly vulnerable to OSH violations. The constant movement of cargo vehicles and personnel between docks, cranes and fuel terminals, and administrative areas generates a complex risk environment. Research demonstrates that port-related incidents primarily occur because of deficient safety culture and insufficient training, together with inadequate hazard communication (Mollaoğlu et al., 2019; Sanni-Anibire et al., 2020).

The location of ports near urban centers intensifies the environmental and societal effects of occupational hazards. When ports near residential areas experience chemical leaks or fuel spills, the dangers extend to both port workers and nearby community members. The spatial externality makes it essential to implement thorough risk management protocols, which should cover areas beyond the immediate work environment.

Port risk management operations need to operate in two modes: prevention and adaptation. The system needs to use historical incident data and environmental monitoring data together with behavioral analytics to detect hazard sources, which will inform context-based interventions. The integration of OSH into port governance functions as an essential sustainable logistics strategy rather than only fulfilling regulatory requirements.

HIRARC: Structure, Application, and Limitations

The Hazard Identification, Risk Assessment, and Risk Control (HIRARC) framework functions as a structured method for workplace hazard management (Wong et al., 2022). The three phases of this system occur in a specific order:

1. Hazard Identification: Systematic detection of potential sources of harm.
2. Risk Assessment: Evaluation of likelihood and severity using qualitative or quantitative matrices.
3. Risk Control: Implementation of mitigation strategies based on a control hierarchy.

Various industrial sectors, including construction and manufacturing, and maritime operations, have successfully adopted HIRARC as the risk management framework. The framework's power emerges from its clear structure and its ability to adapt to various operational environments

(Kabul & Yafi, 2022). A study has demonstrated that HIRARC implementation occurs in a fragmented way because work zones do not apply it consistently, and behavioral and contextual variables are rarely incorporated (Priyanka & Basaria, 2023).

Research indicates that behavioral modeling serves as an essential method for improving HIRARC processes. A study used the PreSiM model to discuss road safety and showed that combining HIRARC with attitude-based predictors leads to better compliance along with reduced incident rates (Masuri et al., 2020). The method proves most useful in port operations since human mistakes dominate as the primary cause. Research demonstrates that human actions cause more than 65% of maritime accidents in engine rooms, thus requiring psychological and ergonomic elements to be added to OSH systems (Chowdhury et al., 2024).

Traditional HIRARC models utilize static risk matrices, which present limitations in capturing both uncertainty and expert reliability (Gul, 2020). To solve this problem, researchers presented a fuzzy-based framework using FAHP and fuzzy VIKOR to dynamically prioritize hazards (Gul, 2020). Researchers improved this methodology by developing a Z-numbers-based risk management framework, which uses expert confidence levels and multi-parameter weighting through ZBWM-ZTOPSIS algorithms (Zhang & Mohandes, 2020). The HZRMF framework, designed for green construction, provides valuable methods for port risk assessment through its expert-based modeling and uncertainty measurement approach. A recent study established PFMEA as a reliable tool to build risk threshold models in quality control systems, which leads to more precise acceptance sampling decisions (Reihana et al., 2024).

Risk Acceptance Criteria (RACs): A Missing Link

Conventional HIRARC applications face a major deficiency because they lack uniform Risk Acceptance Criteria (RACs) (Marhavilas & Koulouriotis, 2021). Safety decisions lack consistency because organizations do not have clear risk tolerability thresholds, which creates subjective and potentially misaligned safety protocols. A study examined RACs in OSH through a systematic review, which created four distinct domains for classification (Marhavilas & Koulouriotis, 2021):

1. Individual Risk (IR): Evaluates safety acceptability according to single-person exposure levels.
2. Societal Risk (SR): Refers to the combined risk danger that affects all members of a population.
3. Cost-Benefit (CB): Evaluates economic trade-offs that occur during risk mitigation processes.
4. Environmental Risk (ENV): Refers to the detrimental effects that impact ecological systems.

The flowchart-based RAC integration algorithm proposed by a previous paper creates a standardized method to implement tolerability thresholds within risk assessment procedures (Marhavilas & Koulouriotis, 2021). The method applies directly to port operations since different zones and personnel roles encounter different levels of hazard exposure. Safety decisions lose credibility and consistency when RACs are absent because this question, "How safe is safe enough?" remains fundamental to risk governance (Marhavilas & Koulouriotis, 2021).

The inclusion of RACs in HIRARC strengthens its decision-making precision and matches safety protocols with regulatory demands and stakeholder needs. Ports can advance from reactive compliance to proactive risk governance through benchmarking and continuous improvement processes, which the system facilitates.

Emerging Methodologies: Toward Adaptive Risk Governance

Current OSH frameworks receive direction from modern computational techniques alongside system-theoretic approaches. The 4P4F framework was created by researchers to evaluate Maritime Autonomous Surface Ships (MASS) through hazard classification across operational phases and factor domains (Fan et al., 2020). The autonomous system-focused framework shares a phase-based structure that matches HIRARC and demonstrates why dynamic hazard profiling remains necessary.

The previous research supported that scenario-based risk assessment proves beneficial for autonomous maritime systems (Tao et al., 2024). The research demonstrated that traditional models fail to deliver satisfactory results while emphasizing the necessity of flexible technological solutions (Tao et al., 2024). A research paper developed a system-theoretic framework that employs STPA to determine Risk Control Options (RCOs) by analyzing interactions between technical elements and operators and organizational processes (Chaal et al., 2022).

The methodologies provide essential knowledge to enhance HIRARC implementation within port environments. Through the integration of behavioral predictors with expert reliability and system-level interactions, HIRARC can develop into a powerful adaptive framework that manages modern logistics complexities.

Comparative Study of HIRARC Applications Across Industrial Contexts

Various industrial sectors implement the HIRARC framework by modifying its structure according to the unique risk profiles. Table 1 demonstrates a comparative analysis of the diverse applications of HIRARC together with its operational boundaries beyond traditional port settings.

Table 1. Comparative Overview of HIRARC Applications

Author(s)	Sector	Key Adaptation of HIRARC	Methodological Enhancement	Relevance to Port Operations
(Wong et al., 2022)	Construction	SOP-driven hazard control, static workflows	Qualitative risk matrices	High Similar physical hazards
(Zhang & Mohandes, 2020)	Green Building	Z-numbers modeling, expert confidence weighting	Hybrid ZBWM-ZTOPSIS algorithm	Medium Methodological innovation
(Fan et al., 2020; Tao et al., 2024)	Autonomous Maritime	Phase-factor mapping, scenario-based assessment	4P4F framework, dynamic modeling	High Parallels in operational complexity
(Masuri et al., 2020)	Road Safety	Behavioral predictors, attitude modeling	PreSiM integration	High Human error relevance
(Chowdhury et al., 2024)	Maritime Engine Rooms	Human factors profiling, fatigue analysis	Psychological risk classification	High Ergonomic and procedural overlap
This Paper	Port Operations	Multi-zone hazard profiling, behavioral integration, RACs	Structured HIRARC + fuzzy logic + RAC algorithm	Very High Tailored to port-specific complexity

Vol. 8 (No.2): 32-51, 2025
p-ISSN: 2615-6431
e-ISSN: 2620-7907

Within the construction sector, HIRARC processes have proved effective in controlling hazards involved in the construction of dams(Wong et al., 2022). The research highlighted the need for systematic control hierarchies and hazard identification, especially where physical hazards were high and automation possibilities were low (Wong et al., 2022). The use of qualitative risk matrices, supported by interventions based on standard operating procedures, aligns with practices seen in port operations; construction sites are generally more predictable, leading to workflows that allow for better hazard prediction and the standardization of controls.

Conversely, a different study in support of a risk management framework employing Z-numbers to enhance HIRARC effectiveness offered multi-parameter weightings with different degrees of expert confidence (Zhang & Mohandes, 2020). The combined model, called ZBWM-ZTOPSIS, attempts to correct the shortcomings related to traditional risk matrices by using dynamic prioritization with uncertainty quantification (Zhang & Mohandes, 2020). While the subject of green construction differs from port logistics with respect to types of risks encountered, this conceptual development holds much promise for HIRARC analysis improvement in complex situations with multiple zones.

In the field of maritime autonomous systems, an academic paper proposed the 4P4F framework to identify Risk Influencing Factors (RIFs) in different operational steps and zones (Fan et al., 2020). Although autonomous shipping is the major focus, the phase-based model is theoretically compatible with sequential reasoning in HIRARC. Meanwhile, another research effort proposed a scenario-based approach for risk assessment to overcome the shortcomings related to static models, which is compatible with the needs of dynamic application of HIRARC in port environments (Tao et al., 2024).

Behavioral integration depends on the industry types involved, specifically. Another study using an HIRARC framework simulated on-road safety under PreSiM and found that introducing risk assessment together with attitude predictors significantly enhances compliance (Masuri et al., 2020). Another study implemented this behavioral schema in ship engine rooms and found that risk factors related to fatigue, poor communication, and inadequate training were salient (Chowdhury et al., 2024). These findings highlighted psychological and ergonomic considerations under the HIRARC approach, especially for occupational environments like ports.

Methodology

This study adopts a systematic and reproducible approach to applying the HIRARC model to eight operational areas within a major container terminal. Existing studies on similar logistical settings have utilized unsupervised clustering approaches to find central points by reducing variability within clusters and maximizing cost apportionment, all of which are related to hazard zonation within a port safety setting (Nurprihatin et al., 2023). The procedural framework developed for this study aims to provide comprehensive hazard profiling, organized risk assessment, and situation-appropriate control measures. Figure 1 presents the sequential layout of the research design with its five main stages: work activity categorization, hazard detection, risk assessment, validation by experts, and adoption of risk reduction measures.

1. Work Activity Classification
   The first step involved the classification of operational activities into two categories: routine and non-routine tasks. The classification is very applicable to port operations where fluidness of processes and diversity of tasks influence the degree of hazard exposure. Systematic observation in a checklist format was utilized to identify tasks at different locations, such as powerhouses,

Vol. 8 (No.2): 32-51, 2025
p-ISSN: 2615-6431
e-ISSN: 2620-7907

workshops, STS crane site, container yard dock, and fuel terminals. The classification enabled proper hazard identification and ensured that both prospective and unexpected hazards were covered.

2. Hazard Identification
   Hazard assessment is known by many different names, such as risk assessment, hazard assessment, and/or hazard identification. To improve the reliability of the hazard identification process and provide maximum scope for the data collection, a triangulated research methodology was used in this case study, which is followed by the methods outlined below:
   a. Direct Observation: Researchers conducted site visits to observe and subsequently report on operational methods, equipment, and prior environmental conditions.
   b. Incident Log Review: Researchers selected to review past events (accidents and near misses) as this would detail hazards that were recurrent factors and any latent risks that could emerge.
   c. Structured Interviews: Twenty-five employees from different groups, including specific roles: Operators, Supervisors, and Safety personnel. Employees were asked for an open-ended semi-structured interview protocol that was focused on talking about risks, incidents that had occurred, and procedural weaknesses.
   d. Checklist-Based Inspection: An inspection process employed a checklist for hazard identification that added further standardization so that each zone was consistent and comparable.

   This multi-source strategy ensured both visible and non-visible knowledge of workplace hazards was incorporated into the process.
3. Risk Assessment
   Risks were assessed using a qualitative risk matrix that considers all risks in terms of likelihood and likelihood of harm. Each risk is ranked separately in terms of severity and likelihood on a 5-point scale (1 = lowest, 5 = highest), and the risk score is based on the following risk score formula as shown in Equation (1).

$$Risk\ Score = (Severity\ )(Likelihood) \tag{1}$$

   The resulting scores were classified into three priority levels:
   a. Low (L): Risk score ≤ 4
   b. Medium (M): Risk score between 5 and 9
   c. High (H): Risk score ≥ 10

   This matrix-type approach allowed for easy communication of risk and allowed for prioritization of control methods. In addition to risk levels, hazard frequencies were compiled, and the percentage distribution across risk levels was calculated so that common risk categories and operational hotspots could be identified. The structured decision-making models, such as AHP and TOPSIS, allow for a structured process that can be replicated, as well as formalizing the expert judgements to also maintain coherence with multi-criteria assessment purposes (Nurprihatin et al., 2022).
4. Expert Validation
   To maintain methodological rigor and reduce subjectivity, cross-validation was performed by certified OSH experts. The expert panel reviewed the hazard profiles, risk ratings, and control recommendations, and the feedback was used for the revision of the risk matrix thresholds and to validate the consistency of the categorization of risk-level and defined hazards. This step

strengthened the validity of the assessment, and the risk assessment was more likely to be consistent with processes from industry-related best practices.

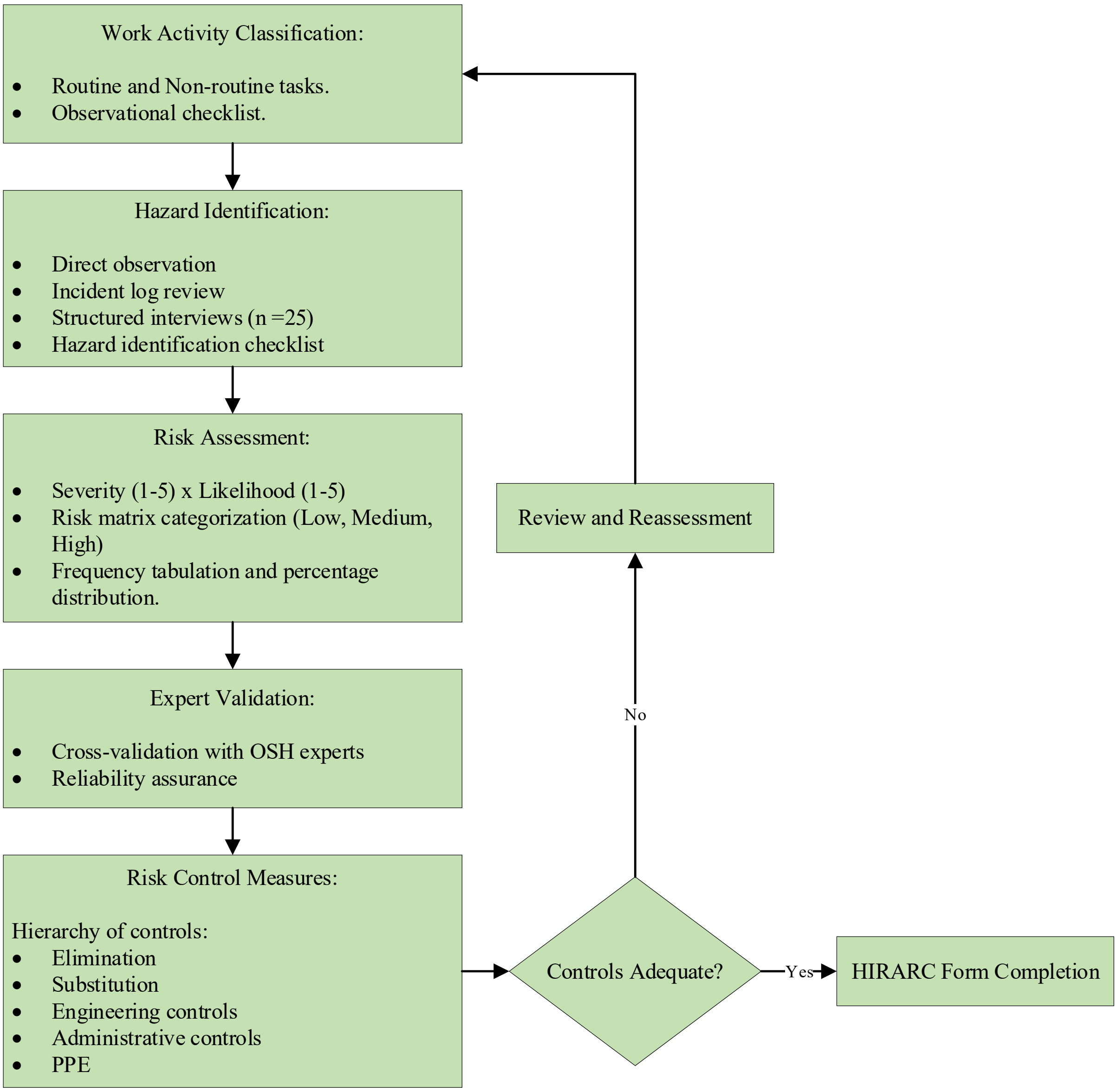

Figure 1. Research Flow Chart

5. Risk Control Implementation

   Risk control measures were prepared according to the established internationally recognized hierarchy of controls:

   a. Elimination: The hazard is removed from the workplace entirely.
   b. Substitution: Uses safer processes or materials to replace hazardous processes or materials.
   c. Engineering Controls: Elimination of worker exposure to hazards by employing physical separation (barriers, ventilation, etc.).
   d. Administrative Controls: Reduction of exposure through formal and informal systems, procedures, and training.
   e. Personal Protective Equipment (PPE): Provided appropriate PPE (helmets, gloves, masks, etc.) to address residual risks.

Each hazard was associated with appropriate risk controls based on risk rating and the context of the elapsed task. For example, high-risk activities such as fuel transfer and container stacking were addressed through engineering interventions and strict procedural protocols. Meanwhile, medium-risk tasks such as stair climbing and document handling were mitigated through administrative controls and PPE usage.

Results and Discussions

Where the 4P4F framework addresses navigation risks in autonomous shipping through phase-factor mapping (Fan et al., 2020), this research defines a risk governance model for human-intensive port contexts. Nevertheless, both frameworks share a systemic perspective, highlighting that risk assessment must capture operational context and technological dynamics to maintain safety integrity. Tables 2 through 9 show the activity and hazard identification in each area. From these hazards, the Management System Team needs to consider the hazards to prevent any injuries to the employees.

Tables 2 through 9 present the results of the HIRARC implementation across eight distinct operational zones within the container terminal: Workshop, Operators' Rest Room, CY Dock, STS Crane Area, Powerhouse, Pumphouse, Terminal Truck and Fuel Area, and Main Gate In/Out. Each table documents the hazard identification, risk assessment (severity × likelihood), and corresponding control measures for specific activities within each zone. The structured tabulation enables comparative analysis of risk exposure and control adequacy across spatially and functionally diverse environments.

The Workshop zone revealed a predominance of medium-risk hazards (e.g., electric shock, slips, ergonomic strain), with one low-risk activity (radiation from A-RTG screens), as shown in Table 2. Control measures were largely administrative (e.g., SOPs, hygiene checklists) and PPE-based. The recurrence of electrical hazards underscores the need for routine equipment inspection and cable integrity monitoring.

Despite its passive function, the Rest Room exhibited medium-risk exposures, particularly related to COVID-19 transmission and electrical hazards, as exhibited in Table 3. The findings highlight that non-operational zones are not exempt from safety concerns and require behavioral controls (e.g., health protocols) and environmental hygiene measures.

CY Dock emerged as the highest-risk zone, with multiple activities scoring a risk value of 15 (High), as presented in Table 4. These included container handling, truck movement, and berthing operations. Hazards such as pileups, falls into the sea, and container crashes necessitated engineering controls (e.g., vehicle flow design, brake checks) and strict procedural enforcement. The clustering of high-risk scores in this zone validates its prioritization for resource allocation and safety audits. Similar to how Tailor-Made Value Stream Mapping (TVSM) was used to identify bottlenecks and reduce non-value-added activities in café service operations, applying a customized mapping approach to port zones can enhance visibility of procedural inefficiencies and support targeted risk mitigation (Nurprihatin et al., 2024).

The STS Crane zone presented moderate risks, primarily linked to loading/unloading operations and stair climbing, as displayed in Table 5. Control strategies emphasized SOP adherence, equipment checks, and behavioral compliance (e.g., no smoking policies). The integration of ergonomic and procedural controls was critical in mitigating fall-related hazards.

Vol. 8 (No.2): XXX-XXX, 2025
p-ISSN: 2615-6431
e-ISSN: 2620-7907

Table 2. Hazard Identification, Risk Assessment, and Risk Control in Workshop Area

No	Work Area	Activity/Facility	Hazard Identification	Risk Assessment				Risk Control
				S	L	R	Risk Exposure	
1	Workshop	Organizing documents into document cabinet	Hitting by the document	2	3	6	M	Making a list of documents and compiling routine documents that will be accessed at the bottom of the list
2		Connecting the cable to the socket	Got electric shock	2	3	6	M	a. Turning on electricity according to SOP b. Performing routine checks and maintenance on electrical equipment c. Ensuring there are no chipped cables
3		Operating the A-RTG equipment	Light radiation and computer screen	4	1	4	L	Using the latest equipment that has been equipped with anti-radiation coating
4		Conducting meeting	Infecting with covid-19 virus	3	3	9	M	a. Implementing health protocols b. If there is not enough room, you will use the zoom meeting facility
5		Cleaning workshop	Slipping	2	3	6	M	a. Creating SOP and hygiene checklists b. Information about the area being cleaned with a symbol/sign
6		Parking the vehicle	Hitting by an overhead crane	2	3	6	M	a. Ensuring that the overhead crane is properly locked
			Hitting by another vehicle					a. Parking vehicles in sequence
7		Climbing up the stairs	Slipping or falling	2	3	6	M	a. Cleaning stairs regularly b. Creating the flow for up and down c. Climbing the stairs carefully
8		Data monitoring in server room	Got electric shock	2	3	6	M	a. Performing routine checks and maintenance on electrical equipment b. Monitoring according to SOP c. Ensuring there are no chipped cables
9		Arranging parts or repairing tools	Slipping or falling	2	3	6	M	a. Creating a list of parts or tool locations b. Arranging parts or tools according to priority
10		Repairing of tools or machines	Got electric shock Injuries to the hands or other body parts	3	3	9	M	a. Making repairs according to procedure b. Wearing Personal Protective Equipment c. Be careful while making repairs

Vol. 8 (No.2): XXX-XXX, 2025
p-ISSN: 2615-6431
e-ISSN: 2620-7907

No	Work Area	Activity/Facility	Hazard Identification	Risk Assessment				Risk Control
				S	L	R	Risk Exposure	
			Falling					d. Arranging repair tools neatly according to needs e. Ensuring there are no chipped cables f. Performing routine checks and maintenance on electrical equipment

Table 3. Hazard Identification, Risk Assessment, and Risk Control in Operators' Rest Room Area

No	Work Area	Activity/Facility	Hazard Identification	Risk Assessment				Risk Control
				S	L	R	Risk Exposure	
1	Operators' Rest Room	Connecting the cable to the socket	Get Electric Shock	2	3	6	M	a. Turn on electricity according to SOP b. Perform routine checks and maintenance on electrical equipment c. Ensure there are no chipped cables
2		Taking a rest	Infecting with covid-19 virus	3	3	9	M	a. Implementing health protocols b. Use the Zoom meeting facility if there is not enough room
3		Climbing the stairs	Slipping	2	3	6	M	a. Create SOP and hygiene checklists b. Create sign/symbol for area being cleaned
4		Conducting meeting	Slipping or falling	2	3	6	M	a. Clean stairs regularly b. Create the flow for up and down c. Climb the stairs carefully

Journal of Business and Audit Information Systems (JBASE)
Online Version: http://journal.ubm.ac.id/index.php/jbase
DOI:
Vol. 8 (No.2): XXX-XXX, 2025
p-ISSN: 2615-6431
e-ISSN: 2620-7907

Table 4. Hazard Identification, Risk Assessment, and Risk Control in CY Dock Area

No	Work Area	Activity/Facility	Hazard Identification	Risk Assessment				Risk Control
				S	L	R	Risk Exposure	
1	CY Dock	Shipping berthing	The ship hit the crane dock	5	3	15	H	a. Cooperate with Pandu to anchor the ship to the TP pier b. Carried out the reservation process according to the SOP c. Be careful during the backup process d. Provide information/warning to the crew if the ship is very close to the dock
2		Carrying containers from STS to stacking fields and vice versa by using an Internal Truck	Pileup	5	3	15	H	a. Create vehicle flow b. Prohibit people from crossing the trucks' path c. Every driver has SIO and uses safety equipment
			Falling into the sea	5	3	15	H	a. Install vehicle signs b. Limit maximum speed c. Ensure the truck brakes can work properly d. Perform periodic maintenance
			Crashing by a container	5	3	15	H	a. Make sure the container is in the right position b. Ensure the Twist Lock is installed properly
3		Security patrol routine	Crashing by a container	3	3	9	M	a. Patrol according to a predetermined path b. Use Personal Protective Equipment
4		Repairing port facilities	Hitting by a truck	3	3	9	M	a. Install warning sign b. Use Personal Protective Equipment c. Make repairs according to procedure
5		Stacking containers in the stacking field	Container fell	2	3	6	M	a. Ensure the Twist Lock is installed properly b. Carried out the preparation process according to the Procedure c. Perform routine A-RTG maintenance
6		Climbing the ladder for A-RTG maintenance/repair	Slipping or falling	2	3	6	M	a. Clean stairs regularly b. Use Personal Protective Equipment c. Climb the stairs carefully
7		Doing reefer container arrangement	Hitting by a truck/reach stacker	2	3	6	M	a. Use Personal Protective Equipment b. Actively coordinating with drivers using HT

Vol. 8 (No.2): XXX-XXX, 2025
p-ISSN: 2615-6431
e-ISSN: 2620-7907

No	Work Area	Activity/Facility	Hazard Identification	Risk Assessment				Risk Control
				S	L	R	Risk Exposure	
			Get electric shock					a. Use Personal Protective Equipment b. Ensure there are no chipped cables c. Perform routine checks and maintenance on electrical equipment
8		Dangerous goods container arrangement	Containers explode	3	3	9	M	a. Place the container i a safe place b. Use Personal Protective Equipment c. Be careful during the container preparation process
9		Performing CY dock cleaning and maintenance actions	Hitting by a truck	3	3	9	M	a. Install warning signs b. Use Personal Protective Equipment c. Carried out cleaning and maintenance actions according to schedule and procedures

Table 5. Hazard Identification, Risk Assessment, and Risk Control in STS Crane Area

No	Work Area	Activity/Facility	Hazard Identification	Risk Assessment				Risk Control
				S	L	R	Risk Exposure	
1	STS Crane Area	Carrying out the loading and unloading process	A wildfire or Dropped Container	3	3	9	M	a. Carried out the loading and unloading process according to the SOP b. Check and fill out routine reports before loading and unloading c. Ensure tool can function properly d. Make sure there are no sparks before carrying out the loading and unloading process e. No smoking in the operator’s cabin
2		Climbing the stairs	Slipping or falling	2	3	6	M	a. Cleaning stairs regularly b. Climb stairs carefully
3		Cleaning STS Crane	Slipping or falling	2	3	6	M	a. Clean STS Crane according to procedure b. Use Personal Protective Equipment c. Bring cleaning supplies as needed and arrange them neatly (not blocking the way)

Journal of Business and Audit Information Systems (JBASE)
Online Version: http://journal.ubm.ac.id/index.php/jbase
DOI:

Vol. 8 (No.2): XXX-XXX, 2025
p-ISSN: 2615-6431
e-ISSN: 2620-7907

Table 6. Hazard Identification, Risk Assessment, and Risk Control in Powerhouse Area

No	Work Area	Activity/Facility	Hazard Identification	Risk Assessment				Risk Control
				S	L	R	Risk Exposure	
1	Powerhouse	Connecting the cable to the socket	Getting electric shock	2	3	6	M	a. Turn on electricity according to SOP b. Perform routine checks and maintenance on electrical equipment c. Ensure there are no chipped cables d. Use Personal Protective Equipment[i1]
2		Turning on the Generator	Hearing loss	3	3	9	M	a. Use Personal Protective Equipment
			Gas poisoning emissions	3	3	9	M	a. Using Mask b. Do work based on the procedure c. Equip the room with adequate ventilation
3		Checking the Electrical Panel	Getting electric shock	2	3	6	M	a. Use Personal Protective Equipment b. Perform routine checks and maintenance on electrical equipment c. Ensure there are no chipped cables
4		Climbing up the stairs	Slipping or falling	2	3	6	M	a. Clean stairs regularly b. Create the flow for up and down c. Climb the stairs carefully
5		Repairing of electrical equipment	Repairing of electrical equipment	3	3	9	M	a. Perform reparation based on the procedure b. Use Personal Protective Equipment c. Be careful while doing reparation d. Arrange repair tools neatly based on the needs e. Ensure there are no chipped cables f. Perform routine checks and maintenance on electrical equipment
			Injuries to the hands or other body parts					

Vol. 8 (No.2): XXX-XXX, 2025
p-ISSN: 2615-6431
e-ISSN: 2620-7907

Table 7. Hazard Identification, Risk Assessment, and Risk Control in Pumphouse Area

No	Work Area	Activity/Facility	Hazard Identification	Risk Assessment				Risk Control
				S	L	R	Risk Exposure	
1	Pumphouse	Water distribution process	Cavitation	2	2	4	L	a. Perform the water distribution process based on the SOP
			Explosion	2	2	4	L	b. Ensure the water pressure and temperature are within a reasonable threshold c. Provide fire extinguishers and hydrants around the pumphouse d. Use Personal Protective Equipment
			Getting Electric shock	2	3	6	M	a. Turn on electricity based on the SOP b. Perform routine checks and maintenance on electrical equipment c. Ensure there are no chipped cables

Table 8. Hazard Identification, Risk Assessment, and Risk Control in Terminal Truck and Fuel Area

No	Work Area	Activity/Facility	Hazard Identification	Risk Assessment				Risk Control
				S	L	R	Risk Exposure	
1	Terminal Truck and Fuel	Filling fuel to the storage tank or to the Internal Truck	Fuel spill/slip/fall	5	3	15	H	a. Fill the fuel into the tank based on the SOP b. Use Personal Protective Equipment
			Wildfire	5	3	15	H	a. Ensure there are no sparks/sources of fire during refueling b. Provide APAR/Hydrant around the refueling area

Vol. 8 (No.2): XXX-XXX, 2025
p-ISSN: 2615-6431
e-ISSN: 2620-7907

Table 9. Hazard Identification, Risk Assessment, and Risk Control in Main Gate In/Out Area

No	Work Area	Activity/Facility	Hazard Identification	Risk Assessment				Risk Control
				S	L	R	Risk Exposure	
1	Main Gate In/Out	Checking vehicles that enter and exit the terminal area	Crashing by the vehicle	3	3	9	M	a. Make maximum speed signs/be careful b. Give a signal to stop the vehicle before the vehicle passes the gate c. Make circular letter regarding the implementation of the Normal Security Level
			Infection with Covid-19 virus	3	3	9	M	a. Implement Health Protocol b. Use gloves when checking the vehicle
2		Cleaning the gate in/out	Falling/crashing by vehicles that pass through the gate in/out	2	3	6	M	a. Make SOPs and hygiene checklists b. Use symbols/signs to inform area being cleaned

Hazards in the Powerhouse were predominantly electrical and chemical in nature, including electric shocks, hearing loss, and gas emissions, as revealed in Table 6. All activities were rated medium-risk, with control measures spanning PPE usage, ventilation, and procedural adherence. The zone's exposure to auditory and respiratory hazards suggests a need for enhanced environmental monitoring and ergonomic design.

The Pumphouse exhibited a mix of low and medium-risk hazards, including cavitation, explosion, and electric shock, as shown in Table 7. Control measures were largely engineering-based (e.g., pressure regulation, fire suppression systems) and procedural. The relatively low risk scores reflect effective hazard containment, though periodic reassessment is recommended.

This zone recorded high-risk scores (15) for fuel spills and fire hazards during refueling operations, as exhibited in Table 8. Control measures included SOP enforcement, spark prevention, and fire suppression readiness. The findings underscore the criticality of hazard anticipation and emergency preparedness in fuel-handling zones.

The Main Gate zone presented medium-risk hazards related to vehicle collisions and COVID-19 exposure, as presented in Table 9. Controls focused on signage, traffic management, and health protocols. Although not a core operational zone, its role as a transitional interface necessitates vigilant safety oversight.

Journal of Business and Audit Information Systems (JBASE) *Vol. 8 (No.2): XXX-XXX, 2025*
Online Version: http://journal.ubm.ac.id/index.php/jbase *p-ISSN: 2615-6431*
DOI: *e-ISSN: 2620-7907*

Conclusion

This study has demonstrated the practical and theoretical value of implementing a comprehensive HIRARC framework across multi-zone port operations. By systematically identifying hazards, assessing risk levels, and recommending control measures tailored to eight distinct operational zones, the research provides a replicable model for occupational safety governance in high-throughput maritime environments. The findings reveal that while catastrophic risks are relatively rare, medium-level hazards dominate the operational landscape, accounting for 87% of all identified risks. This distribution underscores the importance of sustained vigilance and proactive control strategies, even in zones traditionally perceived as low-risk.

The integration of behavioral insights, expert validation, and structured risk matrices has significantly enhanced the robustness of the HIRARC application. Behavioral compliance plays a critical role in shaping safety outcomes, particularly in environments where human-machine interaction is frequent and procedural lapses can escalate into serious incidents (Masuri et al., 2020). This study reinforces that view by identifying behavioral vulnerabilities, such as fatigue, inattentiveness, and procedural non-compliance, as recurrent risk factors across zones like the STS crane area and rest facilities.

Moreover, the incorporation of fuzzy logic and Z-numbers-based modeling offered a promising avenue for refining hazard prioritization under uncertainty (Zhang & Mohandes, 2020). Although this study employed a qualitative risk matrix, future iterations could benefit from hybrid models that integrate expert confidence levels and multi-parameter weighting to improve decision accuracy. Similarly, the absence of standardized Risk Acceptance Criteria (RACs) remains a critical gap in conventional HIRARC applications. The lack of tolerability thresholds undermines the consistency and credibility of safety decisions (Marhavilas & Koulouriotis, 2021). This research partially addresses that gap by applying expert-informed thresholds, but further formalization of RACs is recommended.

The comparative analysis across zones reveals that high-risk areas, such as the CY Dock and Fuel Terminal, require more intensive engineering and administrative controls, while medium-risk zones benefit from behavioral interventions and PPE enforcement. This stratified approach aligns with the hierarchy of controls and supports efficient resource allocation. The use of structured interviews, incident log reviews, and direct observation has ensured that hazard identification is both comprehensive and context-sensitive. Cross-validation with OSH experts further strengthens the reliability of the findings and aligns the methodology with best practices in industrial safety research.

From a strategic perspective, this study contributes to the evolving discourse on adaptive risk governance in logistics and maritime operations. Researchers discussed the scenario-based and system-theoretic approaches to safety management, while grounding the framework in the operational realities of port terminals (Chaal et al., 2022; Tao et al., 2024). The multi-zone profiling and control mapping presented here can serve as a blueprint for other industrial environments seeking to implement HIRARC in a scalable and behaviorally informed manner.

In conclusion, the success of HIRARC implementation is not solely dependent on hazard elimination but also on shaping workers' attitudes, embedding safety culture, and aligning control strategies with operational complexity. The findings of this study affirm that a comprehensive, zone-specific, and expert-validated HIRARC framework can significantly enhance occupational safety outcomes in port operations. Future research should explore the integration of computational models, RAC algorithms, and real-time monitoring systems to further elevate the precision and responsiveness of risk management practices.

References

Binti Ramli, F., Binti Mokhtar, S. N., Bin Jamaluddin, M. H., Bin Harun, M. N., Bin Mat Salim, M. A., Bin Lokman, M. N., Bin Zailan, A. R., Binti Md. Yunus, N., & Binti Mohd Nor, N. H. (2020). Awareness Among Students and Staff on Occupational Safety and Health (OSH) in Universiti Teknologi Malaysia. *Proceedings of the International Conference on Student and Disable Student Development 2019 (ICoSD 2019)*, 13–18. https://doi.org/10.2991/assehr.k.200921.003

Chaal, M., Bahootoroody, A., Basnet, S., Banda, O. A. V., & Goerlandt, F. (2022). Towards System-theoretic Risk Assessment for Future Ships: A Framework for Selecting Risk Control Options. *Ocean Engineering*, *259*, 1–15. https://doi.org/10.1016/j.oceaneng.2022.111797

Chowdhury, M. N., Shafi, S., Mohd Arzaman, A. F., Teoh, B. A., Kadhim, K. A., Salamun, H., Kadir, F. K. A., Said, S., Kadir, K. A., Embong, A. M., Aziz, N. A. A., Jusoh, M. H., Pham, L. H. H. P., & Xuan, A. N. S. (2024). Navigating Human Factors in Maritime Safety: A Review of Risks and Improvements in Engine Rooms of Ocean-Going Vessels. *International Journal of Safety and Security Engineering*, *14*(1), 1–14. https://doi.org/10.18280/ijsse.140101

Dodoo, J. E., & Al-Samarraie, H. (2023). A Systematic Review of Factors Leading to Occupational Injuries and Fatalities. In *Journal of Public Health (Germany)* (Vol. 31, Issue 1, pp. 99–113). Springer Nature. https://doi.org/10.1007/s10389-020-01427-4

Fan, C., Wróbel, K., Montewka, J., Gil, M., Wan, C., & Zhang, D. (2020). A Framework to Identify Factors Influencing Navigational Risk for Maritime Autonomous Surface Ships. *Ocean Engineering*, *202*, 1–15. https://doi.org/10.1016/j.oceaneng.2020.107188

Gul, M. (2020). A Fuzzy-based Occupational Health and Safety Risk Assessment Framework and A Case Study in an International Port Authority. *Journal of Marine Engineering and Technology*, *19*(4), 161–175. https://doi.org/10.1080/20464177.2019.1670994

Jain, A., Hassard, J., Leka, S., Di Tecco, C., & Iavicoli, S. (2021). The Role of Cccupational Health Services in Psychosocial Risk Management and the Promotion of Mental Health and Well-being at Work. In *International Journal of Environmental Research and Public Health* (Vol. 18, Issue 7, pp. 1–24). MDPI AG. https://doi.org/10.3390/ijerph18073632

Kabul, E. R., & Yafi, F. (2022). HIRARC Method Approach as Analysis Tools in Forming Occupational Safety Health Management and Culture. *Sosiohumaniora*, *24*(2), 218. https://doi.org/10.24198/sosiohumaniora.v24i2.38525

Marhavilas, P. K., & Koulouriotis, D. E. (2021). Risk-acceptance Criteria in Occupational Health and Safety Risk-assessment—The state-of-the-art Through A Systematic Literature Review. In *Safety* (Vol. 7, Issue 4, pp. 1–38). MDPI. https://doi.org/10.3390/safety7040077

Masuri, M. G., Dahlan, A., Md Isa, K. A., & Hashim, R. (2020). The Application of HIRARC on Attitude Towards Safe Driving Scale (ASDS) According to PreSiM Model. *Environment-Behaviour Proceedings Journal*, *5*(14), 281–286. https://doi.org/10.21834/ebpj.v5i14.2182

Mollaoğlu, M., Bucak, U., & Demirel, H. (2019). A Quantitative Analysis of the Factors That May Cause Occupational Accidents at Ports. *Journal of Eta Maritime Science*, *7*(4), 294–303. https://doi.org/10.5505/jems.2019.15238

Nurprihatin, F., Antonius, R., Rembulan, G. D., Djajasoepena, R., & Sulistyo, E. (2022). Analytical Hierarchy Process and TOPSIS Approach to Perform Supplier Selection in Construction Industry. *Management Systems*, *15*(2), 130–138. https://doi.org/10.30813/jiems.v15i2.4124

Nurprihatin, F., Lee, F. S., Andry, J. F., Kurahman, A. P., Widiwati, I. T. B., Vaezi, A., & Abushaega, M. M. (2024). Reducing the Operation Lead Time using Integrated Standardized Service Time and Tailor-Made Value Stream Mapping. *Management and Production Engineering Review*, *15*(3), 1–17. https://doi.org/10.24425/mper.2024.151486

Nurprihatin, F., Rembulan, G. D., & Liman, S. D. (2023). Application of Ward's Method and K-Means Clustering in Determining Logistics Hub Locations Considering Logistics Costs. *AIP Conference Proceedings*, *2693*(1). https://doi.org/10.1063/5.0119818

Priyanka, V., & Basaria, F. T. (2023). Minimizing Work Risks in Indonesia: A Case Study Analysis of Hazard Identification, Risk Assessment, and Risk Control Implementation. *E3S Web of Conferences*, *426*, 1–5. https://doi.org/10.1051/e3sconf/202342601017

Reihana, N. S., Nurprihatin, F., Islam, S. S., Redi, A. A. N. P., Young, M. N., & Prasetyo, Y. T. (2024). Application of Process Failure Modes and Effect Analysis for Acceptance Quality Limit in Lot Sentencing. *Proceedings of 7th International Conference on Computers in Management and Business*, 212–218. https://doi.org/10.1145/3647782.3647815

Sanni-Anibire, M. O., Mahmoud, A. S., Hassanain, M. A., & Salami, B. A. (2020). A Risk Assessment Approach for Enhancing Construction Safety Performance. *Safety Science*, *121*, 15–29. https://doi.org/10.1016/j.ssci.2019.08.044

Tao, J., Liu, Z., Wang, X., Cao, Y., Zhang, M., Loughney, S., Wang, J., & Yang, Z. (2024). Hazard Identification and Risk Analysis of Maritime Autonomous Surface Ships: A Systematic Review and Future Directions. *Ocean Engineering*, *307*, 1–20. https://doi.org/10.1016/j.oceaneng.2024.118174

Wong, C. F., Teo, F. Y., Selvarajoo, A., Tan, O. K., & Lau, S. H. (2022). Hazard Identification Risk Assessment and Risk Control (HIRARC) for Mengkuang Dam Construction. *Civil Engineering and Architecture*, *10*(3), 762–770. https://doi.org/10.13189/cea.2022.100302

Zhang, X., & Mohandes, S. R. (2020). Occupational Health and Safety in Green Building Construction projects: A Holistic Z-numbers-based Risk Management Framework. *Journal of Cleaner Production*, *275*, 1–19. https://doi.org/10.1016/j.jclepro.2020.122788