RISK ANALYSIS OF SAFETY IN MARINE INFRASTRUCTURE WORK

ANAT CHANTEMDUANG

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การวิเคราะห์ความเสี่ยงด้านความปลอดภัยในงานก่อสร้างโครงสร้างพื้นฐานทางทะเล

นายอาณัติ จันทร์เต็มดวง

วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาปรัชญาดุษฎีบัณฑิต
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RISK ANALYSIS OF SAFETY IN MARINE INFRASTRUCTURE WORK

Suranaree University of Technology has approved this thesis submitted in partial fulfillment of the requirements for the Degree of Doctor of Philosophy

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คำสำคัญ : ความปลอดภัยในโครงสร้างพื้นฐานทางทะเล/ความเสี่ยงในงานขุดลอกและถมคืนพื้นที่/อันตรายในงานก่อสร้างท่าเรือ/การบริหารจัดการความเสี่ยงอาชีวอนามัย/การประเมินความเสี่ยงด้านความปลอดภัย

งานก่อสร้างโครงสร้างพื้นฐานทางทะเล เช่น งานขุดลอก งานถมคืนพื้นที่ และการก่อสร้างท่าเรือน้ำลึก เป็นกิจกรรมที่มีความเสี่ยงด้านความปลอดภัยสูง เนื่องจากสภาพแวดล้อมการทำงานที่ซับซ้อน ต้องปฏิบัติงานใกล้หรือบนผิวน้ำ และใช้เครื่องจักรหนักที่มีความเฉพาะทาง ซึ่งอาจส่งผลให้เกิดอุบัติเหตุและอันตรายต่อผู้ปฏิบัติงานได้ง่าย การศึกษานี้มีวัตถุประสงค์เพื่อวิเคราะห์ความเสี่ยงด้านความปลอดภัยในกิจกรรมก่อสร้างทางทะเลอย่างเป็นระบบ ระบุปัจจัยเสี่ยงหลัก ประเมินผลกระทบ และพัฒนากลยุทธ์ในการลดความเสี่ยงอย่างมีประสิทธิภาพ

งานวิจัยนี้ใช้แนวทางการบริหารความเสี่ยงตามมาตรฐานสากล โดยผสานการวิเคราะห์เชิงคุณภาพและเชิงปริมาณ การระบุอันตรายดำเนินการผ่านการทบทวนวรรณกรรมและกรณีศึกษา ในขณะที่การประเมินความเสี่ยงอาศัยข้อมูลจากการสัมภาษณ์ผู้เชี่ยวชาญและการวิเคราะห์ทางสถิติโดยใช้เทคนิค Delphi เพื่อพัฒนาแนวทางควบคุมความเสี่ยง กรณีศึกษาที่ใช้ในงานวิจัยเป็นโครงการก่อสร้างโครงสร้างพื้นฐานทางทะเลในประเทศไทย

ผลการศึกษาพบว่าปัจจัยเสี่ยงที่มีระดับความรุนแรงสูงและสูงมากในงานขุดลอก งานถมคืนพื้นที่ และการก่อสร้างท่าเรือ ได้แก่ ความล้มเหลวของเครื่องจักร สภาพพื้นดินไม่เสถียร สภาพอากาศแปรปรวน และความเสี่ยงด้านปฏิบัติการทางทะเล อย่างไรก็ตาม ด้วยกลยุทธ์ลดความเสี่ยงที่มีการวางแผนอย่างเป็นระบบ เช่น การปรับปรุงมาตรฐานความปลอดภัย การอบรมพนักงาน และการติดตามความเสี่ยงแบบเรียลไทม์ สามารถลดระดับความเสี่ยงให้อยู่ในระดับที่ยอมรับได้

งานวิจัยนี้มีส่วนช่วยพัฒนาการบริหารความปลอดภัยในโครงการก่อสร้างทางทะเล โดยนำเสนอกรอบแนวทางที่สามารถนำไปใช้ซ้ำได้สำหรับการประเมินและจัดการความเสี่ยง ผลลัพธ์ของการศึกษานี้เน้นย้ำถึงความสำคัญของมาตรการความปลอดภัยที่ออกแบบให้มีความเหมาะสมกับความท้าทายเฉพาะของงานก่อสร้างทางทะเล และการปรับปรุงข้อกำหนดด้านกฎหมายเพื่อยกระดับมาตรฐานความปลอดภัยในอุตสาหกรรมนี้

สาขาวิชา วิศวกรรมโยธาและการบริหารงานก่อสร้าง ลายมือชื่อนักศึกษา ....

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Marine infrastructure construction, including dredging, land reclamation, and deep seaport development, presents unique safety challenges due to its dynamic and high-risk working environment. The combination of working near or on water, operating specialized heavy machinery, and managing complex geotechnical conditions increases the likelihood of accidents and operational hazards. This study aims to conduct a comprehensive safety risk analysis across these construction activities, identifying key hazards, assessing their impact, and formulating effective risk mitigation strategies.

The research employs a structured risk management approach based on international frameworks, integrating qualitative and quantitative analyses. Hazard identification was carried out through literature reviews and case studies, while risk assessments were conducted via expert consultations and statistical evaluations. The study involved interviews with industry professionals, applying the Delphi technique to refine risk control strategies. A case study of a marine infrastructure project in Thailand was analyzed to validate the proposed methodologies.

Findings indicate that several high and very high-risk factors exist across dredging, land reclamation, and seaport construction, including equipment failures, unstable ground conditions, adverse weather, and maritime operational risks. Through structured risk mitigation strategies, including enhanced safety protocols, improved training programs, and real-time risk monitoring, these hazards were controlled to acceptable levels.

This study contributes to the advancement of safety management in marine infrastructure projects by proposing a replicable framework for risk assessment and mitigation. The findings emphasize the necessity of tailored safety

measures and regulatory enhancements to improve occupational safety standards in the sector.

School of Civil Engineering and Construction Management

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CHAPTER I
INTRODUCTION

1.1 Background and Significance

Marine infrastructure construction plays a crucial role in global economic growth by facilitating maritime trade, transportation, and industrial development. This includes large-scale projects such as dredging and land reclamation for port expansion and deep seaport construction to accommodate increasing cargo volumes and larger vessels. The rapid growth in maritime trade has led to an increasing demand for infrastructure development, particularly in industrial port zones. However, these projects present significant safety risks due to their complex nature and hazardous working environments.

The construction industry, in general, is characterized by various risks arising from dynamic and uncertain worksite conditions. Dredging and reclamation activities involve specialized equipment, underwater operations, and exposure to hazardous substances, posing significant threats to worker safety. Similarly, deep seaport construction requires working at height, over water, and on temporary structures, which increases the likelihood of fatal accidents such as falls and drownings. Given these inherent risks, it is essential to implement strategic safety risk management measures to protect construction workers and enhance project efficiency.

Seaport development plays a critical role in enhancing water transportation efficiency, reducing logistics costs, and strengthening international trade connectivity. In Thailand, the strategic geographical location and long coastline make the country well-positioned to expand its maritime infrastructure. National initiatives such as the Eastern Economic Corridor (EEC) project have emphasized the development of deep seaports to support industrial growth and regional competitiveness. Despite its potential, deep seaport construction in Thailand occurs infrequently due to the substantial financial investment, environmental concerns, and extensive regulatory scrutiny involved. As a result, both construction workers and supervisory personnel often lack prior experience and familiarity with the unique conditions and operational complexities of deep seaport construction. This knowledge gap significantly contributes to elevated safety risks, particularly in high-hazard activities such as dredging, reclamation, and offshore structural work.

While safety management in general construction projects has been extensively studied, there remains a significant gap in research focused on safety risk analysis specific to marine infrastructure, particularly deep seaport construction. These projects involve complex, large-scale operations in challenging marine environments, where conventional land-based safety practices may be insufficient. The infrequent nature of deep seaport development in Thailand further exacerbates this issue, as workers and site supervisors often lack prior exposure to such high-risk construction settings. Consequently, the absence of domain-specific safety guidelines, coupled with limited institutional knowledge and experience, increases the likelihood of accidents, operational delays, and project cost overruns. There is therefore an urgent need for a comprehensive risk management framework tailored to the safety challenges of deep seaport construction in Thailand, which integrates both theoretical insights and practical safety strategies.

One of the most prominent examples of deep seaport development in Thailand is the Map Ta Phut Industrial Port Phase 3, which forms a critical part of the Eastern Economic Corridor (EEC) initiative. This project aims to expand Thailand's capacity for industrial-scale maritime logistics and petrochemical exports. As illustrated in Figure 1.1, the development encompasses large-scale marine construction activities such as dredging, land reclamation, breakwater installation, and quay wall construction. These operations require high levels of coordination, advanced marine engineering, and rigorous safety protocols due to their complexity and environmental sensitivity. The project serves as a representative case of the types of safety risks inherent in modern seaport construction, particularly in environments where such developments are not frequently undertaken and where workforce familiarity with marine-specific hazards remains limited.

Figure 1.1 The Map Ta Phut Industrial Port Phase 3 Project.

1.2 Safety Risks and Project Implications

Safety risks in marine infrastructure construction extend beyond human injury and loss of life. Accidents at construction sites often result in delays, cost overruns, and legal liabilities. Regulatory non-compliance can lead to project shutdowns, reputational damage, and increased insurance costs. Moreover, in the highly competitive construction industry, a company's commitment to safety is a key factor influencing contractor selection. By effectively managing safety risks, companies can ensure operational continuity, financial stability, and compliance with legal and ethical obligations.

1.3 Safety Risks in Dredging and Reclamation Work

Dredging and reclamation are essential processes in industrial port development, involving the excavation of sediments to create land or deepen waterways. These activities contribute significantly to infrastructure expansion in coastal regions. However, they also present multiple safety risks, including:

1.3.1 Heavy machinery operation hazards (e.g., dredgers, excavators, barges)

1.3.2 Structural failures (e.g., collapsing dredged slopes, unstable reclaimed land)

1.3.3 Underwater working conditions (e.g., poor visibility, entrapment risks)

Historical accident data from regulatory agencies highlight the dangers associated with these operations, including incidents involving contact with moving machinery, falls, and underwater accidents. While past studies have explored safety management in dredging operations, there is a lack of comprehensive risk assessment models tailored specifically for dredging and reclamation projects within industrial port construction. This research aims to bridge that gap by conducting systematic risk analysis and developing effective mitigation strategies.

1.4 Safety Risks in Deep Seaport Construction

Deep seaport construction is another critical aspect of marine infrastructure development, requiring extensive civil and structural engineering work in offshore environments. The construction process typically includes:

1.4.1 Piling and foundation work in marine conditions

1.4.2 Superstructure assembly (e.g., quay walls, breakwaters, terminal facilities)

1.4.3 Installation of heavy lifting equipment (e.g., cranes, loading systems)

These activities introduce significant safety concerns, with falling from heights, drowning risks, and structural collapses being among the most common causes of fatal accidents. According to global construction safety statistics, offshore construction accident rates are notably higher than those in general building construction. The lack of standardized safety management frameworks for deep seaport projects exacerbates these risks. By reviewing current safety practices and analyzing case studies, this research seeks to enhance risk management strategies for offshore construction.

1.5 Research Objectives

This thesis aims to analyze, assess, and propose risk management strategies for improving safety in marine infrastructure construction. The specific objectives include:

1.5.1 Identifying and assessing key safety risks in dredging and reclamation work as well as deep seaport construction.

1.5.2 Developing a strategic risk management framework to mitigate safety hazards.

1.5.3 Conducting case studies on industrial port projects to validate proposed risk control measures.

1.5.4 Providing guidelines for enhancing safety performance in marine infrastructure projects.

1.6 Structure of the dissertation

This thesis is structured into five main chapters:

Chapter 1: Introduction – Provides an overview of the research background, significance, safety risks, and objectives.

Chapter 2: Literature Review – Examines existing studies on safety risk management in marine construction.

Chapter 3: Safety Risk Analysis in Dredging & Reclamation Work – Conducts a risk assessment for dredging and reclamation activities, identifying hazards and proposing mitigation measures.

Chapter 4: Safety Risk Analysis in Deep Seaport Construction – Analyzes safety risks specific to deep seaport construction, with a case study approach.

Chapter 5: Conclusion and Recommendation – Summarizes key findings and presents recommendations for improving safety in marine infrastructure projects.

CHAPTER II
LITERATURE REVIEW

2.1 Introduction

Marine infrastructure construction is a complex and high-risk domain, encompassing a variety of specialized works such as dredging, land reclamation, and deep seaport construction. These projects are exposed to unique environmental, operational, and human-related hazards due to their offshore or nearshore locations and the use of specialized equipment. This chapter provides a comprehensive review of the existing literature on construction safety risks, with a focus on risk management frameworks, hazard identification techniques, and previous studies in marine infrastructure construction. The review is categorized into three key areas: general construction safety risk frameworks, dredging and land reclamation safety risks, and safety in deep seaport construction.

2.2 Construction Safety Risk Management: Theoretical Background

The field of construction safety management has evolved significantly, driven by the need to reduce accidents, improve project efficiency, and protect worker welfare. Several models have been developed to guide risk identification, assessment, and control.

The Project Management Institute (PMI) provides a widely used risk management framework, which includes:

1) Plan Risk Management
2) Risk Identification
3) Qualitative Risk Analysis
4) Quantitative Risk Analysis
5) Risk Response Planning
6) Risk Monitoring and Control

Other relevant frameworks include the ISO 31000 standard for risk management and Occupational Health and Safety Management Systems (OHSAS 18001/ISO 45001), which are used to systematize risk processes across various industries, including construction.

Suraji et al. (2001) proposed a conceptual model linking accident causation to project management processes. Their work highlighted that a significant portion of construction accidents results from inadequate safety planning and failure in organizational management systems.

2.2.1 Core Theories of Safety Management in Construction

A foundational understanding of safety management in construction is built upon several established theories that explain how and why accidents occur, and how they can be prevented. These theories guide the development of modern risk assessment frameworks and support proactive safety strategies in marine construction environments.

2.2.1.1 Heinrich’s Domino Theory (1931)

One of the earliest safety models, Heinrich’s Domino Theory, posits that accidents result from a sequential chain of events, much like a line of falling dominoes. The theory identifies five factors in accident causation: ancestry, personal fault, unsafe acts/conditions, accident, and injury. Removing one "domino," particularly the unsafe act or condition, can prevent the entire sequence from culminating in injury.

This theory emphasizes human behavior and unsafe actions as central to accident prevention.

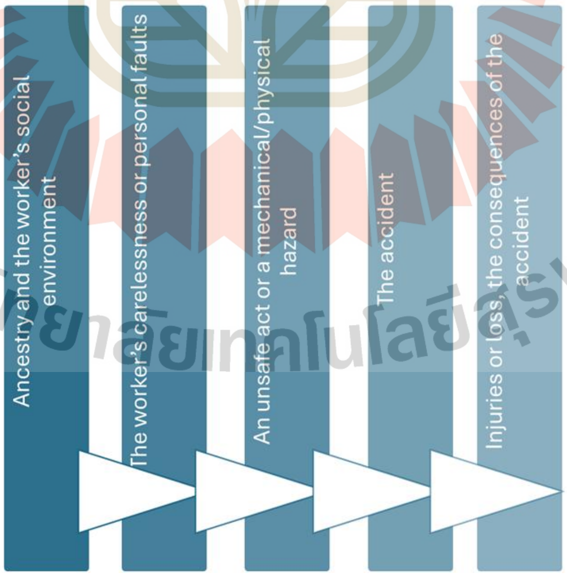


Figure 2.1 Heinrich’s Domino Theory.

2.2.1.2 Bird's Updated Domino Theory (1974)

Frank Bird extended Heinrich's model by focusing more on management system failures. He proposed that 90% of accidents are caused by unsafe acts, 10% by unsafe conditions, and that these are often the result of organizational weaknesses. Bird's model shifts responsibility from individual workers to systemic issues in planning and control.

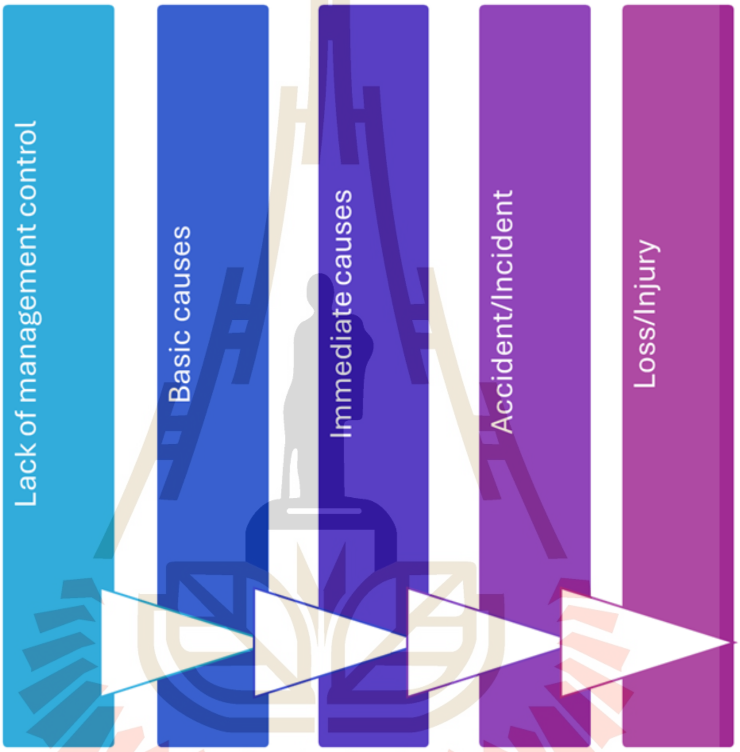


Figure 2.2 Bird's Updated Domino Theory.

2.2.1.3 Reason's Swiss Cheese Model (1990)

James Reason introduced the Swiss Cheese Model to describe how multiple layers of defense can still allow accidents if the holes (weaknesses) in each layer align. These layers represent barriers such as procedures, training, and equipment. When holes in each layer coincide, hazards pass through and result in accidents.

This model is widely used in complex and high-risk industries like marine construction due to its applicability to systemic and latent failures.

In addition to theoretical models of accident causation, the Swiss Cheese Model proposed by Reason (1990) offers a layered defense perspective.

It conceptualizes organizational defenses as layers of Swiss cheese, where holes represent latent conditions and active failures. Accidents occur when these holes align, allowing a trajectory of accident opportunity to pass through. This model has practical applicability in identifying and reinforcing weak points in safety management systems.

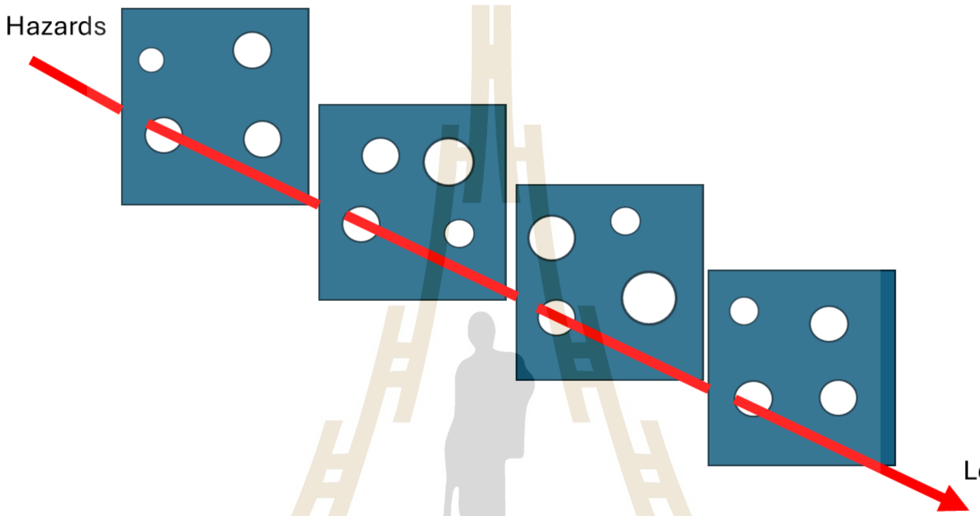


Figure 2.3 Reason's Swiss Cheese Model.

2.2.1.4 Energy Release Theory

This theory, proposed by Haddon (1963), explains accidents as the result of uncontrolled energy release, such as mechanical, electrical, thermal, or chemical energy. Effective safety systems aim to either prevent the release of such energy or reduce its harmful effects through protective barriers and control systems.

The theory posits that accidents occur when there is an uncontrolled release of energy mechanical, electrical, thermal, chemical, or otherwise that encounters a vulnerable human or structural target. The central idea is that injuries are a function of both the amount and nature of energy involved, as well as the exposure duration and the susceptibility of the individual or system.

In the context of marine infrastructure construction, the relevance of this theory is significant. Operations such as dredging, reclamation, and heavy machinery deployment inherently involve large-scale mechanical and hydraulic energy, often in unstable or unpredictable environments. According to Haddon, safety interventions should aim at either (1) preventing the release of hazardous energy or (2) mitigating its effects through engineering controls, protective systems, and procedural safeguards. This perspective supports a proactive approach to accident prevention by focusing on energy control as a primary safety strategy, rather than solely responding to human error or system failure after the fact.

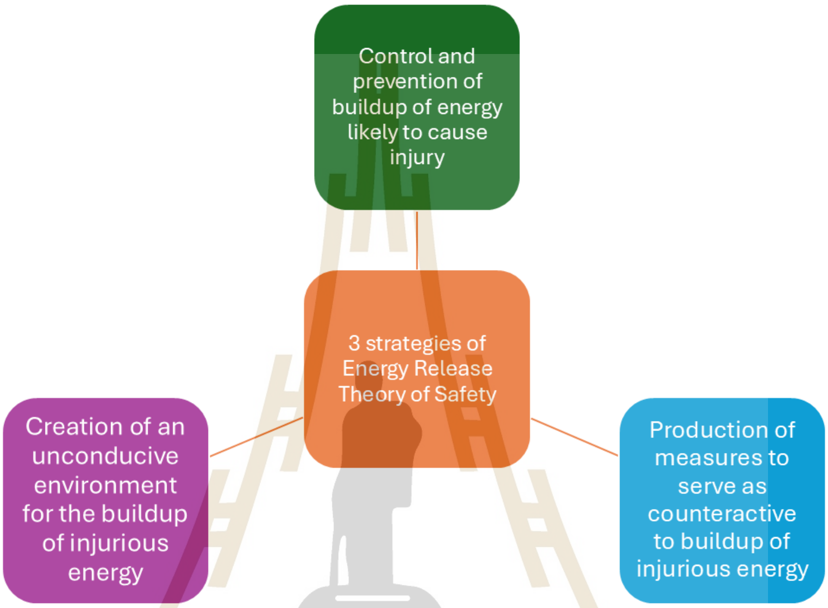


Figure 2.4 Energy Release Theory.

2.2.1.5 Human Factors Theory

This theory identifies that accidents often occur due to human error influenced by factors such as fatigue, stress, poor communication, and inadequate training. In marine construction, this is highly relevant where long hours, changing shifts, and complex coordination between teams are commonplace.

Human Factors Theory, as developed by Dr. Russell Ferrell, emphasizes the critical influence of human behavior, cognition, and limitations on workplace safety outcomes. This theory suggests that most accidents result not solely from mechanical failures or environmental hazards, but from a chain of human-related errors, such as overload, inappropriate response, or incorrect decision-making. It underscores that accidents are often the result of mismatches between workers' capabilities and the demands of the task, especially under high-risk conditions typical of construction and marine infrastructure environments.

In marine infrastructure construction—where conditions are complex, tasks are physically demanding, and risks are elevated, the Human Factors Theory is particularly relevant. Workers are often subjected to extreme weather, long hours, and high cognitive and physical demands, all of which increase the likelihood of human error. Dr. Ferrell's theory classifies the root causes of these incidents into three categories: (1) overload, which refers to excessive task demands beyond a worker’s capacity; (2) inappropriate worker response, such as misjudging risk or misusing equipment; and (3) inappropriate activities, including procedural violations or unsafe behaviors.

Applying Human Factors Theory enables project managers to design better safety interventions by focusing not only on environmental and engineering controls, but also on improving worker training, optimizing workload, and fostering a safety-conscious organizational culture. This approach aligns well with the integrated safety strategies needed for high-risk maritime construction sites, where human performance is a decisive factor in preventing accidents.

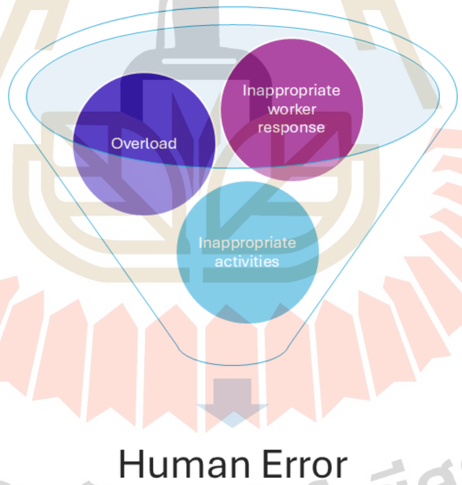


Figure 2.5 Human Factors Theory.

2.2.2 Core Theories of Risk Management

The field of risk management is underpinned by several foundational theories that offer critical insights into decision-making, accident causation, and organizational safety performance. Integrating these theories provides a theoretical lens through which safety risks in marine infrastructure construction can be better understood and managed.

2.2.2.1 The Expected Utility Theory (EUT)

One of the earliest and most influential frameworks is the Expected Utility Theory (EUT) developed by von Neumann and Morgenstern (1944). This theory posits that individuals act rationally under conditions of uncertainty to maximize expected utility. While EUT has been extensively applied in economic and financial contexts, it also provides a baseline for understanding risk-related choices in construction safety decision-making.

In the context of construction safety, EUT provides a conceptual basis for analyzing how stakeholders such as engineers, contractors, and safety managers evaluate potential hazards and decide on preventive actions. By interpreting risk decisions through the lens of utility maximization, EUT offers a structured approach for understanding why certain risks are prioritized over others and how tradeoffs between cost, safety, and performance are justified. Although real world decisions may deviate from perfect rationality, EUT serves as a foundational model for developing more nuanced theories of risk behavior in complex, high-stakes environments such as marine infrastructure construction.

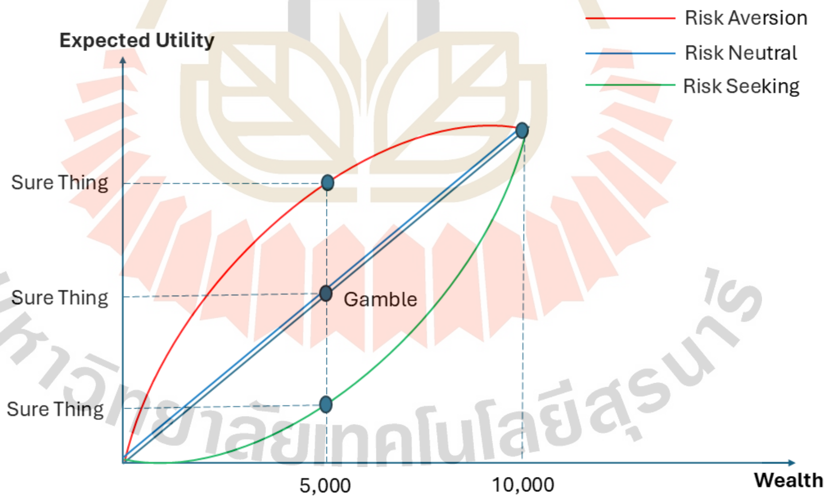


Figure 2.6 The Expected Utility Theory (EUT).

2.2.2.2 Prospect Theory

In contrast, Prospect Theory, introduced by Kahneman and Tversky (1979), challenges the rational actor model by highlighting that individuals evaluate potential losses and gains asymmetrically. This behavioral approach to decision-making is particularly relevant in construction contexts, where safety-related decisions often involve subjective risk perception and cognitive biases among project stakeholders.

Prospect Theory is particularly relevant in the construction industry, where safety-related decisions are often influenced by subjective perceptions of risk, heuristics, and cognitive biases among stakeholders such as project managers, engineers, and workers. For example, the underestimation of low-probability but high-impact events or the overconfidence in safety procedures may result from cognitive distortions rather than rational evaluations. By accounting for these behavioral tendencies, Prospect Theory enhances the understanding of how risk-related decisions are actually made in high-risk environments like marine infrastructure construction, thereby supporting the development of more effective safety interventions and policies.

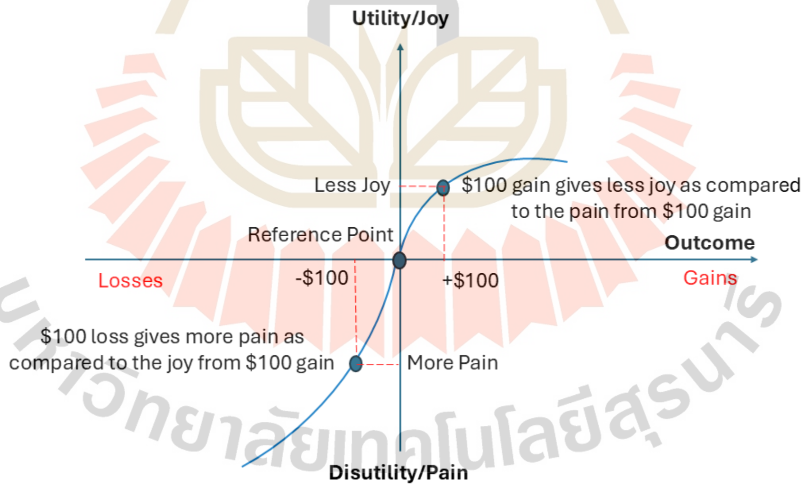


Figure 2.7 Prospect Theory.

2.2.2.3 High Reliability Theory (HRT)

At the organizational level, High Reliability Theory (HRT) emphasizes the practices and cultural attributes that enable organizations operating in high-risk environments such as maritime and offshore engineering to maintain exemplary safety records (Roberts, 1990). Characteristics such as redundancy, continuous training, and decentralized decision-making are hallmarks of high-reliability organizations (HROs), and they provide a useful benchmark for enhancing safety in marine infrastructure projects.

Figure 2.8 High Reliability Theory (HRT).

2.2.2.4 Normal Accident Theory (NAT)

Conversely, Normal Accident Theory (NAT), proposed by Perrow (1984), argues that accidents are inevitable in complex and tightly coupled systems. This theory is especially pertinent to large-scale marine infrastructure construction, where interdependencies among dredging, reclamation, and structural operations can give rise to system-level failures.

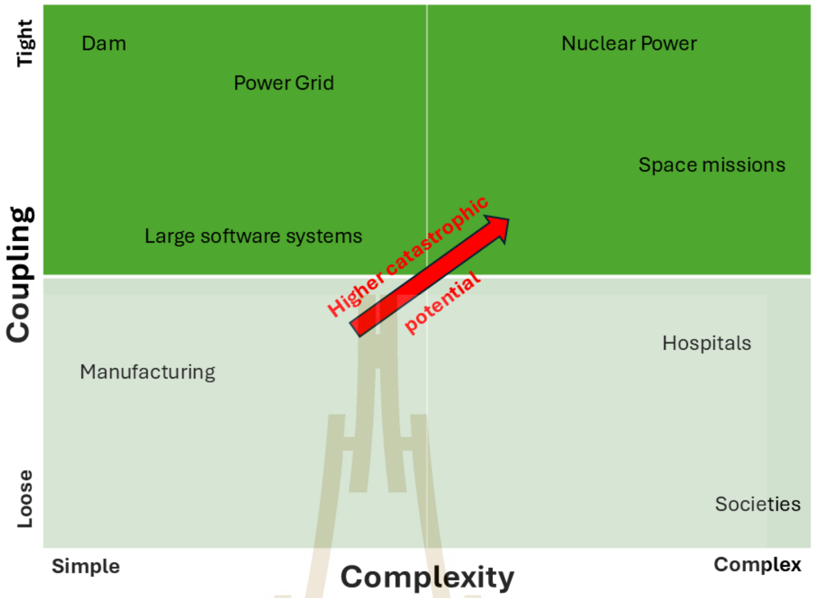


Figure 2.9 Normal Accident Theory (NAT).

2.2.2.5 The ISO 31000 Risk Management Guidelines (ISO, 2018)

The ISO 31000 Risk Management Guidelines (ISO, 2018) provide a standardized, principle-based approach to managing risk across diverse domains. The framework emphasizes the integration of risk management into organizational processes, the importance of customized approaches, and the need for continual improvement.

2.2.2.6 Uncertainty Theory in Risk Management

Uncertainty plays a central role in risk management, particularly in complex and dynamic environments such as marine infrastructure construction. Uncertainty Theory, introduced by Liu (2007), provides a mathematical framework for modeling human uncertainty based on belief degrees, extending beyond traditional probability-based models. Unlike stochastic approaches that rely on randomness, Uncertainty Theory addresses scenarios where the information available is imprecise or incomplete, and decision-makers must rely on subjective judgment rather than objective frequencies.

In construction safety management, uncertainty arises from multiple sources-including geological conditions, weather variability, equipment performance, and human behavior-making traditional probabilistic models insufficient in certain contexts. Uncertainty Theory is therefore instrumental in supporting decision-making under ambiguous or poorly defined conditions, where expert opinions or linguistic assessments are often the only sources of input.

The relevance of Uncertainty Theory in marine construction projects lies in its ability to integrate expert knowledge and risk perception into quantitative risk assessment frameworks. This is particularly useful for evaluating rare or unprecedented events, such as those associated with large-scale dredging operations, offshore piling, or deep seaport development. By incorporating belief structures and expected uncertainty distributions, decision-makers can better estimate potential safety risks and develop robust mitigation strategies.

The incorporation of Uncertainty Theory into safety risk analysis not only enhances the predictive capability of risk assessment models but also fosters more adaptive and resilient project planning.

Collectively, these theories and frameworks form a robust theoretical foundation for analyzing and improving safety risk management in marine infrastructure construction. Their application enables a deeper understanding of how individual, organizational, and systemic factors contribute to risk and informs the development of comprehensive risk mitigation strategies.

2.3 Safety Risk in Dredging and Reclamation Work

Dredging and reclamation are critical for expanding port capacity and creating new land in coastal zones. These operations involve hazards such as:

1) Contact with moving machinery and heavy equipment
2) Falling or slipping on unstable surfaces
3) Drowning or hypoxia from working near or on water
4) Exposure to contaminants in sediments
5) Structural failures of temporary platforms or pipelines

Cruickshank and Cork (2005) and Valyani et al. (2019) emphasized the importance of adapting marine-specific safety guidelines and training to reduce incident frequency in such environments.

Daniel (2011) identified risk factors in dredging operations in Nigerian ports, including weak regulatory enforcement, lack of worker training, and poor site supervision.

Ma et al. (2020) addressed safety management practices in artificial island development and highlighted issues such as equipment malfunction and worker fatigue.

The Health and Safety Executive (HSE, UK) has published accident reports spanning 2012–2021 that underscore the recurrent nature of accidents such as:

1) Being struck by moving equipment
2) Falls from height
3) Contact with hazardous substances

Recent innovations include the application of RFID tracking (Bugg et al., 2018) to monitor worker movements and prevent unauthorized access to dangerous areas.

Despite these efforts, there remains a lack of integrated risk analysis models tailored to dredging and reclamation, particularly in Southeast Asia. This thesis addresses this gap by analyzing real project data and expert insight to identify and control high-risk activities in these operations.

2.4 Safety Risk in Deep Seaport Construction

Deep seaport construction involves large-scale marine and coastal engineering tasks, such as piling, caisson installation, and breakwater construction. These environments introduce unique hazards, including:

1) Falling from heights or into water
2) Unstable or temporary structures
3) Equipment malfunctions in saline and corrosive environments
4) Weather and tidal influences
5) Limited accessibility for emergency response

Zhang et al. (2020) found that accident rates in offshore construction work are 27% higher than in general construction. The International Labour Organization (ILO, 2022) emphasizes the need for maritime-specific occupational health and safety (OHS) measures, especially in developing regions where regulation is less robust.

Li and Ng (2018) noted that many studies focus on port operation safety, with limited attention to the construction phase. Their findings align with Wang et al. (2020), who noted a lag in updating safety management protocols in response to modern port construction techniques.

Mahapatra and Kushwaha (2020) proposed safety guidelines for port construction based on accident case studies, identifying heavy lifting, wave impacts, and underwater welding as critical risk points.

2.5 Risk Identification and Assessment Techniques

Commonly applied risk identification techniques in construction include:

1) Checklists and expert judgment
2) Delphi technique: for achieving consensus among specialists
3) Hazard and Operability Studies (HAZOP)
4) Failure Mode and Effect Analysis (FMEA)
5) Job Safety Analysis (JSA)
6) Risk assessment approaches are divided into:
7) Qualitative methods, such as risk matrices (likelihood × severity)
8) Quantitative methods, using statistical tools to estimate risk magnitudes and model uncertainty

Gunduz and Laitinen (2018) provided a practical framework for small to medium-sized enterprises (SMEs), balancing resource constraints and safety demands.

This research applies both qualitative and quantitative approaches, combining expert scoring, statistical analysis, and Delphi-based risk control planning to formulate practical and effective risk mitigation strategies.

2.6 Gaps in Literature

While many studies address general construction safety and some examine marine projects, several key gaps persist:

1) Few studies integrate both dredging/reclamation and deep seaport construction safety analysis in a single framework.
2) There is limited case-based research in Southeast Asia, especially in industrial port development projects.
3) Most existing research focuses either on technical risks or human error, but not their interdependence.
4) There is a lack of standardized safety risk management models for marine infrastructure construction.

This literature review underscores the complexity and high-risk nature of marine infrastructure construction. While several safety management frameworks exist, their adaptation to specific contexts like dredging, reclamation, and deep seaport construction remains insufficiently addressed. This research contributes by developing a tailored, evidence-based risk analysis model grounded in real-world case studies and expert insights, aiming to improve worker safety and overall project success in marine infrastructure construction.

CHAPTER III
RESEARCH METHODOLOGY

3.1 Introduction

This chapter outlines the methodology used to analyze safety risks in marine infrastructure construction, focusing on two key domains: (1) dredging and land reclamation, and (2) deep seaport construction. The framework is grounded in the Project Management Institute's (PMI) risk management process as outlined in the PMBOK® Guide Fifth Edition (PMI, 2013) and combines both qualitative and quantitative analysis techniques to ensure a comprehensive risk assessment. The six core risk management processes risk planning, risk identification, qualitative risk analysis, quantitative risk analysis, risk response planning, and risk monitoring and control serve as the backbone of the research design.

The research adopts the Project Risk Management Process from the PMBOK® Guide, Fifth Edition (PMI, 2013), which includes 6 systematic steps for managing risks in project environments. These steps guide the structured identification, analysis, and treatment of risks throughout the project lifecycle. The process is illustrated in Figure 3.1.

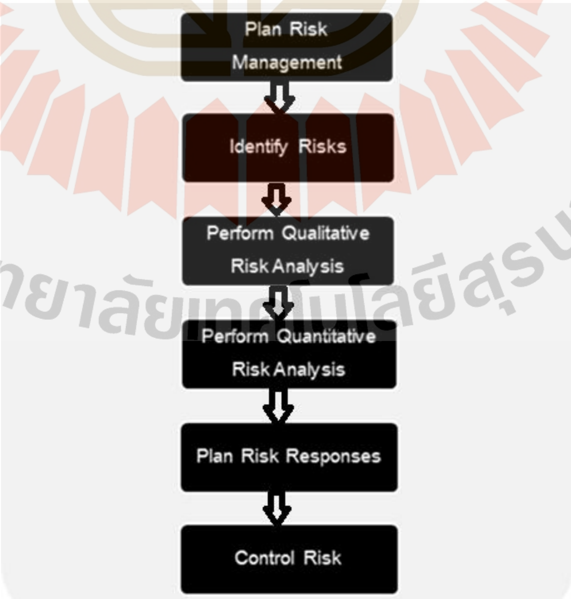


Figure 3.1 The Project Risk Management Process from the PMBOK® Guide – Fifth Edition (PMI, 2013).

3.2 Research Design

The study adopts a mixed-methods approach, integrating document analysis, specialist interviews, and structured surveys. Data was collected from case studies of marine infrastructure projects in Thailand, including the Map Ta Phut Industrial Port Phase 3, as well as from key industry stakeholders such as engineers, safety officers, and project managers.

This study employs a research design aligned with the 6-step risk management process outlined in the PMBOK® Guide, Fifth Edition (PMI, 2013). Each step is tailored to the context of marine infrastructure construction, specifically in deep seaport and reclamation works. The goal is to systematically identify, assess, and mitigate safety risks to support strategic safety risk management. The applied research design process is illustrated in Figure 3.2.

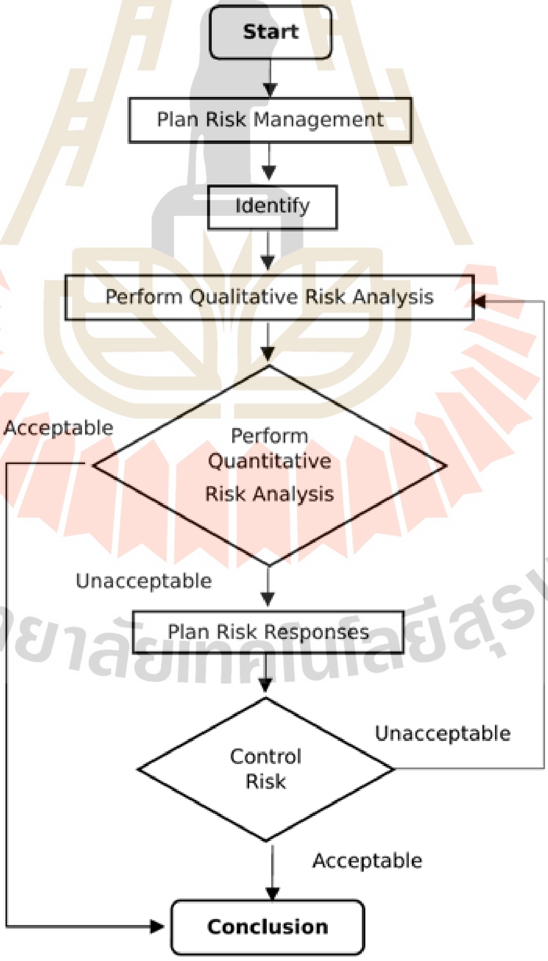


Figure 3.2 Research Design Process.

3.2.1 Literature Review

A comprehensive literature review was undertaken to establish the theoretical, empirical, and methodological foundation for this research. The review served multiple critical purposes:

1) To identify existing safety risk factors in marine infrastructure construction,

2) To explore theoretical models of risk and safety management, and

3) To assess methodological approaches applied in similar research contexts.

The literature sources included peer-reviewed academic journals, international construction and engineering safety guidelines (e.g., IMO, ILO, and ISO standards), government regulations, and case studies from completed marine port development projects. Particular attention was paid to studies focusing on dredging, land reclamation, and deep seaport construction—domains directly relevant to this research.

This review highlighted several recurring categories of safety risks, such as physical hazards from heavy machinery and unstable terrain, operational hazards due to poor communication or lack of training, and environmental risks related to weather and marine conditions. In addition, theoretical frameworks such as Human Factors Theory, Energy Release Theory, and the Project Management Institute (PMI) Risk Management Framework were reviewed to inform the conceptual framework for this study.

The literature review also explored recent trends in safety risk assessment methods, including the use of qualitative tools like risk matrices and quantitative models such as sensitivity analysis and Monte Carlo simulation. Studies employing the Delphi method for expert consensus in risk prioritization were especially relevant, providing guidance for the methodological design of this research.

Furthermore, the review identified knowledge gaps in the context of large-scale seaport projects in Southeast Asia, particularly regarding the application of structured risk management processes in emerging economies like Thailand. The Map Ta Phut Industrial Port Phase 3 Project was selected as a case study partly in response to these gaps, offering an opportunity to examine safety risk management practices in a real-world, high-investment port development environment.

The findings from the literature review were systematically synthesized to form the basis of the research instruments used in this study, including the development of the risk identification checklist, the construction of the 5x5 risk matrix, and the formulation of the expert evaluation questionnaire for Delphi analysis. This step ensured that the study's design was informed by current academic knowledge while also being practically grounded in the unique characteristics of marine infrastructure construction.

3.2.2 Case Study Selection

The case study method was employed to provide an in-depth investigation of safety risk management within a real-world marine infrastructure project. The Map Ta Phut Industrial Port Development Project Phase 3, located in Rayong Province, Thailand, was selected as the primary case study due to its scale, complexity, and relevance to the research objectives.

This project represents a major national infrastructure investment under Thailand's Eastern Economic Corridor (EEC) initiative, involving large-scale dredging, land reclamation, breakwater construction, and port terminal development. As such, it encapsulates a full range of high-risk construction activities in a marine environment, including interactions with coastal and offshore systems, the use of heavy machinery, and extensive stakeholder coordination.

The selection of this case was guided by the following criteria:

1) Relevance to research objectives: The project includes both dredging and deep seaport construction, aligning with the two focus areas of this thesis.

2) Current operational status: The project was under active construction during the data collection period, allowing direct access to stakeholders and up-to-date documentation.

3) Stakeholder diversity: The project involves public and private sector partners, international consultants, and a range of subcontractors, providing a broad spectrum of perspectives on safety practices.

4) Accessibility: Permission for site visits, document review, and expert interviews were granted by project authorities, enabling comprehensive data collection.

By focusing on a single, information-rich case, the research was able to gather detailed and context-specific data for risk identification, assessment, and treatment. This case study also served as the foundation for developing and validating risk assessment tools, including the application of the PMI risk management process, risk matrix scoring, tornado diagram analysis, and the Delphi technique with domain experts.

3.2.3 Conceptual Framework

The conceptual framework of this study was developed based on insights from the literature review, industry best practices, and the contextual specifics of the selected case study—Map Ta Phut Industrial Port Development Project Phase 3. The framework integrates theories of risk perception, decision-making under uncertainty, and structured project risk management processes to guide the investigation of safety risks in marine infrastructure construction.

At its core, the framework adopts the Project Management Institute's (PMI) Risk Management Process (PMI, 2013), which includes six interconnected stages:

1) Plan Risk Management,
2) Identify Risks,
3) Perform Qualitative Risk Analysis,
4) Perform Quantitative Risk Analysis,
5) Plan Risk Responses, and
6) Monitor and Control Risks.

These steps serve as the operational backbone for both data collection and analysis in this research.

To contextualize the risk landscape, the framework also incorporates key theories drawn from the literature:

1) Expected Utility Theory and Prospect Theory (Kahneman & Tversky, 1979; von Neumann & Morgenstern, 1944), to understand decision-making behavior under risk.

2) Energy Release Theory (Haddon, 1963), to classify and interpret types of construction hazards.

3) Human Factors Theory (Ferrell, 1990s), to consider how individual, organizational, and environmental elements contribute to risk.

4) Uncertainty Theory (Liu, 2007), to account for the probabilistic nature of risk perception and management in complex environments.

The conceptual model positions these theoretical inputs in relation to practical data collection instruments: a 5x5 risk assessment matrix for qualitative evaluation, a tornado diagram for quantitative sensitivity analysis, and the Delphi technique for consensus-building and validation of risk treatment strategies.

The case study site acts as the applied testing ground for the framework, allowing real-world risk factors to be mapped against theoretical categories and assessed using structured tools. By doing so, the framework enables a comprehensive, theory-informed, and practice-based approach to safety risk analysis in marine infrastructure construction.

A systematic literature review was conducted as an integral component of the research methodology to establish a strong theoretical foundation and identify key risk factors in marine infrastructure construction. The process followed a structured approach, consisting of seven distinct stages to ensure comprehensiveness and academic rigor.

1) Define Research Objectives and Scope;

The literature review began by clarifying the research objectives and the thematic boundaries. This included focusing on safety risk management within marine infrastructure construction particularly in deep seaport and reclamation projects. Emphasis was placed on identifying common hazards, theoretical models of risk, and proven mitigation strategies.

2) Search for Relevant Literature;

Academic databases such as Scopus, ScienceDirect, Google Scholar, and IEEE Xplore were utilized to retrieve peer-reviewed journal articles, international guidelines (e.g., ISO, ILO), and publications from professional bodies (e.g., Project Management Institute). Key search terms included "marine construction safety," "port infrastructure risk," "Delphi technique in construction," and "risk matrix analysis."

3) Screen and Select Sources;

The collected literature was subjected to inclusion and exclusion criteria based on publication quality, relevance to the topic, and publication date (prioritizing works from the past 10 years). Duplicates and irrelevant works were excluded. The final corpus consisted of both theoretical and empirical studies directly relevant to the context of this research.

4) Organize Literature Thematically;

The selected works were categorized into key thematic areas, including:

4.1) Risk theories and safety management frameworks (e.g., Utility Theory, Prospect Theory, Human Factors Theory)

4.2) Tools and techniques for risk assessment. (e.g., risk matrix, FMEA, tornado diagram)

4.3) Marine and port infrastructure have safety risks.

4.4) Applications of the Delphi method in engineering and construction.

5) Analyze and Synthesize Key Findings;

Each theme was critically analyzed to extract major findings, strengths, and gaps. Comparative analysis was conducted to identify converging insights, methodological contrasts, and contextual differences. The review highlighted that while general risk management approaches are well-documented, their application in marine construction particularly in the Thai context is limited.

6) Identify Research Gaps; The synthesis revealed several gaps in existing literature:

6.1) A lack of integrated frameworks combining PMBOK risk management with both qualitative and quantitative analysis tools in a seaport context

6.2) Limited studies applying Delphi methods for safety risk treatment in industrial port construction.

6.3) A scarcity of research involving active project sites in Thailand. (e.g., Map Ta Phut Industrial Port)

7) Develop Conceptual Framework;

Based on the insights obtained, a conceptual framework was constructed to guide the study. It incorporated:

7.1) The six-step risk management process from the PMBOK Guide. (PMI, 2013)

7.2) Risk identification, analysis, and treatment strategies grounded in empirical evidence.

7.3) Delphi consensus building to validate and refine risk responses. This framework shaped the development of research instruments, including the risk identification checklist, expert interview guidelines, and risk assessment questionnaires.

A diagrammatic representation of the conceptual framework is provided in Figure 3.3. This framework illustrates the logical progression of the study, beginning with a comprehensive literature review that identifies theoretical foundations and critical risk factors. It then integrates the Project Management Institute's (PMI, 2013) six-step risk management process to guide risk analysis in marine infrastructure construction. The model combines both qualitative and quantitative techniques—such as risk matrix scoring and tornado diagram analysis—for risk evaluation. The final stage employs the Delphi technique to refine and validate treatment strategies through expert consensus. This integrative framework ensures a structured, evidence-based, and replicable approach to safety risk management in complex seaport construction environments.

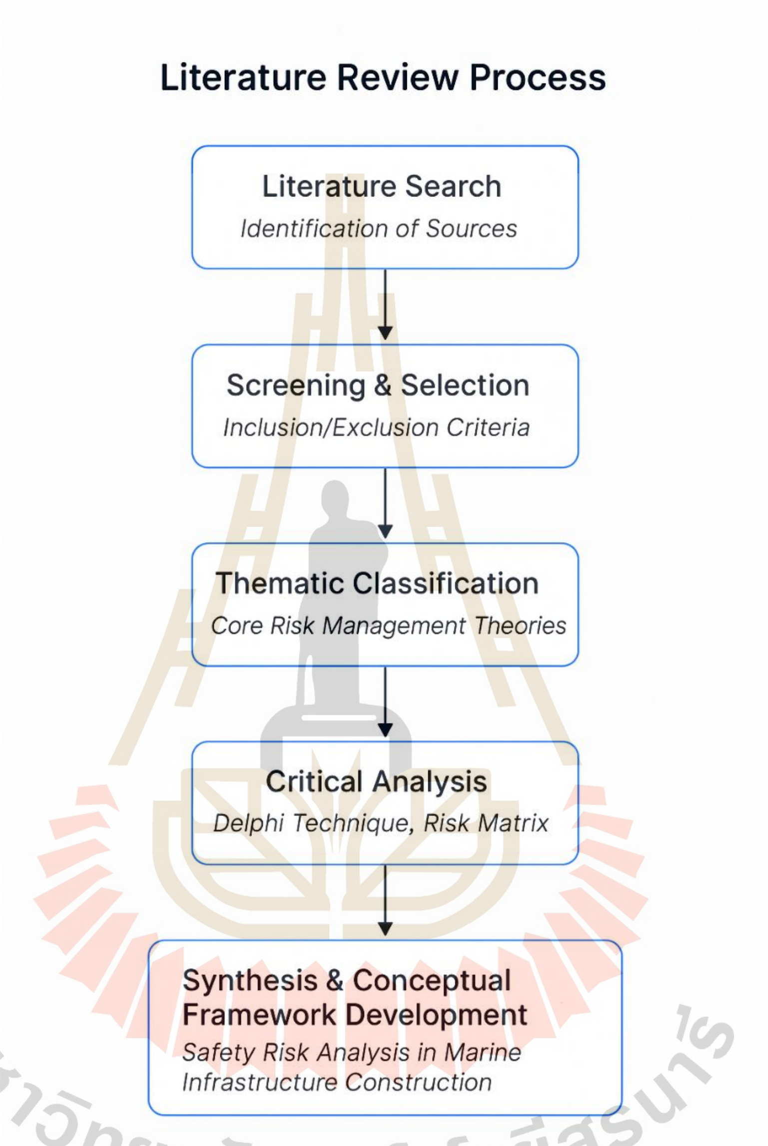


Figure 3.3 Literature Review Process.

3.3 Risk Management Process Framework

3.3.1 Plan Risk Management

This initial step defines how risk management activities are structured and implemented throughout the project. It involves setting the scope of risk analysis, identifying relevant stakeholders, and outlining roles and responsibilities for risk-related tasks. A comprehensive Risk Management Plan (RMP) was developed to provide a systematic framework guiding all subsequent processes and ensuring methodological consistency.

As part of this step, risk assessment criteria were also established to support qualitative and quantitative analyses. The risk scale was defined based on two dimensions: (1) Likelihood of Occurrence, and (2) Impact on Safety Outcomes. Each dimension was rated on a five-point ordinal scale (Very Low, Low, Moderate, High, Very High), allowing risks to be categorized and prioritized within a structured risk matrix in the next phase. This ensures that both the severity and the probability of identified risks are assessed in a standardized manner, facilitating clearer communication and effective decision-making.

3.3.2 Identify Risks

The risk identification process aimed to systematically uncover potential events or conditions that could negatively impact the safety of workers in marine infrastructure construction. This was achieved through a multi-source approach that included an extensive literature review, analysis of historical incident reports, examination of the Work Method Statement from the Map Ta Phut Industrial Port Phase 3 Project, and expert consultations with professionals experienced in deep seaport construction.

Multiple risk identification techniques were employed, such as brainstorming sessions with field experts, the use of standard checklists derived from international safety guidelines, and historical data analysis from similar projects. These methods enabled the recognition of a comprehensive list of potential risks spanning both key domains of marine construction: dredging and land reclamation, and deep seaport structural works.

The identified risks were categorized and documented for further qualitative and quantitative analysis in the subsequent stages of the risk management process.

3.3.3 Perform Qualitative Risk Analysis

This step involved evaluating and prioritizing the identified risks based on their probability of occurrence and potential impact on construction safety. A qualitative risk analysis was conducted using a 5x5 risk assessment matrix, which categorizes risks according to two key dimensions: Likelihood (ranging from Rare to Almost Certain) and Severity (ranging from Insignificant to Catastrophic). The matrix provided a structured framework to rate and visualize the risk exposure levels, facilitating consistent interpretation across stakeholders.

Each risk was assessed by a panel of assessors drawn from engineers, supervisor and safety officers, ensuring that the analysis reflected both theoretical and practical perspectives. The ratings were assigned based on consensus judgments, supported by historical project data and field experience. The outcome of this analysis was a risk register that those prioritized risks into levels; Low, Moderate, High, and Extreme, enabling the research to focus subsequent efforts on managing those risks with the highest potential for adverse safety consequences. The qualitative results also informed us of the selection of specific risks for more detailed quantitative analysis, as described in the next section

3.3.4 Perform Quantitative Risk Analysis

Following the qualitative assessment, a quantitative risk analysis was conducted to estimate the potential impact of key risks on project safety performance with greater precision. This step focused on the high and extreme risks identified in the qualitative phase, aiming to quantify the degree of influence each risk factor may have on safety outcomes in marine infrastructure construction.

The primary tool employed was the Tornado Diagram, which is a sensitivity analysis technique that visually ranks risks based on their relative contribution to overall project variability. This method enabled the identification of the most critical risk drivers by measuring how changes in individual risk variables affected a defined safety performance indicator (e.g., probability of accidents, delays due to safety incidents, or cost overruns related to safety management).

Inputs for the analysis were derived from historical data, expert elicitation, and construction-specific safety records, particularly from the Map Ta Phut Industrial Port Phase 3 Project. The analysis assumed a range of possible values for each key risk and calculated the corresponding outcomes using a risk simulation model.

The Tornado Diagram results provided a prioritized view of influential risks, which helped guide strategic decisions in developing mitigation and response plans. This analysis also supported a more evidence-based approach to resource allocation and safety planning for high-risk activities such as dredging, reclamation, and heavy lifting in deep-sea port environments.

3.3.5 Plan Risk Responses

This stage focused on developing appropriate strategies to mitigate, transfer, accept, or avoid the high-priority risks identified through qualitative and quantitative analyses. The primary objective was to enhance safety performance by proactively reducing the likelihood and/or impact of identified risks in marine infrastructure construction. To ensure a systematic and specialist-driven process, the Delphi Technique was employed. This structured communication method involved multiple rounds of anonymous surveys and feedback among a panel of domain specialists, including safety engineers, marine construction supervisors, and academic specialists in occupational risk management. In each Delphi round, panel members reviewed risk scenarios, evaluated proposed mitigation measures, and provided independent judgments regarding their feasibility and effectiveness. The results were aggregated and statistically analyzed to identify areas of consensus and divergence. Subsequent rounds refined the proposed responses based on the collective feedback, gradually converging toward well-founded and actionable strategies.

Key mitigation and treatment strategies formulated through this process included: Implementing advanced safety training programs tailored to unfamiliar tasks in deep seaport construction, enhancing monitoring systems and near-miss reporting for hazardous activities like dredging and pile driving, introducing engineering controls such as energy isolation mechanisms to address risks identified under Haddon's Energy Release Theory and assigning specialized personnel for critical supervision tasks in line with the Human Factors Theory.

The Delphi Technique ensured that the risk responses were not only theoretically sound but also practical and adaptable to real-world construction settings, particularly those with limited frequency and institutional experience, such as the deep-sea port works.

3.3.6 Monitor and Control Risks

The final stage in the risk management process involves continuous monitoring of identified risks, reassessment of emerging risks, and evaluation of the effectiveness of implemented mitigation strategies. This ensures that safety risk management remains dynamic and responsive throughout the construction lifecycle of marine infrastructure projects. In this research, the Monitor and Control Risks process was operationalized by establishing a risk tracking system that documented the status of each identified risk, including its current severity rating, implemented responses, and any changes observed in risk behavior over time. Project safety officers and site engineers were tasked with regular updates and observations, which were compiled into a centralized safety performance database. Periodic risk audits and reassessments were conducted using the same qualitative and quantitative tools employed during earlier stages, including the 5x5 Risk Matrix and Tornado Diagram. These tools allowed the research team to detect shifts in probability and impact, and to identify residual or secondary risks arising from implemented controls.

Furthermore, feedback mechanisms such as toolbox meetings, site inspections, and worker consultations were integrated into the monitoring process. This helped in capturing frontline experiences and undocumented hazards that may not have been apparent during initial planning. To maintain alignment with the Risk Management Plan, a Risk Review Committee comprising project stakeholders, safety professionals, and academic advisors was convened at key milestones. Their role was to review documented risk events, verify compliance with planned responses, and recommend adjustments or escalations where necessary.

Importantly, as a final step, this study applied the Delphi technique to validate the effectiveness of risk mitigation strategies. A follow-up questionnaire based on the initial risk assessment was distributed to the same panel of assessors to determine whether the residual risks were within acceptable thresholds. If a consensus was reached indicating that the risk levels were acceptable, the mitigation strategy was considered successful, and the process advanced to the conclusion phase. Conversely, if risks were still deemed unacceptable, further control measures were proposed and re-evaluated. By integrating specialist judgment and iterative evaluation, this approach ensured that safety risks in marine infrastructure construction were monitored rigorously, with findings grounded in both field data and validated specialist input.

3.4 Data Collection and Sampling

A purposive sampling strategy was employed to ensure that participants possessed substantial expertise and practical experience in marine infrastructure construction, specifically related to seaport development projects. The study engaged two distinct groups of samples, all of whom are currently involved in the Map Ta Phut Industrial Port Development Phase 3 Project in Rayong, Thailand.

3.4.1 Group 1: Specialists

This group comprised 3 experts with more than 10 years of experience in marine construction. These specialists played a crucial role in the early stages of the study, including brainstorming to identify potential risks, applying the Delphi technique for refining risk treatments, and reviewing the inspection questionnaire to ensure clarity and accuracy.

3.4.2 Group 2: Risk Assessors

The second group consisted of 12 assessors, each with over 3 years of experience in marine construction. Their primary responsibility was to evaluate the likelihood and impact of each identified risk. They participated in both the initial and final risk assessments, thereby contributing to a robust evaluation process that underpins the study's risk prioritization framework.

This stratified expert engagement ensured a well-rounded and evidence-based approach to both identifying and analyzing the key safety risks in marine infrastructure construction.

3.5 Data Analysis Techniques

This study employed a combination of qualitative and quantitative analysis techniques to evaluate and prioritize safety risks in marine infrastructure construction.

3.5.1 Qualitative Analysis

A 5x5 risk matrix was used to assess the likelihood and impact of each identified risk. Thematic analysis was applied to interpret qualitative data obtained from expert interviews and open-ended questionnaire responses. This facilitated a deeper understanding of contextual risk factors and informed the development of tailored mitigation strategies.

3.5.2 Quantitative Analysis

Tornado graph sensitivity analysis was employed to quantify the relative influence of individual risk variables on overall project safety. Standard deviation measures were applied to identify variability in expert responses and prioritize risks with the highest potential variability and impact.

3.5.3 Risk Treatment

The Delphi technique was utilized to refine and validate proposed risk treatment strategies. Through iterative rounds of structured feedback from selected experts, consensus was achieved on the appropriateness and feasibility of the mitigation measures, enhancing the reliability and practicality of the final recommendations.

3.6 Research Validity and Reliability

To enhance the validity of the research, triangulation was employed by integrating data from multiple sources, including literature reviews, expert consultations, and field reports from the Map Ta Phut Industrial Port Phase 3 Project. This methodological approach ensured that the findings were supported by diverse perspectives and contextual evidence.

Reliability was maintained through the consistent application of structured tools, such as standardized risk assessment questionnaires and predefined risk criteria based on the 5x5 matrix. Furthermore, the risk assessment instruments were reviewed and inspected for content validity by three subject-matter specialists using the Index of Item-Objective Congruence (IOC) technique. This process ensured the clarity, relevance, and consistency of assessment items, thereby strengthening the reliability and accuracy of the collected data.

3.7 Ethical Considerations

All research procedures adhered to established ethical standards. Data collection was conducted with the informed consent of all participants, who were fully briefed on the objectives, scope, and use of the research findings. Confidentiality was assured, and all personal or identifiable information was omitted to protect participant privacy.

Participation in the Delphi method was entirely voluntary, and responses were anonymized to prevent potential bias or influence among experts. Ethical approval for the study was obtained in accordance with institutional research guidelines, ensuring transparency, integrity, and respect for the rights of all involved stakeholders.

3.8 Summary

This study adopts a comprehensive methodological framework that integrates both theoretical foundations and practical tools to systematically evaluate safety risks in marine infrastructure construction. Guided by the six risk management processes outlined in the PMI (2013) framework, the research employs a 5x5 risk matrix for qualitative assessment, tornado graph sensitivity analysis for quantitative evaluation, and the Delphi technique for expert-driven risk treatment validation. The combination of these methodologies enables a holistic and replicable approach to safety risk analysis, particularly suited to the complexities and uncertainties inherent in large-scale seaport development projects. This multi-method strategy ensures both analytical rigor and contextual relevance, contributing to the development of evidence-based strategies for risk mitigation and safety enhancement in the field.

CHAPTER IV
SAFETY RISKS IN DREDGING AND RECLAMATION WORK

4.1 Introduction

4.1.1 Safety risks and project implications

The construction industry, in general, is fraught with numerous safety risks due to the complex and ever-changing nature of construction sites. According to Rory (2003), these risks are exacerbated by a lack of information, which increases the potential for harm. These risks pose significant threats not only to the health and well-being of workers but also to the overall success and efficiency of construction projects. Safety hazards can range from falls injuries caused by machinery and improper use of equipment, each of which has the potential to cause serious injury or death. The existence of these risks necessitates strict safety measures and regulations to mitigate potential dangers.

The impact of safety risks extends beyond injury or loss of life to workers. Accidents and incidents at construction sites can cause project delays, increased costs, and legal liabilities. When safety procedures are violated, projects may face work stoppages imposed by regulatory agencies, disrupting timelines and inflating budgets. Financial ramifications also include higher insurance premiums and potential compensation claims, which can strain project resources. In addition to direct costs, safety incidents can damage a construction company's reputation, affecting confidence in its ability to perform. A company's perceived commitment to safety is increasingly becoming a key factor in project owners' contractor selection decision-making processes. Therefore, prioritizing safety is not only a financial obligation but also a strategic imperative. It is essential for maintaining competitive advantage, operational continuity, and fulfilling moral and legal responsibilities.

Addressing construction safety risks is critical to protecting workers from injury or loss of life and ensuring successful project implementation. The interplay between safety and project efficiency emphasizes the need for serious and systematic risk management. By prioritizing safety and implementing comprehensive risk management strategies, construction companies cannot only protect their employees but also achieve sustainable project success and long-term viability in the construction industry.

4.1.2 Safety risk in dredging and reclamation

Dredging and reclamation works are important for the development of port construction projects in maritime transportation (Marsha, 2005). Maritime activities enable the global transfer of commodities, fostering efficient and cost-effective transportation with reliability and environmental benefits (Fratila et al., 2021) asking it a significant contributor to economic growth and development (Jouili, 2016). Dredging and reclamation operations involve extracting sediments from aquatic environments to create land, protect coastal structures, and enhance infrastructure (Nicky and Marsha, 2010). The prominent project examples are the Hong Kong International Airport, the Jurong and Tuas Expansions in Singapore, and Dubai's Palm and World Islands (Rene, 2012). Dredging and reclamation operations necessitate safety attention regarding the exposure of personnel to hazards. These hazards encompass the operations of heavy machinery, potential structural failures, risks associated with underwater conditions, and exposure to hazardous substances (HSE, 2021). Due to the significance and severity of accidents, injuries, and possible loss of human lives. It is imperative to undertake a thorough risk assessment in order to identify, evaluate, and mitigate the potential safety hazards involved. Through a comprehensive investigation of the potential hazards and the use of efficient risk management tactics, project stakeholders possess the ability to actively augment safety measures and alleviate unfavorable outcomes. The Health and Safety Executive (HSE) is the authoritative body responsible for overseeing workplace health and safety in the United Kingdom. Its technical documents have provided data on various types of accidents and the severity of injuries from 2012 to 2021 in the context of dredging and reclamation work. They identified possible accidents such as contact with moving machinery, struck by moving objects, strike against something fixed or stationary, injuries while handling, slips or falls on the same level, and falls from a height. Understanding these common types of accidents is crucial for instituting effective risk mitigation strategies.

Several studies have examined factors related to safety risks in dredging and reclamation operations. In dredging, Daniel (2011) delved into safety management for dredging work in a Nigerian port, providing insights into risk factors in sea dredging. Bugg et al. (2018) assessed the efficacy of RFID tag technology in monitoring personnel safety on dredgers, aiming to enhance safety and diminish fatalities. Rizki (2018) analyzed safety risks in river dredging in Surabaya, Indonesia, with a focus on reducing boat accidents. In reclamation work, Ma et al. (2020) presented safety management guidelines for engineering artificial islands, while

Sevryugina and Apatenko (2020) developed a risk assessment model for vehicles used. Zhen et al. (2021) studied risk factors in sea reclamation, emphasizing risk reduction. Within the marine work, Cruickshank and Cork (2005) provided safety guidelines for coastal and marine construction. Valyani et al. (2019) identified key risks in marine construction projects, Mahapatra and Kushwaha (2020) studied hazards in port construction with preventive measures. In general construction, Holle et al. (2005) proposed safety and lightning education guidelines, and Gunduz and Laitinen (2018) suggested risk assessment methods, providing practical strategies for a safer workplace, especially suitable for SMEs construction businesses.

Notably, these existing studies offer valuable guidance for dredging and land reclamation work. However, there remains a dearth of research that specifically focuses on conducting risk analyses for safety in dredging and land reclamation activities within construction projects. This research aims to address these gaps by conducting a comprehensive risk analysis, focusing specifically on safety in dredging and land reclamation activities in construction. The outcome from this study will support the guideline development to improve safety in this specialized field and contribute to the existing body of knowledge in construction safety.

The objective of this study was to conduct a comprehensive analysis of safety risks associated with dredging and reclamation activities, with the goal of increasing safety and reducing the frequency and severity of potential hazards. Understanding the importance of managing safety risks in dredging and reclamation work offers significant benefits. Construction companies involved in these activities can protect their employees and achieve sustainable project success by focusing on safety.

The next section, which is the current risk management, details the research methodology. This includes a comprehensive risk analysis that integrates meticulous hazard identification from sample projects and literature reviews. The methodology involves gathering insights from experts with direct work experience to evaluate potential risks through a risk assessment process.

4.2 Dredging and reclamation safety risk management

This study employed the risk management technique outlined by the Project Management Institute (PMI, 2013). It is a systematic approach widely adopted in project management. This approach is not only reliable but also internationally recognized in project risk management. Highlighting the framework’s capacity to improve security, ensure project success, and foster ongoing enhancements in risk management practices. Accordingly, the research methodology was constructed (see Figure 4.1) demonstrating the input, process, and output in each analysis process.

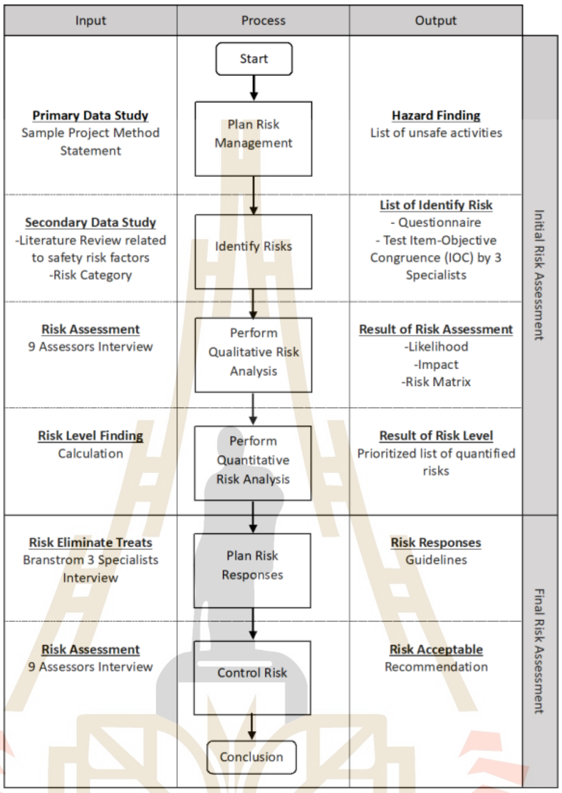


Figure 4.1 Research methodology.

In this research, two groups of people will assist in completing the study: a group of specialists and a group of assessors performing risk assessments.

1) Specialist Group:
   a) Number of Participants: 3
   b) Experience: More than 10 years of direct experience working in dredging and reclamation.
   c) Role: This group will help check the risk assessment checklist in the “Identify Risks” step and provide opinions on responses to risks in the “Plan Risk Responses” step. This information is shown in Table 4.1
2) Risk Assessor Group:
   a) Number of Participants: 12.

b) Experience: More than 5 years of direct experience working in dredging and reclamation.

c) Role: This group will help evaluate the risk in each factor in the "Perform Qualitative Risk Analysis" step and the "Control Risks" step, which is the final step in the risk assessment process. This information is shown in Table 4.2

Table 4.1 Specialist group demographic information.

Position	Frequency	% of Total
Senior Manager	1	33.33
Senior Engineer	1	33.33
Project Manager	1	33.33
Discipline	**Frequency**	**% of Total**
Civil Engineering	3	100
Total Work Experience	**Frequency**	**% of Total**
35 or more	1	33.33
30–35	1	33.33
25–29	1	33.33
Dredging and Reclamation Work Experience	**Frequency**	**% of Total**
25 or more	1	33.33
20–24	1	33.33
15–19	1	33.33
Education level	**Frequency**	**% of Total**
Postgraduate	2	66.67
Undergraduate	1	33.33

Table 4.2 Risk assessor group demographic information.

Position	Frequency	% of Total
Manager	6	50.00%
Project Engineer	4	33.33%
Inspector	2	16.67%
Discipline	**Frequency**	**% of Total**
Civil Engineering	9	75.00%
occupational health and safety	3	25.00%
Total Work Experience	**Frequency**	**% of Total**
30 or more	6	50.00%
20–29	4	33.33%
10–19	2	16.67%
Dredging and Reclamation Work Experience	**Frequency**	**% of Total**
10 or more	6	50.00%
6–9	4	33.33%
3–5	2	16.67%
Education level	**Frequency**	**% of Total**
Postgraduate	5	41.67%
Undergraduate	7	58.33%

The following will explain in detail the study of each step of safety risk management in dredging and reclamation work.

4.2.1. Plan risk management

First of all, it is worth mentioning that this paper applied risk management to the case study of the Map Ta Phut Industrial Port Phase 3 Development Project, situated in Rayong province, Thailand. The methodology steps began with a plan for risk management and the development of a systematic risk categorization. This step involved a primary data collection of the method statement of the case study project from the field investigation and observation to preliminarily identify hazardous activities and compile the list of unsafe practices. Concurrently, the secondary data was gathered from a comprehensive literature review to pinpoint and delineate the various risks inherent in dredging and reclamation work. The findings from these two steps were subsequently utilized in the development of a semi-structured interview questionnaire for assessor opinions evaluation on risk identification.

The analysis of primary data has provided insights into the processes involved in dredging and filling, as outlined in Figure 4.2 This depiction highlights five sequential steps as placing a revetment for reclamation boundary definition, installing a silt curtain for controlling silt spread and ensuring environmental protection, constructing a silt pond for drainage, conducting dredging operations to excavate seabed sand, conveying it through a floating pipeline, and finally transporting the dredged sand to the land reclamation area. These steps elucidate activities that inherently entail certain safety risks.

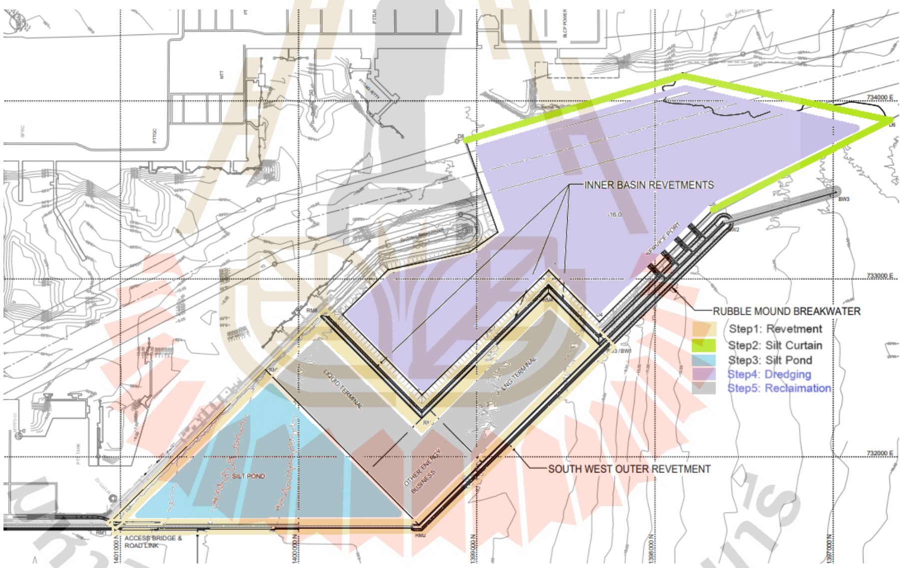


Figure 4.2 Work sequence and method statement of sample project.

4.2.2 Identify risks

Subsequently, an examination of secondary data pertaining to safety in dredging and reclamation work was conducted, as illustrated in Table 4.3. This comprehensive review delineates specific risk factors such as noise, crashes, pipe movement, lifting falls, diving, slips, and uncertain sea conditions within the context of dredging and reclamation operations, offering valuable insights into potential safety challenges.

Table 4.4 presents the identification of risk factors, organized into 7 categories and 22 sub-factors. These categories encompass a range of risks, including as:

1) Contact with moving machinery, poses a significant risk due to the continuous operation of dredging machinery, increasing the likelihood of operator injury or harm.

2) Struck by moving objects is heightened in areas with water and land traffic, particularly in temporary traffic zones, increasing the risk of accidents.

3) Strike against something fixed or stationary underscores the potential damage to stationary objects when adequate protection measures are lacking.

4) Injuries while handling, lifting, or carrying often result from inadequate knowledge or understanding of proper work practices, leading to frequent accidents.

5) Slips, trips, or falls on the same level underscores the unfamiliar working environment, contributing to frequent accidents.

6) Falls from height presents a significant risk due to the differences in working surfaces and poses a considerable threat to worker safety.

7) Weather hazards, highlight the potential hazards posed by natural disasters, which can escalate if work continued unabated.

Table 4.3 Summary of dredging and land reclamation safety risk factors.

Past study	Safety risk factor
Cruickshank and Cork (2005)	Noise, crash, pipe moving, lifting fall, diving, slip, and uncertain sea.
Holle et al. (2005)	Lightning.
Daniel (2011)	Heavy machine, fire, and diving.
Bugg et al. (2018)	Hazard during remove dredging sand.
Gunduz and Laitinen (2018)	Fall from scaffolding, work lighting, fire, and noise.
Rizki (2018)	Ship collision, and workers fall into the sea.
Ma et al. (2020)	Noise from the dredger machine disturbs.
Mahapatra and Kushwaha (2020)	Collision, falling, lifting fall, lighting, noise, and toppling.
Sevryugina and Apatenko (2020)	Vehicle of reclamation crashed by the breaker’s imperfection.

This categorization derives from a synthesis of findings in both primary and secondary data studies, forming the framework for a semi-structured interview questionnaire designed to assessor's opinions on risk identification. The subsequent evaluation of the index of item objective congruence by 3 specialists ensures alignment with research objectives, enhancing the robustness of the questionnaire. The unanimous evaluation results affirm the accuracy of the questionnaire in risk identification.

Table 4.4 Risk factors identification.

Item	Risk Identification
Contact with Moving Machinery	
(1)	The operator was injured in contact with the running dredger.
(2)	Noise from the dredger machine disturbs operator.
Struck by Moving Objects	
(1)	Dredger collides with cargo/fishing boat.
(2)	Vehicle of reclamation crashed by the driver's negligence.
(3)	Vehicle of reclamation crashed by the breaker's imperfection.
(4)	Dredging sand overlaps the workers.
(5)	Dredging sand conveying pipe fall on worker while connecting.
Strike against Something Fixed or Stationary	
(1)	Dredger collides with a pier or embankment.
(2)	Fire on dredger.
(3)	Diver was tied up by curtain cable.
(4)	Insufficient working light.
Injuries while Handling, Lifting, or Carrying	
(1)	Crane is unstable and fall on the workers.
(2)	Failure of lifting gear leading to heavy loads fall on workers.
Slips, Trips, or Falls on Same Level	
(1)	Operators slip on the dredger.
(2)	Worker were sedimented by quicksand at the silt pond.
Falls from Height	
(1)	Dredger operators fall into the sea.
(2)	General workers fall into the sea.

Table 4.4 Risk factors identification. (Continued)

Item	Risk Identification
Falls from Height	
(3)	Operator/worker fall from temporary scaffolding.
(4)	Operators fall from dredger's ladder.
(5)	Vehicle of reclamation falls into the sea.
Weather hazards	
(1)	Storm, strong wind blows dredger.
(2)	Lightning in land reclamation open space.

4.2.3 Perform qualitative risk analysis

In this step, face-to-face interviews were conducted with 9 experts. After the identification of risks in the preceding phase, a structured questionnaire was developed to involve experts in the risk assessment process. Both the likelihood and impact of each risk were classified into 5 score levels. To ensure the reliability of subjective evaluations among the experts, the risk measurement and assessment index were initially established based on procedure outlines the risk management of Nanyang Technological University (2023), as illustrated in Table 4.5

Table 4.5 Risk assessment index.

Score level	1: Very Low	2: Low	3: Moderate	4: High	5: Very High
Likelihood	One per ten years	One per five years	One per three years	One per year	Likely to occur many times per year
Impact	No injury	Injury at least 3 days of hospitalization	Injury at least 10 days of hospitalization	Injury at least 30 days of hospitalization	Fatality

The subjective evaluation on the likelihood of incidents and the severity of the impact among all 9 assessors were gathered and averaged. Then, the results of initial risk assessment representing the likelihood, the impact, and the risk exposure level were concluded in Table 4.6 The scores presented in the table, ranging from 1 to 5, indicate the frequency of likelihood in the second column and denote the level of impact in the third column of the table.

ISO 31000 (PECB, 2018) recommends using a risk matrix as a tool for assessing and prioritizing risks based on their likelihood and impact. This tool helps visualize the severity of each risk, assisting in the decision-making process for risk management. By prioritizing risks into different levels, it becomes easier to identify which risks require immediate attention and which can be monitored over time.

In this research, the scale under ISO 31,000, as shown in Figure 4.3, was applied to propose a risk matrix and scoring system for risk prioritization based on the likelihood and impact scores. Risk levels were arranged into five categories as follows: Low, Moderate Medium, Medium High, High, and Very High.

Table 4.6 Initial risk assessment.

Item	Initial Risk Assessment	
	Likelihood	Impact
A		
(1)	4	4
(2)	4	4
B		
(1)	4	4
(2)	3	3
(3)	3	3
(4)	3	3
(5)	3	3

Table 4.6 Initial risk assessment. (Continued)

Item	Initial Risk Assessment	
	Likelihood	Impact
C		
(1)	3	3
(2)	3	3
(3)	2	2
(4)	3	3
D		
(1)	3	5
(2)	4	4
E		
(1)	4	3
(2)	2	4
F		
(1)	3	5
(2)	3	5
(3)	3	4
(4)	3	4
(5)	2	5
G		
(1)	4	5
(2)	2	5

Based on the results of the qualitative risk analysis, values for both the Likelihood and Impact of various risks were obtained. These values have been plotted onto a risk matrix, which visually represents the risk level for each identified risk factor. The risk levels are prioritized and displayed in Figure 4.4.

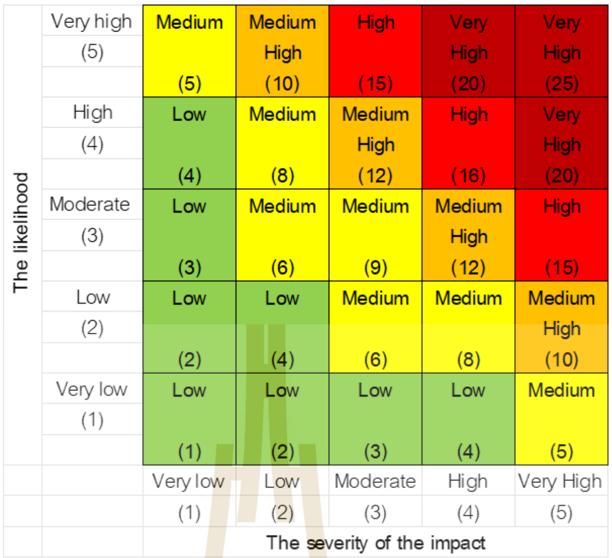


Figure 4.3 Risk matrix (Modified from Lehner, 2021).

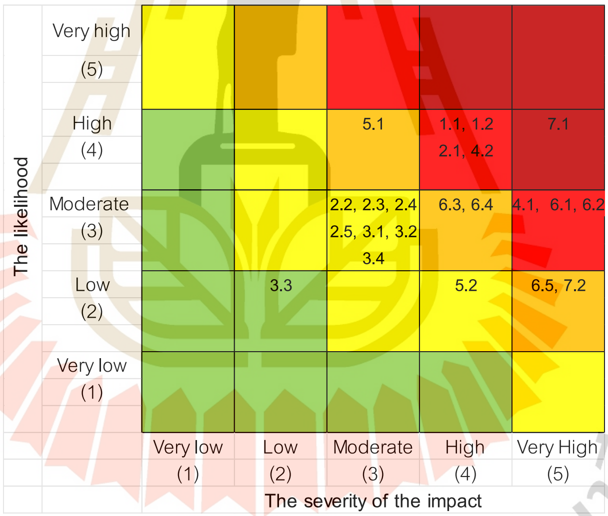


Figure 4.4 Initial risk assessment matrix.

4.2.4 Perform quantitative risk analysis

In this quantitative risk analysis process, a prioritized list of quantified risks based on the numerical analysis conducted is presented. The likelihood and impact values from the previous steps were multiplied to obtain the risk priority values. These values help in determining which risks need immediate attention and which can be monitored over time. The calculation items and the resulting prioritized list are detailed in Table 4.7.

This table enables stakeholders to focus on the most critical risks first, ensuring efficient allocation of resources for risk mitigation and management.

Table 4.7 Prioritized list of quantified risks.

Item	Likelihood Value	Impact Value	Risk Priority Value Likelihood x Impact)	Priority Level
A				
(1)	4	4	16	High
(2)	4	4	16	High
B				
(1)	4	4	16	High
(2)	3	3	9	Medium
(3)	3	3	9	Medium
(4)	3	3	9	Medium
(5)	3	3	9	Medium
C				
(1)	3	3	9	Medium
(2)	3	3	6	Medium
(3)	2	2	4	Low
(4)	3	3	9	Medium
D				
(1)	3	5	15	High
(2)	4	4	16	High
E				
(1)	4	3	12	Medium High
(2)	2	4	8	Medium

Table 4.7 Prioritized list of quantified risks. (Continued)

Item	Likelihood Value	Impact Value	Risk Priority Value Likelihood x Impact)	Priority Level
F				
(1)	3	5	15	High
(2)	3	5	15	High
(3)	3	4	12	Medium High
(4)	3	4	12	Medium High
(5)	2	5	10	Medium High
G				
(1)	4	5	20	Very High
(2)	2	5	10	Medium High

4.2.5 Plan risk responses

The risk response is planned based on the identified risks and assessments to develop appropriate risk management strategies. The strategies are proposed on the prevention, mitigation, and control measures to minimize or eliminate safety risks. A panel discussion was conducted through a brainstorming session involving interviews with 3 specialists. The aim was to exchange ideas and collaboratively analyze the causes of risk events in each factor. The outcome of this discussion was the establishment of a comprehensive guideline designed to avoid, mitigate, and reduce risk levels. The primary focus of this guideline is to effectively control operational safety risks in dredging and reclamation operations.

This phase constitutes an essential risk response strategy aimed at mitigating potential hazards in the workplace. To this end, specialists were interviewed using a series of brainstorming questions designed to elicit insights and recommendations for addressing each identified risk factor. Through this collaborative process, measures to reduce or avoid risks were explored and documented, resulting in the creation of a comprehensive work manual. Table 4.8 delineates the responses to safety risks in dredging and reclamation work, showcasing the concerted efforts to enhance workplace safety and minimize potential incidents.

Table 4.8 Proposed guidelines.

Item	Risk Rating Level	Risk Response	Guidelines for Risk Control
A			
(1)	High	Avoid & mitigate	Before repairing, the machine must be stopped and must have protective equipment and safety guard.
(2)	High	Avoid & mitigate	Provide operators with suitable hearing protection such as earmuffs or earplugs and controls to reduce noise levels at the source.
B			
(1)	High	Avoid	Equip the dredger and cargo/fishing boats with advanced navigation aids and technologies, such as radar, VHF radios, GPS, and AIS.
(2)	Medium	Avoid & mitigate	Enforce speed limits, safe driving practices and implement a system for monitoring driver behavior.
(3)	Medium	Avoid	Conduct post-operation inspections of breakers to assess their condition before and after use.
(4)	Medium	Avoid	Designate exclusion zones around the dredging area to keep workers at a safe distance from the sand discharge and implement warning signals.
(5)	Medium	Avoid & mitigate	Establish control zones around the area where the sand conveying pipe is being connected and Require workers to wear safety fall protection equipment.
C			
(1)	Medium	Avoid & mitigate	Install collision avoidance systems on the dredger to detect and alert the crew of potential collisions with piers or embankments.
(2)	Medium	Avoid & mitigate	Install effective fire detection and alarm systems on the dredger to provide early warning in case of a fire outbreak and install fire extinguishers.

Table 4.8 Proposed guidelines. (Continued)

Item	Risk Rating Level	Risk Response	Guidelines for Risk Control
(3)	Low	Avoid	Equip the curtain cables with an emergency release mechanism that can be activated immediately in case a diver becomes entangled.
(4)	Medium	Avoid & mitigate	Install backup lighting systems, such as battery-powered emergency lights or backup generators.
D			
(1)	High	Avoid	Assess and ensure that the ground where the crane is positioned is stable and capable of supporting the crane's weight and the loads it lifts.
(2)	High	Avoid	Ensure that all materials to be lifted are properly rigged and securely attached to the crane's hook or lifting device.
E			
(1)	Medium High	Avoid	Ensure that the dredger's decks have non-slip surfaces or anti-skid coatings and require operators to wear appropriate footwear with slip-resistant soles.
(2)	Medium	Avoid & mitigate	Establish safe work perimeters around the silt pond and clearly mark them with warning signs and provide workers with appropriate life vests.
F			
(1)	High	Avoid & mitigate	Provide dredger operators with appropriate personal protective equipment, including life jackets or personal floatation devices (PFDs).
(2)	High	Avoid & mitigate	Install safety lanyards and tethers on vessels or work platforms to secure general workers when working near the water's edge and provide worker's life jackets.

Table 4.8 Proposed guidelines. (Continued)

Item	Risk Rating Level	Risk Response	Guidelines for Risk Control
(3)	Medium High	Avoid & mitigate	Proper scaffolding design and provide operators and workers with appropriate personal fall protection equipment, such as harnesses and lanyards.
(4)	Medium High	Avoid & mitigate	Equip the ladder with non-slip steps or rungs to enhance grip and prevent slipping and provide operators with safety harnesses.
(5)	Medium High	Avoid	Implement a traffic management plan that includes clear instructions on vehicle routes and areas where vehicles need to slow down and install guardrails/barriers.
G			
(1)	Very High	Avoid	Implement an early warning system to alert personnel of potential storms or strong winds include provisions for securing and evacuating the dredger if necessary.
(2)	Medium High	Avoid	Instruct workers to stay away from tall objects, metal structures, avoid using electronic, and stop working and enter a safe area during lightning storms.

4.2.6 Control risk

The final step involves controlling risks through a comprehensive final assessment, which includes conducting interviews with 9 assessors to tackle the identified risks. This process aims to verify the guidelines for reducing risk levels effectively.

To ensure the validity of the findings, a follow-up questionnaire was conducted with the same nine assessors who participated in the initial survey. This phase included a thorough final risk assessment to verify the effectiveness of the deployed risk response methods in minimizing risks. As a result, the overall risk levels were reduced to a level deemed acceptable. Table 4.9 presents an exhaustive evaluation of the identified risks and their respective levels, both prior to and after the implementation of risk response methods.

While Figure 4.5 depicts the risk matrix obtained from this phase. The outcomes derived from the final column in table indicate that the risk assessment was at a low level. This implies that it falls within an acceptable risk range.

Table 4.9 Final risk assessment.

Item	Initial Risk Rating			Final Risk Rating		
	Risk Assessment		Risk Assessment	Risk Assessment		Risk Assessment
	Likelihood	Impact		Likelihood	Impact	
A						
(1)	4	3	High	1	1	Low
(2)	4	3	High	2	1	Low
B						
(1)	4	5	High	2	2	Low
(2)	3	5	Medium	1	1	Low
(3)	3	5	Medium	1	1	Low
(4)	3	4	Medium	2	1	Low
(5)	3	3	Medium	1	1	Low
C						
(1)	3	4	Medium	1	1	Low
(2)	3	5	Medium	1	2	Low
(3)	2	5	Low	1	1	Low
(4)	3	3	Medium	1	1	Low
D						
(1)	3	5	High	1	2	Low
(2)	4	4	High	2	2	Low
E						
(1)	4	3	Medium High	1	1	Low
(2)	2	4	Medium	1	1	Low

Table 4.9 Final risk assessment. (Continued)

Item	Initial Risk Rating			Final Risk Rating		
	Risk Assessment		Risk Assessment	Risk Assessment		Risk Assessment
	Likelihood	Impact		Likelihood	Impact	
F						
(1)	3	5	High	1	1	Low
(2)	3	5	High	1	1	Low
(3)	3	4	Medium High	1	2	Low
(4)	3	4	Medium High	1	1	Low
(5)	2	5	Medium High	1	2	Low
G						
(1)	4	5	Very High	2	1	Low
(2)	2	5	Medium High	1	1	Low

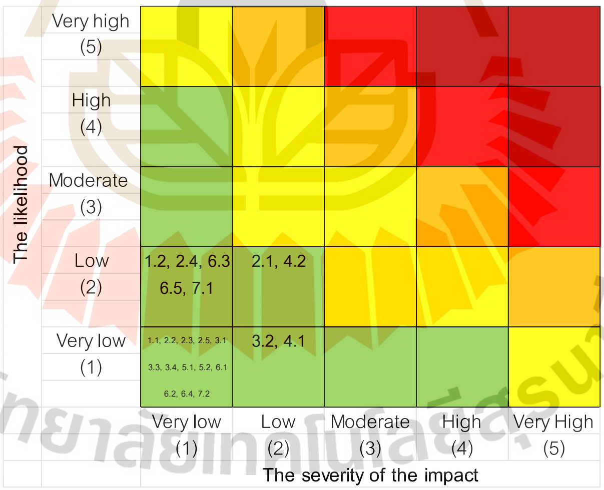


Figure 4.5 Final risk assessment matrix.

4.3 Discussion

When comparing the results of this study with past research, several consistent themes emerge, indicating the ongoing relevance and importance of addressing safety risks in dredging and reclamation work as.

1) Contact with moving machinery, previous studies by Cruickshank and Cork (2005) and Daniel (2011) have also emphasized the dangers associated with heavy machinery in dredging operations, aligning with the findings of this study.

2) Struck by moving objects, similar to Bugg et al. (2018) and Rizki (2018), this study highlights the risk of collisions involving dredgers and other vehicles during material handling, reinforcing the importance of safety protocols in such environments.

3) Strike against something fixed or stationary. consistent with past research by Cruickshank and Cork (2005), this study identifies the risk of collisions with fixed structures, such as piers or embankments, as well as fires on dredgers, underscoring the persistent hazards in these operations.

4) Injuries while handling, lifting, or carrying, findings from Holle et al. (2005) and Mahapatra and Kushwaha (2020) align with this study's identification of risks associated with unstable cranes and lifting gear failure, highlighting ongoing challenges in ensuring safe lifting practices.

5) Slips, trips, or falls on the same level, the concerns raised by Daniel (2011) regarding slip and fall incidents are consistent with the findings of this study, emphasizing the need for vigilance in preventing accidents on slippery surfaces.

6) Falls from height, similar to Holle et al. (2005), this study identifies the risk of falls from elevated surfaces, including into the sea, underscoring the continued importance of fall protection measures.

7) Weather hazards, the identification of weather-related hazards, such as storms and lightning during land reclamation, corresponds with past research by Cruickshank and Cork (2005), highlighting the ongoing challenges posed by adverse weather conditions.

However, while past research has addressed certain risk factors, this study acknowledges its limitations in comprehensively covering all inherent risks in dredging and reclamation work. By identifying and compiling new risk factors and evaluating the reliability of the questionnaire, this study aims to bridge this gap and provide a more comprehensive understanding of safety risks in these operations. The proactive measures formulated in response to the identified risks, along with subsequent assessments indicating risk mitigation to acceptable levels, contribute valuable insights and guidelines for future work in this reducing the potential for safety risks in dredging and reclamation work.

The risk assessment methodology employed involved several key steps, including qualitative and quantitative analyses, to ensure effective risk management. Methodology Overview:

1) Qualitative analysis
   a. Risk Identification: Risks were identified through sample project method statement study and literature review related to safety risk factors.
   b. Likelihood and Impact Assessment: Likelihood and impact values were assigned to each identified risk and subsequently plotted on a risk matrix.
2) Risk matrix utilization
   a. The use of a risk matrix was instrumental in visualizing and prioritizing risks based on their likelihood and impact. This approach facilitated the identification of the most critical risks requiring immediate attention.
3) Quantitative analysis
   a. Risk Priority Value Calculation: Likelihood and impact values were multiplied to obtain a risk priority value for each risk. This quantitative measure further aided in the prioritization process.
4) Risk response development
   a. Specialist Brainstorming: A brainstorming session with specialists was conducted to develop guidelines aimed at reducing identified risks.

By conducting this comprehensive final assessment and mitigation process, it was ensured that the proposed strategies were both practical and effective in minimizing risks. This robust approach not only validated the effectiveness of the risk response methods but also provided a clear path for future risk management improvements in other dredging and reclamation work. Including construction in other marine infrastructure projects.

While this research provides valuable insights, it is essential to acknowledge its limitations. The study’s focus on specific projects introduces potential constraints stemming from variations in topography, weather conditions, and design specifics, as well as differences in dredging and reclamation technologies. The findings, therefore, may not universally apply to all contexts within these domains. To address this limitation, future studies could adopt a more extensive approach, encompassing a diverse range of projects and locations. Such an inclusive strategy, involving rigorous data collection, risk analysis, and assessment, could contribute to the creation of a substantial database. This, in turn, would facilitate the development of advanced technologies in risk management, promising heightened accuracy in risk assessments and significantly benefiting occupational health and safety practices.

The results of this study highlight the critical importance of addressing safety risks in dredging and reclamation. By following a detailed risk management process aligned with the guidelines of the Project Management Institute (PMI), which is an internationally recognized authority in project management, and incorporating insights from sample projects and personnel with direct experience in this field, this study provides comprehensive guidelines for managing safety risks in dredging and reclamation. Construction companies engaged in dredging and reclamation can apply the findings of this study to enhance their safety protocols. Implementing the recommended measures will not only protect workers but also contribute to the sustainable success and long-term viability of construction projects in the marine construction sector. The research offers further guidance on effective risk management practices, which will enable the industry to achieve higher safety standards and promote a culture of continuous improvement in workplace safety.

4.4 Conclusion

Aligned with Project Management Institute (PMI) guidelines, this study meticulously follows a structured risk management process, plan risk management and identification stages. The risk identify covers seven main categories and twenty-two sub-risk factors through qualitative and quantitative assessments. Expert evaluations identify safety risks in dredging and reclamation as notably high and very high, leading to proactive risk response strategies, validated by industry experts. Emphasizing adherence to safety protocols and international standards, the study concludes with a final expert assessment, indicating low or acceptable risk levels. Serving as a crucial reference for decision-makers, the study underscores the significance of proactive risk awareness in ensuring the sustainable progress of dredging and reclamation projects.

This research study stands as a valuable guide for proactive safety control practices in dredging and reclamation work, providing a comprehensive overview of potential risks and hazards inherent in the job. The study not only identifies these risks but also offers clear guidelines for their mitigation, thereby reducing overall risk. Its exemplary nature makes it a valuable resource for decision-makers involved in managing safety in similar types of work. The insights gained from this study can be directly applied to enhance safety measures, making it an instrumental tool for fostering a secure work environment in dredging and reclamation projects.

CHAPTER V
SAFETY RISK ANALYSIS IN DEEP SEAPORT CONSTRUCTION

5.1 Introduction

Ports play an important role in international trade and economic development by serving the flow of goods and connecting land and sea. Port construction is driven by many factors, including the need to expand trade, accommodate larger ships, and support regional economic growth (UNCTAD, 2020). As the international trade market has increased, with an average annual growth of 3.5% over the past decade, the need for new and expanded ports has also increased significantly (World Bank, 2021). However, port construction is complex and raises security concerns. They often involve a unique combination of marine and coastal construction, often withstanding complex environmental conditions. Working above water area poses significant safety risks, including an increased risk of Falling from a height and drowning, especially when working on temporary or unstable structure. All supevisors oversee construction worker, including civil engineers, health and safety personnel, foreman, contractor, and construction workers, to ensure safety and efficiency.

The safety risks associated with offshore construction are significant and can lead to serious accidents, injuries, and deaths. According to the International Labour Organization (ILO, 2022), the construction sector accounts for a large proportion of accidental work, with particular emphasis on maritime activities. Zhang et al. (2020) found that the accident rate in port construction work is 27% higher than in general construction work. Accidents during offshore construction are indeed often more severe and result in higher fatality rates compared to onshore construction. A study by Suraji et al. (2001) analyzed the root causes of construction accidents and found that the complexity and hazardous nature of offshore environments contribute significantly to the severity of incidents. The study emphasizes that factors such as adverse weather conditions, remote locations, and the interplay between human and organizational elements increase the risk and potential consequences of accidents in offshore construction. There is a gap in knowledge and research in this area. While domestic safety management has been extensively studied, the unique challenges associated with port construction projects remain underexplored. Previous studies generally focus on the operational security of existing ports rather than the construction phase (Li and Ng, 2018). In addition, the rapid development of port technology has exceeded the development of security management strategies (Wang et al., 2020). By reviewing current practices, identifying key problems, and proposing mitigation strategies, this research aims to enhance the implementation of safety guidelines in key areas of seaport construction.

5.2 Literature Review

5.2.1 Risk Management in Construction Projects

Risk management in construction projects is guided by frameworks such as ISO 31000 and the Project Management Institute's (PMI) risk management processes. These frameworks emphasize the importance of risk identification, qualitative and quantitative analysis, and response planning. According to ISO 31000 (2018), an effective risk management framework should include risk identification, risk analysis, risk treatment, and monitoring. The Project Management Institute's (PMI, 2013) provides a structured approach to risk planning, identification, analysis, and response. These methodologies are widely used in safety-critical industries such as oil and gas, offshore wind energy, and maritime infrastructure. Studies have shown that construction projects involve multiple dynamic risks, which vary depending on the project type and location. For instance, Zou et al. (2007) identified key risks in construction projects in China, including tight project schedules, design variations, and financial challenges. Similarly, Brown and Taylor (2018) explored safety risks in general construction, identifying common hazards such as fall risks, equipment failures, and structural instability. Zhang et al. (2023) conducted a study on safety risk factors in metro shield construction, identifying key risks and proposing mitigation strategies. This research highlights the importance of effective risk management practices in ensuring construction safety.

5.2.2 Risk Management in Seaport Construction Projects

Seaport construction differs significantly from other construction projects due to work activities on the water, specialized equipment, and exposure to marine hazards. Tam et al. (2004) highlighted that risks in port construction are influenced by tides, currents, and extreme weather conditions, which increase the complexity of risk management. Choudhry et al. (2016) emphasized that offshore and nearshore construction require marine safety measures, including drowning prevention, vessel stability assessments, and diving safety protocols.

In marine construction, additional considerations arise due to unstable working surfaces, underwater operations, and environmental hazards. Accidents in offshore construction are often more severe and result in higher fatality rates compared to onshore projects. A study analyzing major offshore oil and gas accidents found that failures during drilling and exploitation can lead to catastrophic events, causing significant loss of life and environmental damage. The study emphasizes that such accidents, though relatively rare, have severe consequences when they occur (Brkic & Stajic, 2019). While previous studies have explored construction risk management, limited research has focused specifically on deep seaport construction. Some studies, such as Lee et al. (2019), have analyzed maritime safety, but they do not fully address the unique risks associated with marine construction.

5.2.3 Tools of Risk Management

The construction of deep seaports presents unique safety challenges due to the marine environment, high-risk work conditions, and complex engineering processes. Effective safety risk management in this sector requires a systematic approach to risk identification, assessment, and mitigation.

The "What-If" technique is a structured brainstorming approach used to identify potential hazards in high-risk industries. Initially developed for the process and chemical industry (Kletz, 1999), it has been adapted for construction and engineering safety assessments. In the seaport construction, the "What-If" analysis is particularly useful because it provides flexibility in identifying site-specific hazards that may not be covered by standardized checklists. Swuste et al. (2012) noted its effectiveness in uncovering hidden hazards by posing hypothetical scenarios.

Risk assessment in seaport construction often involves a combination of qualitative and quantitative methods. The 5×5 risk matrix is a qualitative tool commonly used to assess and prioritize risks based on their likelihood and impact. It provides a visual representation that helps organizations identify risks requiring immediate mitigation and management. Aven (2016) stated that qualitative risk assessment involves expert judgment to classify risks into categories, which is useful for early-stage risk screening. Quantitative risk assessment applies statistical methods to calculate risk scores based on probability distributions and severity ratings. Kaplan & Garrick (1981) discussed the use of mean, standard deviation, and tornado diagrams to refine risk prioritization.

Risk mitigation strategies must be practical, evidence-based, and validated by industry experts. The Delphi method (Linstone & Turoff, 2002) is a widely used approach for developing expert-driven risk mitigation measures. It involves multiple rounds of expert consultation to refine safety recommendations and achieve consensus. In seaport construction, the Delphi technique has been successfully applied in areas such as diving safety and emergency response planning (Ortega et al., 2015), marine construction accident prevention (Shapira & Simcha, 2009) and improving work-at-height safety in offshore projects (Mohamed et al., 2021). By applying the Delphi technique, this study ensures that risk mitigation strategies are validated by industry specialists and can be replicated in future projects.

5.3 Materials and methods

5.3.1 Study Design

This study adopts a mixed-methods approach, integrating qualitative and quantitative risk assessment techniques to analyze safety risks in deep seaport construction. The research focuses on the Map Ta Phut Industrial Port Phase 3 Project in Rayong, Thailand, a large-scale industrial port development.

The study is structured based on the Project Management Institute (PMI) risk management framework, which includes risk identification, qualitative and quantitative analysis, and risk mitigation. This framework is widely recognized in construction project management and is optimized for systematic risk assessment in this study.

The research methodology, illustrated in Figure 5.1, provides a structured approach to plan risk management, identify risks, perform qualitative risk analysis, perform quantitative risk analysis, plan risk responses and control risk, ensures that the findings are beneficial, robust, and applicable to similar seaport construction projects, contributing to enhanced safety management practices in the construction industry.

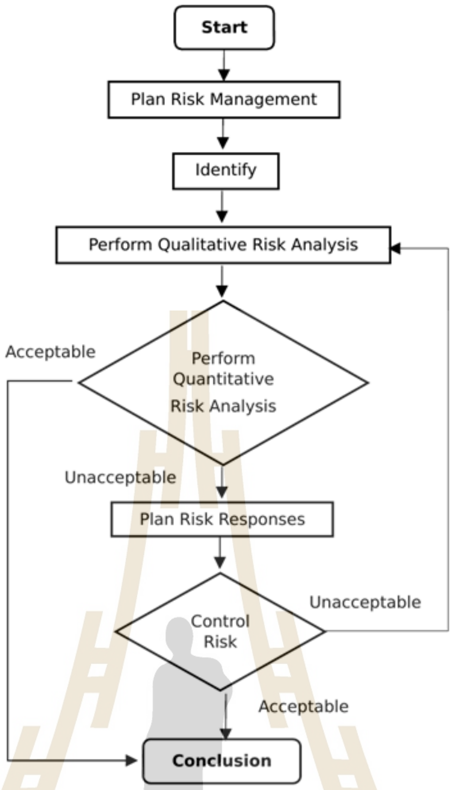


Figure 5.1 Study Methodology.

5.3.2 Data Collection Methods

Primary Data Collection was gathered through expert interviews, on-site observations, and risk assessment workshops. The study engaged 3 specialists with extensive experience in seaport construction, who participated in systematic brainstorming sessions utilizing the What-If analysis technique. Each specialist possesses over 10 years of direct experience in seaport construction, with their qualifications detailed in Table 5.1, hypothetical "What if?" scenarios were posed to assess potential safety risks associated with various construction activities at the Map Ta Phut Industrial Port Phase 3 Project. The identified risks were cross-referenced with sample project work method statements, as illustrated in Figure 5.2, to ensure practical relevance.

Table 5.1 Specialist demographic information.

Position	Frequency	% of Total
Senior Manager	1	33.33%
Senior Engineer	1	33.33%
Project Manager	1	33.33%
Discipline	**Frequency**	**% of Total**
Civil Engineering	3	100.00%
Total Work Experience	**Frequency**	**% of Total**
35 or more	1	33.33%
30–35	1	33.33%
25–29	1	33.33%
Seaport Construction Work Experience	**Frequency**	**% of Total**
25 or more	1	33.33%
20–24	1	33.33%
15–19	1	33.33%
Education level	**Frequency**	**% of Total**
Postgraduate	2	66.67%
Undergraduate	1	33.33%

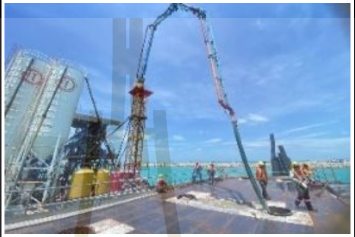
Work Seq. No. /Activity	Work Photo	Work Seq. No. /Activity	Work Photo	Work Seq. No. /Activity	Work Photo
1. Piling Driving		4. Pile Concrete Plug		7. Demolish the platform	
2. Platform Installation		5. Pile Cap and Beam Work		8. Fender Installation	
3. Pile Cutting -Off		6. Deck Slab Work		9.Pile Cathodic Protection Work	

Figure 5.2 Sample project work method statement.

Secondary data collection, to validate the identified risks and establish a comparative analysis with previous studies, an extensive literature review was conducted. Data sources included peer-reviewed journal articles, industry reports, and regulatory guidelines, with a particular focus on ISO 31000:2018 (Risk Management) and ISO 45001:2018 (Occupational Health and Safety Management Systems). These references provided a framework for evaluating risk management best practices and aligning the study with international safety standards.

5.3.3 Risk Identification and Assessment Techniques

The What-If analysis was employed to systematically identify potential hazards by posing hypothetical "What would happen if?" questions for each major construction activity, enabling a proactive approach to risk identification. Identified risks were then assessed using a 5×5 risk matrix, where likelihood (1–5 scale) represents the frequency of occurrence, and impact (1–5 scale) reflects the severity of consequences. This risk assessment framework follows the guidelines of the UK Health and Safety Executive (HSE, 2021) and aligns with the ISO 31000 risk management standard, ensuring a structured and reliable evaluation process. A panel of 12 experienced assessors, each with direct expertise in construction safety, conducted the risk assessment. They were responsible for evaluating likelihood and impact scores for each identified risk factor during the "Perform Qualitative Risk Analysis" phase and overseeing the "Control Risks" phase as the final step in the risk assessment process. Their detailed qualifications are presented in Table 5.2.

Table 5.2 Risk assessor group demographic information.

Position	Frequency	% of Total
Manager	6	50.00%
Project Engineer	4	33.33%
Inspector	2	16.67%
Discipline	**Frequency**	**% of Total**
Civil Engineering	9	75.00%
occupational health and safety	3	25.00%
Total Work Experience	**Frequency**	**% of Total**
30 or more	6	50.00%
20–29	4	33.33%
10–19	2	16.67%
Seaport Construction Work Experience	**Frequency**	**% of Total**
10 or more	6	50.00%
6–9	4	33.33%
3–5	2	16.67%
Education level	**Frequency**	**% of Total**
Postgraduate	5	41.67%
Undergraduate	7	58.33%

5.3.4 Risk Analysis Methods

The study employed both qualitative and quantitative risk analysis methods to ensure a comprehensive assessment of safety risks in deep seaport construction. In the qualitative analysis, 12 experienced assessors assigned likelihood and impact scores to each identified risk factor, with the overall risk level determined using in Equations R = L x I, where R represents the overall risk level, L denotes the likelihood of occurrence, and I indicate the impact or severity of consequences.

Risks were categorized into four levels: Low Risk (1–4), Medium Risk (5–9), High Risk (10–16), and Very High Risk (17–25) to prioritize mitigation strategies effectively. The 5×5 risk matrix used for this classification is illustrated in Figure 5.3, providing a visual representation of how risks were assessed based on frequency and severity.

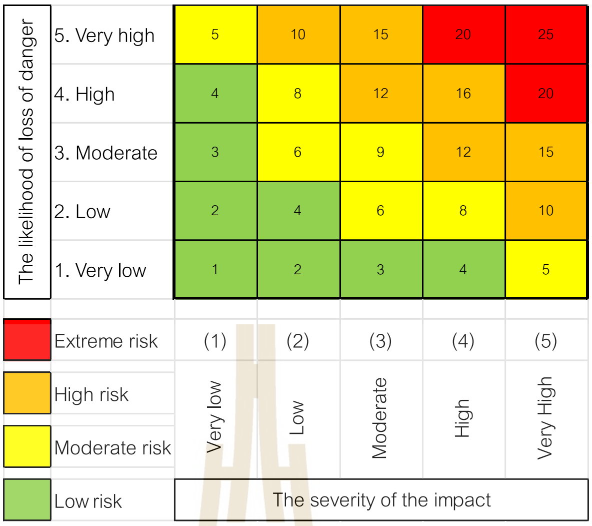


Figure 5.3 5x5 Risk matrix.

For the quantitative analysis, the mean and standard deviation of risk levels across assessors were calculated to assess variability in risk perception. A tornado diagram was used to visualize the highest and lowest variations in risk scores, ensuring a data-driven approach to identifying critical risks that require immediate attention. This combined methodology enhances risk evaluation, supports informed decision-making, and strengthens safety management in deep seaport construction projects.

5.3.5 Risk Mitigation and Validation

A structured risk mitigation approach was implemented using the Delphi technique, ensuring expert-driven validation of proposed safety measures. This iterative process involved multiple rounds of expert consultation, where each identified risk factor was systematically reviewed, and specialists proposed three potential mitigation strategies. These recommendations were refined through consensus, enhancing their applicability and effectiveness in deep seaport construction. To assess the impact of the mitigation measures, a final reassessment was conducted using the 5×5 risk matrix, allowing for a comparative analysis of pre- and post-mitigation risk levels. This validation process ensured that the proposed safety strategies were both practical and effective, reinforcing a data-driven approach to risk reduction in complex maritime construction environments.

5.3.6 Ethical Considerations

This study adhered to ethical guidelines for workplace safety research and complied with the requirements of the Human Research Ethics Office, Institute of Research and Development, Suranaree University of Technology. Informed consent was obtained from all participants before conducting interviews, risk assessments, and expert consultations. To ensure confidentiality, personal data were anonymized, and findings were reported in an aggregated format. Ethical approval was secured where required, ensuring compliance with principles of voluntary participation, transparency, and professional integrity. The study aligns with internationally recognized standards, including ISO 31000:2018 (Risk Management) and ISO

5.4 Safety Management in Deep Seaport Construction

5.4.1 Plan Risk Management

The safety risk assessment was conducted using a standardized likelihood and impact scale (ranging from 1 to 5) based on the principles outlined in ISO 31000:2018 (Risk Management) and ISO 45001:2018 (Occupational Health and Safety Management Systems). This approach ensures a systematic and comprehensive evaluation of risks specific to deep seaport construction. To define the likelihood scale, the typical duration of the construction phase for deep seaport projects, which range from 2 to 4 years, was considered. An average duration of 3 years was used as the reference timeframe for expected occurrences of risk events. The impact scale was determined based on the severity of potential injuries or consequences. Table 5.3 presents the defined likelihood levels, corresponding numerical expectations within a 3-year construction period, and the impact levels categorized by injury severity.

Table 5.3 Risk scale definition.

Score level	1: Very Low	2: Low	3: Moderate	4: High	5: Very High
Likelihood	Rare: 0 – 1 occurrence(s) per 3 years.	Unlikely: 2 – 3 occurrences per 3 years.	Possible: 4 – 5 occurrences per 3 years.	Likely: 6 – 8 occurrences per 3 years.	Almost Certain: More than 9 occurrences per 3 years
Impact	Negligible: No injuries; no medical attention required.	Minor: Minor injuries requiring only first aid treatment.	Moderate: Injuries requiring medical treatment at a hospital.	Major: Extensive injuries, potentially causing temporary disability.	Catastrophic: Fatalities or permanent disabilities with long-term effects.

The risk score is calculated by dividing the risk scores, giving a range of 1 to 25. Risk can be described as low (1-4), medium (4-9), high (9-16) and very high (16-25). General acceptance (Low Risk) risk in the range of 1-4 is considered acceptable. Tolerable (medium risk) risks 4–9 is tolerated if the risk reduction is less than the improvement achieved. Undesirable (high risk) risks 9–16 is undesirable and should be minimized unless there are special circumstances. Unbearable (very high risk), risks in the range of 17-25 are intolerable and must be minimized at all risks.

5.4.2 Identify Risks

5.4.2.1 Results of What-If Analysis for Construction Processes

The What-If analysis was conducted through a brainstorming session with three specialists to evaluate potential hazards associated with deep seaport construction activities. The preliminary hazard identification focused on nine key construction activities, derived from the work method statements of the Maptaphut Industrial Port Phase 3 Project, representing a typical sequence of seaport construction. These activities included Pile Driving, Platform Installation, Pile Cutting-Off, Pile Concrete Plug Installation, Pile Cap and Beam Work, Deck Slab Work, Demolition of the Temporary Platform, Fender Installation, and Pile Cathodic Protection Work. Each phase presents unique hazards and operational challenges, requiring a systematic risk identification process. The What-If technique, a flexible, high-level risk identification method, is method effectively identified hazards resulting in construction projects (Kohrt et al., 2013). This method was applied to systematically assess potential risks by analyzing the Work Method Statement of the nine-step construction process at Maptaphut Industrial Port Phase 3. The results of this hazard identification process, along with corresponding risks, are presented in Table 5.4: Questions and Identified Hazards, providing a structured approach to recognizing safety risks and supporting the development of effective risk mitigation strategies for deep seaport construction projects.

Table 5.4 Results of What-If Analysis for identified risks.

Work Sequenc No./Work Activit	What would happen if	Potential Risk
1) Piling Driving	1) the lifting mechanism failed during pile driving?	Lifting Object Failure
	2) the crane became unstable during pile driving?	Crane Instability
2) Platform Installation	1) the working platform was improperly secured?	Working Platform Instability
	2) waves impacted the platform during installation?	Wave Impact on Working Area
	3) the vessel became unstable or collided with another vessel?	Vessel Instability and Collision
3) Pile Cutting Off	1) the temporary structure used for pile cutting became unstable?	Temporary Structure Instability
	2) gas cutting equipment malfunctioned?	Gas Cutting Explosions
	3) a grinding disc broke during cutting operations?	Grinding Disc Breakage
4) Pile Concrete Plug	1) workers slipped on the wet floor during concrete plug work?	Slips on the Working Floor
5) Pile Cap and Beam Work	1) a worker fell into a steel pipe pile hole?	Falls into Steel Pipe Pile Holes
	2) workers fell from heights while working?	Falls from Heights
	3) a worker experienced an electric shock while welding formwork?	Electric Shock During Welding
6) Deck Slab Work	1) workers fell from the deck slab to lower levels or water?	Falls from Heights
7) Demolish the platform	1) platform instability caused workers to fall during demolition?	Working Platform Instability

Table 5.4 Results of What-If Analysis for identified risks. (Continued)

Work Sequence No./Work Activit	What would happen if	Potential Risk
7) Demolish the platform	2) waves impacted the demolition area?	Wave Impact on Working Area
8) Fender Installation	1) workers were exposed to lightning strikes outdoor?	Lightning Strikes
	2) a worker drowned while working close to the water?	Drowning
9) Pile Cathodic Protection Work	1) divers experienced physical disorders related to underwater conditions?	Diving-Related Physical Disorders
	2) the diving equipment malfunctioned?	Diving Equipment Failure
	3) divers became entangled with underwater obstructions or equipment?	Diving Entanglement
	4) divers encountered marine life hazards?	Marine Life Hazards
	5) poor underwater visibility impeded diving operations?	Poor Underwater Visibility
	6) divers had poor communication with surface support?	Diving Communication Failure
	7) divers faced strong underwater currents?	Underwater Currents Endangering Diver

The What-If technique is a flexible, high-level risk identification method that can be used independently or as part of a step-by-step approach. It is widely applied in construction projects due to its effectiveness in systematically identifying potential hazards. In this study, the What-If technique was employed to analyze risks based on the Work Method Statement of a nine-step sample project at Maptaphut Industrial Port Phase 3. Through this systematic approach, various hazards associated with different construction activities were identified. After applying the What-If technique, the identified risks were further analyzed and filtered, resulting in a final list of 21 risk factors specific to deep seaport construction. These risks include lifting object failure, crane instability, working platform instability, temporary structure instability, slipping on the working floor, falls into steel pipe pile holes, falls from heights, drowning, gas cutting explosions, grinding tool failure, electric shock during welding, wave impact on the working area, lightning strikes, physical disorders from diving, diving equipment failure, diving entanglement, marine life hazards, poor underwater visibility, diving communication failure, underwater currents endangering divers, and vessel instability or collision. This comprehensive identification ensures a targeted risk assessment approach tailored to the unique hazards present in seaport construction.

5.4.2.2 Comparison of 21 Identified Risk Factors with Previous Studies

A comparative analysis of the 21 identified risk factors with existing literature (Table 5.5) confirms that most risks align with common hazards in deep seaport construction. However, certain risks, such as marine construction interference and dynamic seabed conditions, appear to be underrepresented in previous studies. This gap underscores the need for a more targeted risk assessment approach tailored to the unique challenges of seaport construction projects. Addressing these overlooked factors will enhance risk mitigation strategies and improve overall safety management in deep seaport construction.

Table 5.5 Comparison of Identified Risk Factors with Previous Studies.

Item	Safety Risk Identification	Aulady et al., (2018)	Cruickshank, I., & Cork, S. (2005)	Holle et al., (2005)	Mahapatra et al., (2020)	Spouge, J. (1999)
1	Lifting objection failure.	X	X		X	
2	Crane instability.	X	X		X	X
3	Working platform instability.		X			
4	Temporary structure instability.		X			
5	Slip on the working floor.	X				
6	Falls into steel pipe pile hole					
7	Fall from heights.	X				
8	Drowning				X	
9	Gas cutting explode.				X	
10	Grinding broke to worker.				X	
11	Electric shock in welding.				X	
12	Waves impacting the working area.		X			X
13	Lightning strikes.			X		

Table 5.5 Comparison of Identified Risk Factors with Previous Studies. (Continued)

Item	Safety Risk Identification	Aulady et al., (2018)	Cruickshank, I., & Cork, S. (2005)	Holle et al., (2005)	Mahapatra et al., (2020)	Spouge, J. (1999)
14	Physical disorders from diving.					X
15	Diving equipment failure.					X
16	Diving entanglement.					X
17	Marine life hazards.					X
18	Diving poor visibility.					X
19	Diving communication failure.					X
20	Underwater currents endangering Diver.					X
21	Vessel Instability and Collision.		X		X	X

5.4.2.3 Validation via Semi-Structured Questionnaire (IOC Testing)

To validate the risk identification process, a semi-structured questionnaire was developed and tested using the Index of Item-Objective Congruence (IOC) method. Three specialists with over 10 years of experience in seaport construction reviewed the questionnaire to ensure content validity. Items with an IOC score above 0.75 were considered valid for inclusion in the final risk assessment framework. To validate these risk factors, 3 specialists with over 10 years of experience in seaport construction evaluated them using the Index of Item-Objective Congruence (IOC) checklist. The results of this evaluation are presented in Table 5.6, which formed the basis for the semi-structured questionnaire later interviewed to 12 risk assessors for comprehensive risk assessment.

Table 5.6 Questionnaire Item-Objective Congruence (IOC) of Safety Risk Assessment.

Task	Details	Specalist1	Specalist2	Specalist3	Average
Consistency with Objectives	Assess whether each question in the questionnaire aligns with the objectives of the research or risk assessment.	1	1	1	1
Clarity of Content	Check if the content of the questions is clear, easy to understand, and free from ambiguity.	1	1	1	1
Appropriateness of Language	Evaluate whether the language used in the questionnaire is appropriate for the target audience.	1	1	1	1
Content Coverage	Ensure that the questions cover all dimensions of the risks intended to be assessed.	1	1	1	1

5.4.3 Perform Qualitative Risk Analysis

5.4.3.1 Initial Risk Assessment Results

A qualitative risk assessment was conducted by 12 experienced assessors with extensive in supervising seaport construction projects. The assessment utilized expert judgment to evaluate the likelihood and impact of each identified risk factor. Table 5.7 presents the initial risk assessment results, providing a structured evaluation of the critical risks associated with deep seaport construction.

Table 5.7 Initial Risk Assessment.

Risk Fact	Risk Matrix	Rank Assessors 1	2	3	4	5	6	7	8	9	10	11	12	Avr.	SDV.
1	Likelih	4	4	3	3	3	4	4	5	3	4	4	4		
	Impact	5	4	4	5	4	5	5	5	4	5	5	4		
	Risk	20	16	12	15	12	20	20	25	12	20	20	16		4.14
2	Likelih	4	3	4	3	3	4	4	3	3	4	4	5		
	Impact	5	3	4	3	4	5	5	3	5	5	5	5		
	Risk	20	9	16	9	12	20	20	9	15	20	20	25		5.43
3	Likelih	4	3	3	2	2	3	3	3	2	3	3	5		
	Impact	5	3	3	3	4	4	4	3	5	4	4	5		
	Risk	20	9	9	6	8	12	12	9	10	12	12	25		5.36
4	Likelih	4	3	3	2	3	3	3	3	2	3	3	5		
	Impact	5	3	3	4	4	4	4	3	5	4	4	5		
	Risk	20	9	9	8	12	12	12	9	10	12	12	25		5.02
5	Likelih	3	3	3	3	3	4	3	2	4	3	4	3		
	Impact	3	3	3	2	2	3	3	2	2	3	3	3		
	Risk	9	9	9	6	6	12	9	4	8	9	12	9		2.32
6	Likelih	3	4	1	1	2	2	2	2	2	2	4	1		
	Impact	5	5	4	4	3	5	5	5	5	5	5	3		
	Risk	15	20	4	4	6	10	10	10	10	10	20	3		5.73
7	Likelih	3	3	3	3	3	4	3	4	3	3	4	4		
	Impact	4	4	4	3	4	4	4	5	4	4	5	4		
	Risk	12	12	12	9	12	16	12	20	12	12	20	16		3.47
8	Likelih	3	3	3	3	3	3	3	2	3	3	3	2		
	Impact	5	4	3	5	4	5	5	3	4	5	5	2		
	Risk	15	12	9	15	12	15	15	6	12	15	15	4		3.85
9	Likelih	3	2	2	2	2	3	2	4	2	2	2	2		
	Impact	4	4	4	3	4	4	4	3	4	5	5	4		
	Risk	12	8	8	6	8	12	8	12	8	10	10	8		1.99
10	Likelih	3	2	3	2	2	4	2	3	3	3	3	2		
	Impact	3	3	3	3	3	4	4	5	3	3	4	4		
	Risk	9	6	9	6	6	16	8	15	9	9	12	8		3.32
11	Likelih	3	2	3	2	2	3	2	3	3	3	2	3		
	Impact	4	2	3	3	4	4	4	3	3	4	4	4		
	Risk	12	4	9	6	8	12	8	9	9	12	8	12		2.57
12	Likelih	3	3	4	2	3	3	2	3	2	3	4	5		
	Impact	5	3	3	3	4	5	5	3	4	5	5	5		
	Risk	15	9	12	6	12	15	10	9	8	15	20	25		5.41
13	Likelih	3	3	2	2	2	3	3	3	2	3	3	5		
	Impact	5	5	3	5	4	5	5	3	4	5	5	5		
	Risk	15	15	6	10	8	15	15	9	8	15	15	25		5.15
14	Likelih	3	3	2	2	3	3	3	3	2	3	2	5		
	Impact	5	3	4	5	3	5	5	4	5	5	5	5		
	Risk	15	9	8	10	9	15	15	12	10	15	10	25		4.71

Table 5.7 Initial Risk Assessment. (Continued)

Risk Fact	Risk Matrix	Rank Assessors												Avr.	SDV.
		1	2	3	4	5	6	7	8	9	10	11	12		
15	Likelih	3	2	2	2	2	3	2	2	3	2	3	3		
	Impact	5	4	3	5	4	5	5	3	3	5	5	5		
	Risk	15	8	6	10	8	15	10	6	9	10	15	15		3.53
16	Likelih	3	3	2	2	2	3	2	2	2	2	3	3		
	Impact	4	3	2	3	4	4	5	2	4	4	4	4		
	Risk	12	9	4	6	8	12	10	4	8	8	12	12		2.99
17	Likelih	2	3	2	2	2	3	2	2	2	2	3	2		
	Impact	3	3	3	3	3	3	4	3	3	3	4	3		
	Risk	6	9	6	6	6	9	8	6	6	6	12	6		1.95
18	Likelih	3	3	4	2	3	3	3	2	3	2	3	4		
	Impact	3	3	2	5	4	4	4	2	3	4	4	5		
	Risk	9	9	8	10	12	12	12	4	9	8	12	20		3.82
19	Likelih	3	3	2	2	2	3	3	3	3	3	2	5		
	Impact	4	3	3	4	4	4	5	3	3	4	4	4		
	Risk	12	9	6	8	8	12	15	9	9	12	8	20		3.85
20	Likelih	3	3	3	2	2	3	2	2	2	3	3	3		
	Impact	5	3	3	3	4	5	5	3	3	3	5	3		
	Risk	15	9	9	6	8	15	10	6	6	9	15	9		3.44
21	Likelih	3	4	2	2	2	3	2	2	2	2	3	2		
	Impact	5	4	4	5	5	5	5	3	5	5	5	4		
	Risk	15	16	8	10	10	15	10	6	10	10	15	8		3.32

5.4.3.2 Initial Risk Assessment Matrix

Following the evaluation by all 12 assessors, the assessment results were plotted onto a 5×5 risk matrix, with the number of assessors indicated in Figure 5.4. This visualization provides a clear depiction of the distribution of risk levels, enabling a more comprehensive understanding of high-priority risks that require immediate mitigation measures.

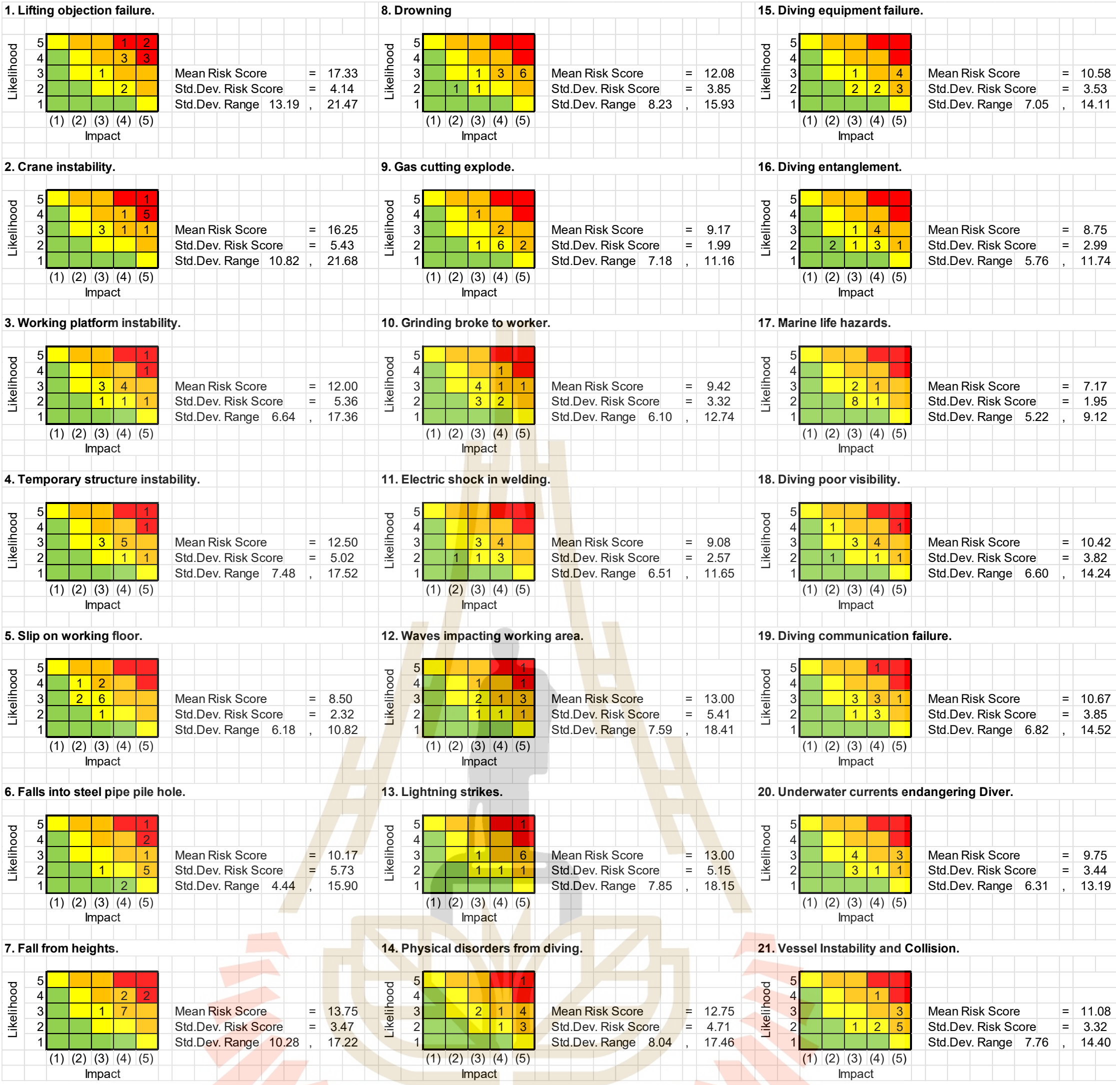


Figure 5.4 Initial Risk Assessment Metrix.

5.4.4 Perform Quantitative Risk Analysis

The quantitative risk assessment was conducted to evaluate the potential impact of each identified risk factor, providing a deeper understanding of their severity and guiding the implementation of appropriate mitigation measures, particularly for high-risk factors. The analysis involved plotting the standard deviation (range between highest and lowest assessments) of each risk factor on a tornado diagram to illustrate the relative significance of each risk. The risk levels were categorized into four groups: low risk (0–4), medium risk (4–9), high risk (9–16), and very high risk (16–25). As shown in Figure 5.5, all identified risks fall within the medium-to-risk categories. Addressing these risks through targeted mitigation strategies will enhance operational safety and efficiency. Specific risk reduction measures will be determined in the next phase of the study.

ID	Risk Factor	Risk Score		
		Lowest	Average	Hieghest
1	Lifting objection failure.	13.19	17.33	21.47
2	Crane instability.	10.82	16.25	21.68
3	Working platform instability.	6.64	12.00	17.36
4	Temporary structure instability.	7.48	12.50	17.52
5	Slip on the working floor.	6.18	8.50	10.82
6	Falls into steel pipe pile hole.	4.44	10.17	15.90
7	Fall from heights.	10.28	13.75	17.22
8	Drowning	8.23	12.08	15.93
9	Gas cutting explode.	7.18	9.17	11.16
10	Grinding broke to worker.	6.10	9.42	12.74
11	Electric shock in welding.	6.51	9.08	11.65
12	Waves impacting the working area.	7.59	13.00	18.41
13	Lightning strikes.	7.85	13.00	18.15
14	Physical disorders from diving.	8.04	12.75	17.46
15	Diving equipment failure.	7.05	10.58	14.11
16	Diving entanglement.	5.76	8.75	11.74
17	Marine life hazards.	5.22	7.17	9.12
18	Diving poor visibility.	6.60	10.42	14.24
19	Diving communication failure.	6.82	10.67	14.52
20	Underwater currents endangering Diver.	6.31	9.75	13.19
21	Vessel Instability and Collision.	7.76	11.08	14.40

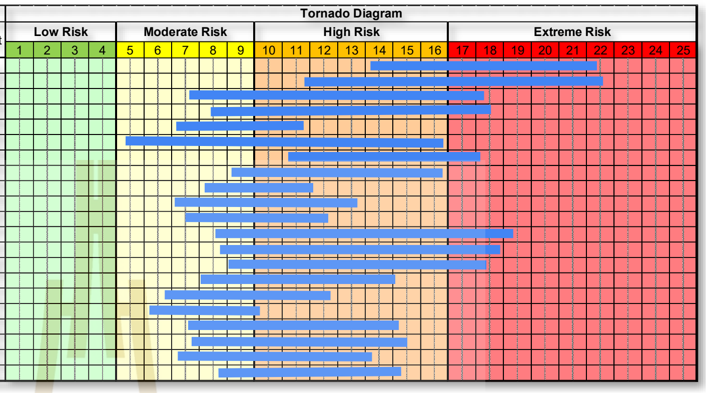


Figure 5.5 Initial Tornado Diagram.

5.4.5 Plan Risk Responses

This phase focuses on mitigating identified risks by developing effective risk response strategies. The Delphi technique was employed, involving 3 specialists who participated in a structured brainstorming session to propose mitigation measures for each identified risk. Each specialist independently suggested three mitigation strategies, which were then compiled into a comprehensive set of recommendations. These recommendations were subsequently reviewed and refined through an iterative process. In the first round, all 3 specialists reached a consensus on the proposed mitigation strategies. The final set of risk response measures, as presented in Table 5.8, will serve as the foundation for risk mitigation in the final stage of the study.

Table 5.8 Final Risk Mitigation Strategies Developed Using the Delphi Technique.

ID	Risk Factor	Risk Reduction Guidelines
1	Lifting objection failure.	1. Planning and Preparation: Develop a lifting plan including load weights, lifting methods, and emergency procedures, ensure the lifting area is stable, free of obstacles, and has safe access paths, and use a permit-to-work system, require multiple approvals for high-risk operations. 2. Equipment and Technology: Install safety systems, use overload warning systems, tilt alarms, and motion limiters, and ensure cranes and lifting devices match the load's weight and dimensions. 3. Workforce Training and Competency: Train all workers involved in lifting operations on safe practices, and daily safety briefings, review specific tasks and risks before operations. 4. Operational and Supervisory Controls: Keep workers away from hazardous zones during lifting and assign experienced supervisors to ensure compliance with procedures.
2	Crane instability.	1. Equipment and Load Management: Ensure loads do not exceed the crane's capacity, check the crane for mechanical issues, worn parts, or hydraulic leaks, and install anemometers to detect high wind conditions and monitor environmental factors like rain. 2. Site Preparation: Conduct geotechnical surveys to ensure the ground can support the crane and load, and place the crane on a level surface, avoiding slopes, trenches, or unstable areas. 3. Operational Controls: Develop a detailed lift plan addressing stability throughout all stages of the operation, and stop operations during unsafe weather conditions, including high winds. 4. Workforce and Administrative Measures: Ensure operators are trained and certified in crane operation and stability control, and require permits for critical lifting operations, involving multiple levels of approval.

Table 5.8 Final Risk Mitigation Strategies Developed Using the Delphi Technique. (Continued)

ID	Risk Factor	Risk Reduction Guidelines
3	Working platform instability.	1. Structural Stability and Strength: Ensure the platform is set on a level and stable surface and use materials that are strong and durable enough for the expected loads. 2. Reinforcement and Maintenance: Use braces, supports, or stabilizers, especially for high-load or high-altitude conditions, and perform maintenance as rust, weakening joints, or damaged planks. 3. Safety Features: Edge Protection, equip platforms with guardrails and toe boards to protect workers from falls, and install anti-slip surfaces to prevent slips and falls. 4. Load Distribution: Evenly distribute loads on the platform to prevent tipping or overloading specific areas. 5. Worker Training: Train workers on the safe use of platforms, load limitations, and the inspection requirements.
4	Temporary structure instability.	1. Design and Material Quality: Conduct a structural analysis to verify compliance with safety standards and codes, use certified and suitable materials designed for the intended purpose, and utilize prefabricated components of proven quality to minimize errors. 2. Construction and Installation: Inspect all materials and components for damage or defects before installation, and install bracing, ties, and anchors to enhance stability against environmental forces. 3. Safety and Training: Train workers on the risks temporary structures and emphasize proper handling and inspection protocols and restrict access to unauthorized personnel near unstable or incomplete structures. 4. Monitoring and Maintenance: Regularly inspect the structure for shifts, cracks, or instability signs, and develop and implement a contingency plan for potential structural failures, including evacuation procedures.

Table 5.8 Final Risk Mitigation Strategies Developed Using the Delphi Technique. (Continued)

ID	Risk Factor	Risk Reduction Guidelines
5	Slip on the working floor.	1. Floor Condition Management: Apply anti-slip coatings or mats in high-risk areas, conduct regular inspections to repair uneven surfaces, cracks, or damage, and ensure proper lighting in work areas for better visibility of floor conditions. 2. Cleaning and Maintenance: Implement a routine cleaning schedule to keep floors free of spills, grease, and debris, and use warning signs or barriers to mark wet or hazardous areas until cleaned or repaired. 3. Pathway and Workflow Optimization: Design pathways and work zones to minimize clutter and reduce trip hazards. 4. Monitoring and Training: Assign supervisors to monitor hazards and enforce corrective actions and train employees on handling spillages and clean-ups effectively.
6	Falls into steel pipe pile hole.	1. Physical Safety Measures: Install guardrails, covers, or barriers around steel pipe pile holes to prevent accidental falls, use temporary safety nets or platforms as additional protective measures for open holes, and place high-visibility warning tape or fencing to clearly demarcate hazardous zones. 2. Worksite Management: Establish safe pathways and designate zones away from open holes for the movement of workers and equipment, restrict access to areas around steel pipe pile holes to authorized personnel only, and assign safety supervisors to monitor activities near steel pipe pile holes and ensure compliance with safety measures. 3. Training and Emergency Preparedness: Develop and practice rescue plans for incidents involving falls into steel pipe pile holes, and ensure emergency equipment (e.g., ladders and first aid kits) is easily accessible at the worksite.

Table 5.8 Final Risk Mitigation Strategies Developed Using the Delphi Technique. (Continued)

ID	Risk Factor	Risk Reduction Guidelines
7	Fall from heights.	1. Engineering Controls: Install guardrails, safety nets, and toe boards on elevated work areas, provide anti-slip surfaces on elevated areas to prevent slips and falls, ensure proper installation and use of scaffolding, ladders, and platforms that meet safety standards, and use personal fall arrest systems (PFAS), including harnesses, lifelines, and anchor points. 2. Worksite Management: Designate restricted access zones under high work areas to prevent injuries from objects falling or debris and monitor weather conditions and pause work during unsafe situations. 3. Training and Awareness: Train workers on the proper use of fall protection systems, safe handling of tools, and work practices, and develop and enforce work-specific safety plans, including safe procedures for tasks performed at height. 4. Emergency Preparedness: Ensure emergency equipment (e.g., ladders and first aid kits) is readily available near high work areas.
8	Drowning.	1. Preparation and Planning: Conduct regular drills to practice emergency response and rescue procedures and develop and implement a site-specific plan to address drowning hazards and rescue procedures. 2. Supervision and Monitoring: Assign trained personnel to monitor activities near water, and regularly check weather, tides, and currents, pausing operations during unsafe conditions. 3. Safety Measures: Personal Protective Equipment (PPE), ensure workers wear life jackets or buoyancy aids when near or above water, and Limit entry to hazardous water zones to authorized personnel only. 4. Training and Awareness: Train workers to recognize drowning hazards and respond effectively to emergencies. 5. Equipment and Tools: Provide lifebuoys, life jackets, and rescue ropes at work sites near water, and equip the site with inflatable boats, throw bags, and other rescue tools for quick response.

Table 5.8 Final Risk Mitigation Strategies Developed Using the Delphi Technique. (Continued)

ID	Risk Factor	Risk Reduction Guidelines
9	Gas cutting explode.	1. Safe Storage and Handling of Gas Cylinders: Store cylinders in a well-ventilated area, away from heat and ignition sources, and Open cylinder valves slowly and use flashback arrests properly. 2. Workplace Safety Measures: Maintain a safe distance between cutting operations and flammable materials or liquids and Restrict access to the cutting area to authorized and trained personnel. 3. Worker Training and Equipment Usage: Train workers in the safe operation of gas cutting equipment and emergency procedures and use proper gas pressure settings as recommended. 4. Fire Prevention and Response: Use fire-resistant barriers or shields to contain sparks and heat and keep class B and C fire extinguishers near the worksite for quick response. 5. Personal Protective Equipment (PPE): Provide fire-resistant clothing, gloves, and eye protection to workers.
10	Grinding broke to worker.	1. Inspection and Maintenance equipment: Inspect grinding wheels for defects before use and use grinding wheels that meet safety standards and allow the wheel to run freely for a few seconds before starting work to check for vibrations or instability. 2. Safe Operating Practices: Ensure grinding wheels operate within specified speed limits (RPM) and maintain a safe distance between workers and the grinding operation area. 3. Workplace Preparation: Keep the grinding area well-lit and free of debris to prevent accidents. 4. Worker Training and Awareness: Train workers on safe grinding practices, including proper handling and operational techniques. 5. Use of Personal Protective Equipment (PPE): Provide and enforce the use of PPE, including safety goggles or face shields, gloves, and hearing protection. 6. Emergency Preparedness: Ensure first aid kits and emergency response equipment are accessible near the worksite.

Table 5.8 Final Risk Mitigation Strategies Developed Using the Delphi Technique. (Continued)

ID	Risk Factor	Risk Reduction Guidelines
11	Electric shock in welding.	1. Inspection and Maintenance: Regularly inspect welding equipment for defects, damaged wires, or insulation issues, and ensure proper grounding of welding machines to prevent electrical faults. 2. Worksite Safety: Avoid welding in damp or wet conditions and keep the welding area dry and free of water or conductive materials. 3. Equipment and Tools: Use insulated tools and equipment to handle live circuits safely and turn off power and unplug equipment before performing maintenance or repairs. 4. Training and Awareness: Train workers on electrical safety, proper welding techniques, and hazard identification, and assign trained personnel to oversee safety and respond to electrical incidents. 5. Access Control and Hazard Demarcation: Mark high-risk areas and restrict access to authorized personnel only.
12	Waves impacting the working area.	1. Planning and Scheduling: Schedule work during low tide or calm weather conditions and monitor weather forecasts and tide schedules to ensure safe operations. 2. Site Assessment and Protection: Conduct site assessments to avoid high-risk areas exposed to waves, and install wave barriers, such as breakwaters, to reduce the impact of waves. 3. Infrastructure and Equipment: Elevate working platforms above potential wave impact zones and use anchors and moorings to stabilize floating or movable structures. 4. Worker Safety: Train workers identify wave hazards and respond effectively during emergencies and restrict access to wave-prone areas to trained personnel only. 5. Emergency Preparedness: Equip the site with life-saving equipment such as lifebuoys, ropes, and inflatable boats.

Table 5.8 Final Risk Mitigation Strategies Developed Using the Delphi Technique. (Continued)

ID	Risk Factor	Risk Reduction Guidelines
13	Lightning strikes.	1. Weather Monitoring and Scheduling: Continuously monitor weather forecasts for lightning activity, and suspend outdoor work when thunderstorms are predicted or present. 2. Lightning Protection Systems: Install lightning rods and grounding systems on structures and equipment, and ground cranes, tall machinery, and other elevated structures effectively. 3. Safe Work Practices: Prohibit the use of metal tools or equipment during storms and restrict access to exposed or high-risk areas when lightning is likely. 4. Emergency Shelters: Designate safe, enclosed shelters for workers to use during storms. 5. Training and Preparedness: Train workers to identify storm hazards and follow safety protocols and equip the site with first aid kits and train workers in lightning strike response.
14	Physical disorders from diving.	1. Dive Planning and Safety Measures: Allow sufficient surface intervals between dives to minimize nitrogen build-up and limit dive durations. 2. Training and Certification: Ensure divers are certified and adequately trained in diving techniques, equipment use, and emergency procedures, and provide additional training on recognizing and responding to symptoms of decompression sickness and barotrauma. 3. Equipment Maintenance and Checks: Regularly inspect and maintain diving equipment to ensure proper functionality and safety and perform pre-dive equipment checks to confirm readiness and reliability. 4. Medical Readiness: Conduct regular medical examinations to ensure divers are physically fit for diving activities. 5. Buddy System: Implement a buddy system for constant monitoring and assistance during dives and ensure clear underwater communication. 6. Emergency Readiness: Have emergency oxygen kits and first aid equipment readily available.

Table 5.8 Final Risk Mitigation Strategies Developed Using the Delphi Technique. (Continued)

ID	Risk Factor	Risk Reduction Guidelines
15	Diving equipment failure.	1. Regular Equipment Maintenance and Inspections: Ensure divers carry backup equipment, such as an alternate air source and spare dive masks, to address emergencies, inspect all diving gear before each dive to identify wear, corrosion, or malfunctions, maintain detailed records of equipment servicing, maintenance schedules, and inspections to ensure timely upkeep, and store diving equipment in a dry, cool, and clean environment to prevent damage from moisture, heat, or contaminants. 2. Pre-Dive Checks: Conduct thorough pre-dive checks, including: Verifying air pressure levels and testing the proper functioning of regulators. 3. Training and Education: Train divers thoroughly in the proper use, assembly, disassembly, and troubleshooting of diving equipment, provide training on emergency response procedures for equipment failure incidents, and train dive teams in effective communication using hand signals or underwater communication devices. 4. Emergency Preparedness: Prepare divers and surface support personnel to handle emergencies effectively.
16	Diving entanglement.	1. Pre-Dive Measures: Conduct site surveys to identify and avoid areas with entanglement hazards (e.g., nets, ropes, and debris), and plan dives strategically, steering clear of risky or complex underwater environments. 2. Diver Preparedness: Train divers to recognize entanglement risks and handle incidents calmly using safe techniques and equip divers with essential cutting tools like dive knives, shears, or line cutters. 3. Safe Practices During Dives: Use the buddy system for monitoring and immediate assistance, and minimize loose or dangling equipment (e.g., hoses or straps) to avoid snags. 4. Post-Dive and Ongoing Safety Protocols: Regularly inspect and clean dive sites to remove entanglement hazards where feasible and ensure surface support teams are trained to respond promptly to divers' distress signals.

Table 5.8 Final Risk Mitigation Strategies Developed Using the Delphi Technique. (Continued)

ID	Risk Factor	Risk Reduction Guidelines
17	Marine life hazards.	1. Pre-Dive Safety: Conduct site surveys to identify and avoid areas with potentially dangerous marine life, and schedule dives during times of low marine life activity. 2. Diver Protection: Equip divers with protective gear (wetsuits, gloves, and hoods) to minimize risks of bites or stings, and use repellents or deterrents for specific hazards, such as jellyfish, when necessary. 3. Training: Train divers on recognizing and avoiding hazardous marine species and provide instruction on maintaining a safe distance from marine animals, particularly aggressive or territorial species. 4. Emergency Preparedness: Stock first aid kits with marine-specific treatments, such as vinegar for stings, and train divers in first aid response for injuries caused by marine life, including venomous bites or stings. 5. Site Monitoring: Regularly monitor dive sites for changes in marine life behavior or conditions that may elevate risks.
18	Diving poor visibility.	1. Pre-Dive Preparation: Monitor weather, tides, and water conditions to avoid high turbidity or rough seas, and schedule dives during optimal natural light conditions for better visibility. 2. Training and Navigation: Train divers in low-visibility navigation using rope-guided techniques and buddy line systems and emphasize maintaining close proximity within buddy pairs during dives. 3. Equipment: Use high-intensity underwater dive lights and have backup lights for emergencies, utilize surface markers and buoys for clear identification of entry and exit points. 4. Support Systems: Ensure a strong buddy system with divers staying physically connected or within arm's reach and have surface support teams ready to assist disoriented divers promptly. 5. Site Improvements: Install fixed guidelines or ropes at frequently used dive sites for navigation aid.

Table 5.8 Final Risk Mitigation Strategies Developed Using the Delphi Technique. (Continued)

ID	Risk Factor	Risk Reduction Guidelines
19	Diving communication failure.	1. Pre-Dive Preparation: Develop and practice hand signals or communication methods and conduct pre-dive meetings to ensure understanding of communication plans and emergency procedures. 2. Equipment Use and Maintenance: Equip divers with underwater communication tools, regularly inspect and maintain communication devices for functionality, and carry auditory signaling devices for surface communication. 3. Training and Techniques: Train divers to effectively use standard hand signals and backup methods (e.g., writing on slates, using light signals). 4. Team Coordination: Maintain a strong buddy system for reliable one-on-one communication. 5. Emergency Preparedness: Ensure surface teams are trained to recognize emergency signals like marker buoys or emergency lights.
20	Underwater currents endangering Diver.	1. Pre-Dive Planning: Monitor weather and tidal conditions before and during dives, schedule dives during slack tides or when currents are minimal and use dive site maps to identify and avoid areas with strong currents. 2. Diver Training: Train divers on managing currents, such as streamlining and using natural shelter, and educate divers on distress signaling procedures in current-related emergencies. 3. Equipment and Support: Provide divers with underwater propulsion devices or dive reels, ensure effective communication between divers and surface support using visual or auditory signals, and position surface support teams for quick retrieval in case divers are swept away. 4. Buddy System: Implement a buddy system for monitoring and assistance during dives.

Table 5.8 Final Risk Mitigation Strategies Developed Using the Delphi Technique. (Continued)

ID	Risk Factor	Risk Reduction Guidelines
21	Vessel Instability and Collision.	1. Operational Planning: Avoid operations in severe weather, high winds, or rough seas, adhere strictly to the vessel's load capacity to prevent capsizing, and use radar, GPS, and collision-avoidance systems to monitor surroundings effectively. 2. Communication and Coordination: Maintain regular communication with other vessels and port authorities using radios or signals. 3. Vessel Stability: Adjust ballast tanks to maintain stability in varying conditions and secure the vessel properly when stationary to prevent drifting or instability. 4. Equipment and Gear: Ensure all navigation and communication systems are functioning properly and equip the vessel with essential life-saving gear, including life jackets, rafts, and emergency beacons. 5. Crew Training and Preparedness: Train the crew on collision response and vessel stability recovery procedures.

5.4.6 Control Risk

Following the integration of the recommended risk mitigation measures, a reassessment was conducted to evaluate their effectiveness. All 12 assessors participated in a second round of evaluations, and the results were analyzed using both qualitative and quantitative risk assessment methods. The reassessment findings are presented in Table 5.9.

Table 5.9 Final Risk Assessment.

Risk Factor	Risk Matrix	Rank Assessors												Average	SDV.
		1	2	3	4	5	6	7	8	9	10	11	12		
1	Likelihood	3	1	2	2	1	1	1	1	1	2	2	1		
	Impact	3	2	3	3	2	3	2	2	2	4	3	1		
	Risk Score	9	2	6	6	2	3	2	2	2	8	6	1	4.08	2.75
2	Likelihood	3	1	2	2	1	1	1	1	1	2	2	2		
	Impact	3	2	3	3	2	4	2	2	2	3	3	2		
	Risk Score	9	2	6	6	2	4	2	2	2	6	6	4	4.25	2.34
3	Likelihood	2	1	1	2	1	2	1	1	1	2	2	1		
	Impact	3	2	3	3	1	2	2	2	2	3	3	1		
	Risk Score	6	2	3	6	1	4	2	2	2	6	6	1	3.42	2.07
4	Likelihood	3	1	1	2	1	3	1	1	1	2	2	1		
	Impact	3	2	2	3	1	2	2	2	2	3	3	1		
	Risk Score	9	2	2	6	1	6	2	2	2	6	6	1	3.75	2.67
5	Likelihood	1	1	1	1	1	2	1	1	1	1	1	1		
	Impact	2	1	1	2	1	2	1	1	1	2	1	1		
	Risk Score	2	1	1	2	1	4	1	1	1	2	1	1	1.50	0.90
6	Likelihood	1	1	2	1	1	1	1	1	1	1	2	1		
	Impact	3	2	3	3	1	3	2	2	2	3	2	1		
	Risk Score	3	2	6	3	1	3	2	2	2	3	4	1	2.67	1.37
7	Likelihood	1	1	1	1	1	2	1	1	1	1	2	1		
	Impact	3	2	3	3	1	3	2	2	2	3	3	1		
	Risk Score	3	2	3	3	1	6	2	2	2	3	6	1	2.83	1.64
8	Likelihood	1	1	2	2	1	1	1	1	1	1	2	1		
	Impact	2	2	3	3	1	3	3	3	2	2	3	2		
	Risk Score	2	2	6	6	1	3	3	3	2	2	6	2	3.17	1.80
9	Likelihood	1	1	2	1	1	1	1	1	1	1	2	1		
	Impact	2	1	3	2	2	3	2	2	2	2	3	1		
	Risk Score	2	1	6	2	2	3	2	2	2	2	6	1	2.58	1.68
10	Likelihood	1	1	2	1	1	2	1	1	1	1	2	1		
	Impact	1	1	3	2	1	3	2	1	2	1	2	1		
	Risk Score	1	1	6	2	1	6	2	1	2	1	4	1	2.33	1.92
11	Likelihood	1	1	2	1	1	1	1	1	1	1	1	1		
	Impact	2	1	3	2	1	3	1	1	2	2	2	1		
	Risk Score	2	1	6	2	1	3	1	1	2	2	2	1	2.00	1.41
12	Likelihood	3	1	2	2	1	1	1	1	2	3	2	1		
	Impact	2	2	3	3	3	3	3	3	3	3	3	2		
	Risk Score	6	2	6	6	3	3	3	3	6	9	6	2	4.58	2.19
13	Likelihood	1	1	1	1	1	1	1	1	1	1	1	1		
	Impact	1	1	3	1	3	3	1	1	1	1	1	1		
	Risk Score	1	1	3	1	3	3	1	1	1	1	1	1	1.50	0.90
14	Likelihood	1	1	2	2	1	2	2	2	1	1	2	1		
	Impact	3	2	2	3	2	3	2	2	2	3	3	1		
	Risk Score	3	2	4	6	2	6	4	4	2	3	6	1	3.58	1.73

Table 5.9 Final Risk Assessment. (Continued)

Risk Factor	Risk Matrix	Rank Assessors												Average	SDV.
		1	2	3	4	5	6	7	8	9	10	11	12		
15	Likelihood	1	2	2	2	1	1	2	1	1	1	2	1		
	Impact	3	1	3	3	2	3	3	2	2	3	3	2		
	Risk Score	3	2	6	6	2	3	6	2	2	3	6	2	3.58	1.83
16	Likelihood	1	1	3	2	1	1	1	1	1	1	1	1		
	Impact	1	1	3	3	1	3	1	1	2	1	2	2		
	Risk Score	1	1	9	6	1	3	1	1	2	1	2	2	2.50	2.50
17	Likelihood	1	1	2	1	1	2	1	1	1	1	1	1		
	Impact	1	1	2	1	1	2	1	1	1	1	1	1		
	Risk Score	1	1	4	1	1	4	1	1	1	1	1	1	1.50	1.17
18	Likelihood	1	1	2	1	1	2	1	1	1	1	1	1		
	Impact	1	1	2	2	1	3	2	1	1	1	2	1		
	Risk Score	1	1	4	2	1	6	2	1	1	1	2	1	1.92	1.56
19	Likelihood	1	1	2	2	1	2	2	2	1	1	1	1		
	Impact	1	2	2	3	1	3	2	2	2	1	3	1		
	Risk Score	1	2	4	6	1	6	4	4	2	1	3	1	2.92	1.88
20	Likelihood	1	2	2	2	1	2	2	2	1	1	2	1		
	Impact	1	2	2	3	2	3	2	2	2	1	3	1		
	Risk Score	1	4	4	6	2	6	4	4	2	1	6	1	3.42	1.98
21	Likelihood	1	1	2	2	1	2	2	2	1	1	2	1		
	Impact	3	2	3	3	3	3	3	3	3	3	3	2		
	Risk Score	3	2	6	6	3	6	6	6	3	3	6	2	4.33	1.78

To further illustrate the distribution of risk levels, the number of assessors assigning each risk level was mapped onto a 5×5 risk matrix, as shown in Figure 5.6.

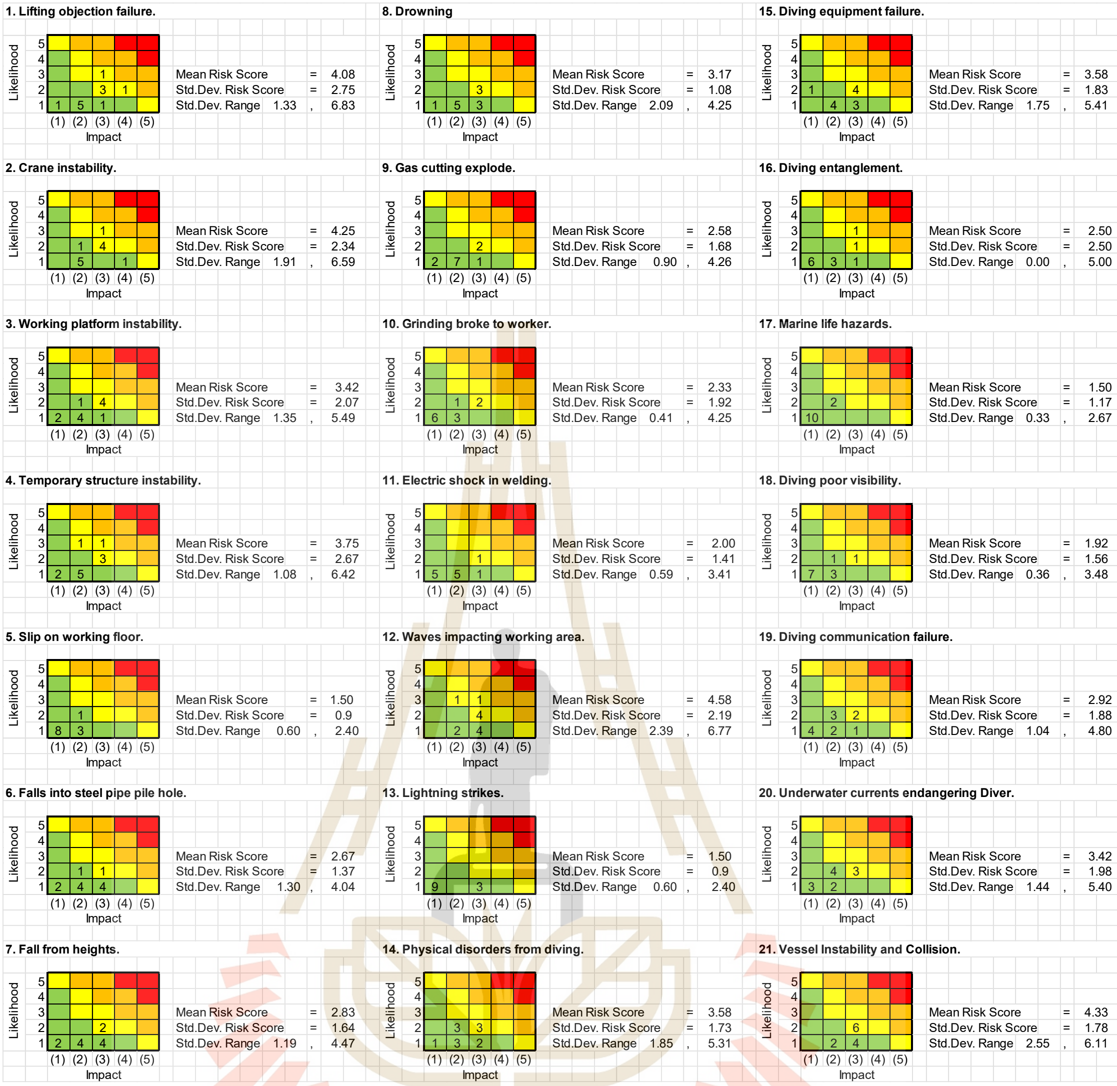


Figure 5.6 Final Risk Assessment Metrix.

Additionally, to highlight the impact of the mitigation strategies, a tornado diagram (Figure 5.7) was generated to compare the standard deviations of risk levels before and after implementing control measures. The analysis indicates a significant reduction in risk severity, with most risk factors being mitigated to an acceptable level, demonstrating the effectiveness of the applied risk control measures.

Item		Risk Score		
		Lowest	Average	Hieghest
1	Lifting objection failure.	1.33	4.08	6.83
2	Crane instability.	1.91	4.25	6.59
3	Working platform instability.	1.35	3.42	5.49
4	Temporary structure instability.	1.08	3.75	6.42
5	Slip on working floor.	0.60	1.50	2.40
6	Falls into steel pipe pile hole.	1.30	2.67	4.04
7	Fall from heights.	1.19	2.83	4.47
8	Drowning	1.08	3.17	4.25
9	Gas cutting explode.	0.90	2.58	4.26
10	Grinding broke to worker.	0.41	2.33	4.25
11	Electric shock in welding.	0.59	2.00	3.41
12	Waves impacting working area.	2.39	4.58	6.77
13	Lightning strikes.	0.60	1.50	2.40
14	Physical disorders from diving.	1.85	3.58	5.31
15	Diving equipment failure.	1.75	3.58	5.41
16	Diving entanglement.	0.00	2.50	5.00
17	Marine life hazards.	0.33	1.50	2.67
18	Diving poor visibility.	0.36	1.92	3.48
19	Diving communication failure.	1.04	2.92	4.80
20	Underwater currents endangering Diver.	1.44	3.42	5.40
21	Vessel Instability and Collision.	2.55	4.33	6.11

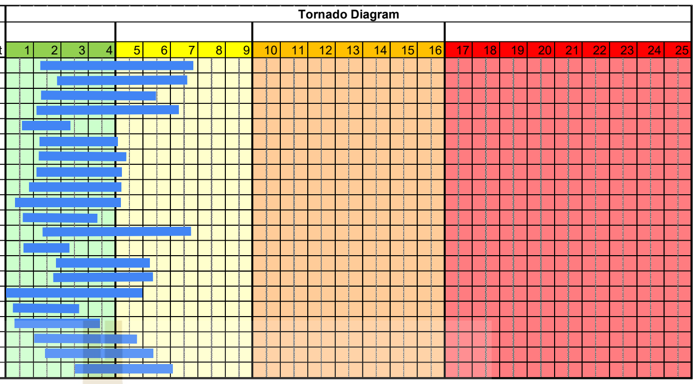


Figure 5.7 Final Tornado Diagram.

5.5 Discussion

This study successfully developed a structured risk management framework for deep-seaport construction by integrating qualitative and quantitative risk assessments. Through a systematic What-If analysis and specialist evaluations using the Delphi technique, 21 critical risk factors were identified, with crane and platform instability, falls and drowning, electrical and fire hazards, diving-related risks, and marine traffic and weather-related risks emerging as the most significant. Among these, lifting object failure was identified as the highest-risk factor. The structured risk assessment approach ensured that mitigation measures were strategically developed and prioritized to enhance safety management in seaport construction.

A key strength of this research is its incorporation of quantitative risk analysis, which enhances the objectivity and reliability of risk evaluation. By analyzing the risk scores assigned by 12 assessors, this study quantified variations in risk perception using statistical measures such as mean and standard deviation. The initial risk assessment showed a standard deviation ranging from a minimum of 1.75 to a maximum of 5.73 on a full risk score scale of 25. This variation suggests significant differences in assesor judgments regarding certain risk factors, reinforcing the need for structured assessment methodologies. To illustrate these variations, a tornado diagram was employed, highlighting the most critical and uncertain risks. After implementing mitigation measures, a re-assessment revealed a notable reduction in variability, with standard deviation values decreasing to a range of 0.9 to 2.25. This decline in risk score dispersion demonstrates that the proposed mitigation strategies effectively reduced uncertainty and stabilized risk perceptions among assessors.

The findings align with prior research on construction risk management (e.g., Cruickshank & Cork, 2005), reaffirming that structural instability, heavy equipment hazards, and environmental conditions are major concerns. However, this study makes a novel contribution by emphasizing underrepresented risks such as drowning and diving-related hazards, which have been largely overlooked in previous research. The integration of qualitative and quantitative risk assessments offers a robust framework for risk prioritization and decision-making in deep-seaport construction.

Despite its contributions, the study has certain limitations. As it focuses on a single case study at Maptaphut Industrial Port Phase 3, generalizability may be limited. Additionally, while expert judgment is valuable, subjective biases may still influence risk evaluations. Future research should expand the dataset by incorporating multiple seaport projects to validate the findings. Moreover, the adoption of advanced probabilistic modeling and real-time risk monitoring systems using Artificial Intelligence (AI) and the Internet of Things (IoT) could enhance predictive capabilities and dynamic risk management. Comparative studies across different regions and project scales will further refine risk mitigation strategies, ultimately contributing to safer and more resilient seaport infrastructure development.

5.6 Conclusion

This research successfully developed a systematic approach for managing safety risks in seaport construction, achieving its primary objective of risk reduction through a structured framework. By following PMI's risk management processes, the study systematically identified, assessed, and mitigated risks specific to seaport construction projects. The qualitative analysis provided a clear understanding of risk levels and their variations, while the Delphi technique facilitated expert consensus on risk mitigation strategies. The final risk assessment confirmed that all risks were reduced to an acceptable level, demonstrating the effectiveness of the proposed recommendations.

This study also emphasizes the importance of addressing unique risks in seaport construction and highlights the need for a standardized repository for risk reporting and assessment across marine infrastructure projects. The findings contribute to the development of a model risk management framework, applicable to other seaport construction projects and related high-risk construction environments.

Furthermore, the study developed a comprehensive risk management framework by integrating qualitative and quantitative risk assessments, successfully identifying 21 critical safety risks. By applying What-If analysis, the Delphi technique, and statistical evaluations, the study identified key hazards, including crane and platform instability, falls and drowning, equipment and tool hazards, weather conditions, and diving-related risks. The results highlight the necessity of marine-specific risk assessment, an area often underrepresented in conventional construction safety research.

The study's practical contributions include an evidence-based risk prioritization model and mitigation strategies, offering valuable guidance for construction managers, engineers, and policymakers in enhancing safety protocols. Integrating structured risk analysis methods into seaport construction risk management improves decision-making processes and fosters a safer working environment.

Despite its contributions, the study has certain limitations. It is based on a single case study (Maptaphut Industrial Port Phase 3), which may limit its generalizability. Additionally, local assessor perceptions may vary across different regions, potentially influencing risk evaluations. Although the proposed risk assessment model provides a structured and adaptable approach, further validation across multiple projects is recommended.

Future research should explore the application of real-time risk monitoring technologies, such as AI and IoT, to enhance dynamic risk assessment in seaport construction. Additionally, conducting comparative studies across different seaport projects and geographical locations would improve risk prediction accuracy and strengthen the applicability of the proposed framework.

By addressing these research gaps, future studies can contribute to the development of more resilient and sustainable safety management practices in seaport construction, ultimately enhancing risk mitigation strategies in marine infrastructure projects.

CHAPTER VI
CONCLUSION AND RECOMMENDATION

6.1 Conclusion

This thesis conducted a comprehensive safety risk analysis in marine infrastructure construction, focusing on two critical domains: dredging and reclamation work and deep seaport construction. Through the application of the Project Management Institute (PMI) risk management framework, this study systematically identified, assessed, and proposed mitigation strategies for the high-risk environments typical of these marine construction activities.

6.1.1 Safety Risk in Dredging and Reclamation Work

Aligned with PMI guidelines, the study began by establishing a structured risk management process encompassing risk planning, identification, and analysis. 22 sub-risk factors across seven primary risk categories were identified through qualitative assessments and validated through expert interviews and case analysis. These included hazards such as machinery-related injuries, underwater excavation risks, and exposure to unstable reclaimed ground.

The analysis found that many of the identified risks in dredging and reclamation operations fell within high to very high severity levels. Accordingly, targeted response strategies were developed and reviewed by domain specialists. A final risk assessment showed that all previously high-risk factors were successfully reduced to acceptable levels. This finding underscores the critical role of proactive planning, expert consultation, and adherence to safety standards in mitigating occupational hazards in these high-risk work environments.

The study offers a replicable model for construction firms and safety practitioners working in similar conditions, providing clear, actionable steps for minimizing occupational hazards and ensuring compliance with safety regulations.

6.1.2 Safety Risk in Deep Seaport Construction

Seaport construction presents unique challenges due to its offshore location and exposure to dynamic marine environments. This research developed a robust risk management model by integrating both qualitative and quantitative assessment methods to address 21 critical safety risks. These included falling from height, equipment instability, weather disruptions, and diving-related hazards.

Using the Delphi technique and What-If analysis, the study formulated a practical, expert-validated risk mitigation framework. The final stage of the risk reassessment confirmed that all identified safety risks were brought down to acceptable levels. This outcome demonstrates the efficacy of applying structured and strategic safety management in seaport construction projects.

In addition to its methodological contributions, the study introduced a standardized structure for safety risk documentation and analysis that can be scaled and adapted across various marine infrastructure contexts. While the findings are based on a single case study (Map Ta Phut Industrial Port Phase 3), the methodology's adaptability provides a foundation for broader application.

6.2 Recommendations

Based on the findings, the following recommendations are proposed to improve safety risk management in marine infrastructure construction:

1) Establish a Centralized Safety Risk Database: Develop a digital repository to document historical risk cases, mitigation outcomes, and lessons learned from marine construction projects. This centralized database can enhance decision-making and support predictive risk assessments.

2) Adopt Real-Time Monitoring Technologies: Integrate Artificial Intelligence (AI), Internet of Things (IoT), and wearable devices into seaport construction projects to enable real-time risk monitoring and dynamic safety alerts.

3) Enhance Stakeholder Training and Safety Culture: Regular training sessions should be provided for all personnel involved in dredging and port construction. Promoting a strong safety culture across all levels of the workforce will contribute to lower incident rates and greater awareness.

4) Standardized Safety Risk Frameworks Across Projects: Encourage the use of a unified safety risk assessment framework for all marine construction projects. This standardization will improve consistency, comparability, and benchmarking of risk performance across different sites.

5) Conduct Comparative and Longitudinal Studies: Future research should investigate multiple case studies across varying geographical regions and project types to validate and refine the proposed risk assessment models. Long-term monitoring could also uncover trends and new emerging hazards over time.

6) Involve Multidisciplinary Teams in Risk Planning: Engage not only engineers and safety officers but also environmental scientists, behavioral specialists,

and emergency response experts in the early stages of project planning to develop holistic safety strategies.

6.3 Final Remarks

This thesis contributes significantly to the limited body of literature on occupational safety in marine infrastructure construction. By addressing the high-risk nature of dredging, reclamation, and seaport development works, it offers a solid foundation for future safety enhancements in the field. The proposed frameworks and practical insights are expected to guide policymakers, engineers, and construction managers toward safer and more sustainable marine infrastructure development.

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APPENDIX A
PULICATIONS

List of Publication

Chantemduang A., Horpibulsuk S., and Limsawasd Ch., (2024). **Safety risk management for construction workers in dredging and reclamation work of industrial port development projects**. Journal of Infrastructure, Policy and Development, 8(10). https://doi.org/10.24294/jipd.v8i10.6205

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Article

Safety risk management for construction workers in dredging and reclamation work of industrial port development projects

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Abstract: Dredging and reclamation operations are pivotal aspects of coastal engineering and land development. Within these tasks lie potential hazards for personnel operating dredging machinery and working within reclamation zones. Due to the specialized nature of the work environment, which deviates from conventional workplace settings, the risk of workplace accidents is significantly heightened. The aim of this study is to conduct a comprehensive risk analysis of the safety aspects related to dredging and reclamation activities, with the goal of enhancing safety and minimizing the frequency and severity of potential dangers. This research comprises a thorough risk analysis, integrating meticulous hazard identification from sample projects and literature reviews. It involves risk assessment by gathering insights from experts with direct working experience and aims to assess potential risks. The study focuses on defining effective risk management strategies, exemplified through a case study of a nearshore construction project in Thailand. The study identified numerous high and very high-risk factors in the assessment and analysis of occupational safety in dredging and reclamation work. Consequently, a targeted response was implemented to control and mitigate these risks to an acceptable level. The outcome of this study will provide a significant contribution to the advancement of guidelines and best practices for improving the safety of dredging and reclamation operations.

Keywords: dredging and reclamation work; construction hazard; safety risk assessment; safety risk control; safety risk management

1. Introduction

1.1. Safety risks and project implications

The construction industry, in general, is fraught with numerous safety risks due to the complex and ever-changing nature of construction sites. According to Rory (2003), these risks are exacerbated by a lack of information, which increases the potential for harm. These risks pose significant threats not only to the health and well-being of workers but also to the overall success and efficiency of construction projects. Safety hazards can range from falls injuries caused by machinery and improper use of equipment, each of which has the potential to cause serious injury or death. The existence of these risks necessitates strict safety measures and regulations to mitigate potential dangers.

The impact of safety risks extends beyond injury or loss of life to workers. Accidents and incidents at construction sites can cause project delays, increased costs, and legal liabilities. When safety procedures are violated, projects may face work stoppages imposed by regulatory agencies, disrupting timelines and inflating budgets. Financial ramifications also include higher insurance premiums and potential compensation claims, which can strain project resources. In addition to direct costs, safety incidents can damage a construction company's reputation, affecting confidence in its ability to perform. A company's perceived commitment to safety is increasingly becoming a key factor in project owners' contractor selection decision-making processes. Therefore, prioritizing safety is not only a financial obligation but also a strategic imperative. It is essential for maintaining competitive advantage, operational continuity, and fulfilling moral and legal responsibilities.

Addressing construction safety risks is critical to protecting workers from injury or loss of life and ensuring successful project implementation. The interplay between safety and project efficiency emphasizes the need for serious and systematic risk management. By prioritizing safety and implementing comprehensive risk management strategies, construction companies cannot only protect their employees but also achieve sustainable project success and long-term viability in the construction industry.

1.2. Safety risk in dredging and reclamation

Dredging and reclamation works are important for the development of port construction projects in maritime transportation (Marsha, 2005). Maritime activities enable the global transfer of commodities, fostering efficient and cost-effective transportation with reliability and environmental benefits (Fratila et al., 2021) asking it a significant contributor to economic growth and development (Jouili, 2016). Dredging and reclamation operations involve extracting sediments from aquatic environments to create land, protect coastal structures, and enhance infrastructure (Nicky and Marsha, 2010). The prominent project examples are the Hong Kong International Airport, the Jurong and Tuas Expansions in Singapore, and Dubai's Palm and World Islands (Rene, 2012). Dredging and reclamation operations necessitate safety attention regarding the exposure of personnel to hazards. These hazards encompass the operations of heavy machinery, potential structural failures, risks associated with underwater conditions, and exposure to hazardous substances (HSE, 2021). Due to the significance and severity of accidents, injuries, and possible loss of human lives. It is imperative to undertake a thorough risk assessment in order to identify, evaluate, and mitigate the potential safety hazards involved. Through a comprehensive investigation of the potential hazards and the use of efficient risk management tactics, project stakeholders possess the ability to actively augment safety measures and alleviate unfavorable outcomes. The Health and Safety Executive (HSE) is the authoritative body responsible for overseeing workplace health and safety in the United Kingdom. Its technical documents have provided data on various types of accidents and the severity of injuries from 2012 to 2021 in the context of dredging and reclamation work. They identified possible accidents such as contact with moving machinery, struck by moving objects, strike against something fixed or stationary, injuries while handling, slips or falls on the same level, and falls from a height. Understanding these common types of accidents is crucial for instituting effective risk mitigation strategies.

Several studies have examined factors related to safety risks in dredging and reclamation operations. In dredging, Daniel (2011) delved into safety management for dredging work in a Nigerian port, providing insights into risk factors in sea dredging. Bugg et al. (2018) assessed the efficacy of RFID tag technology in monitoring personnel safety on dredgers, aiming to enhance safety and diminish fatalities. Rizki (2018) analyzed safety risks in river dredging in Surabaya, Indonesia, with a focus on reducing boat accidents. In reclamation work, Ma et al. (2020) presented safety management guidelines for engineering artificial islands, while Sevryugina and Apatenko (2020) developed a risk assessment model for vehicles used. Zhen et al. (2021) studied risk factors in sea reclamation, emphasizing risk reduction. Within the marine work, Cruickshank and Cork (2005) provided safety guidelines for coastal and marine construction. Valyani et al. (2019) identified key risks in marine construction projects, Mahapatra and Kushwaha (2020) studied hazards in port construction with preventive measures. In general construction, Holle et al. (2005) proposed safety and lightning education guidelines, and Gunduz and Laitinen (2018) suggested risk assessment methods, providing practical strategies for a safer workplace, especially suitable for SMEs construction businesses.

Notably, these existing studies offer valuable guidance for dredging and land reclamation work. However, there remains a dearth of research that specifically focuses on conducting risk analyses for safety in dredging and land reclamation activities within construction projects. This research aims to address these gaps by conducting a comprehensive risk analysis, focusing specifically on safety in dredging and land reclamation activities in construction. The outcome from this study will support the guideline development to improve safety in this specialized field and contribute to the existing body of knowledge in construction safety.

The objective of this study was to conduct a comprehensive analysis of safety risks associated with dredging and reclamation activities, with the goal of increasing safety and reducing the frequency and severity of potential hazards. Understanding the importance of managing safety risks in dredging and reclamation work offers significant benefits. Construction companies involved in these activities can protect their employees and achieve sustainable project success by focusing on safety.

The next section, which is the current risk management, details the research methodology. This includes a comprehensive risk analysis that integrates meticulous hazard identification from sample projects and literature reviews. The methodology involves gathering insights from experts with direct work experience to evaluate potential risks through a risk assessment process.

2. Dredging and reclamation safety risk management

This study employed the risk management technique outlined by the Project Management Institute (PMI, 2013). It is a systematic approach widely adopted in project management. This approach is not only reliable but also internationally recognized in project risk management. Highlighting the framework's capacity to improve security, ensure project success, and foster ongoing enhancements in risk management practices. Accordingly, the research methodology was constructed (see

Figure 1) demonstrating the input, process, and output in each analysis process.

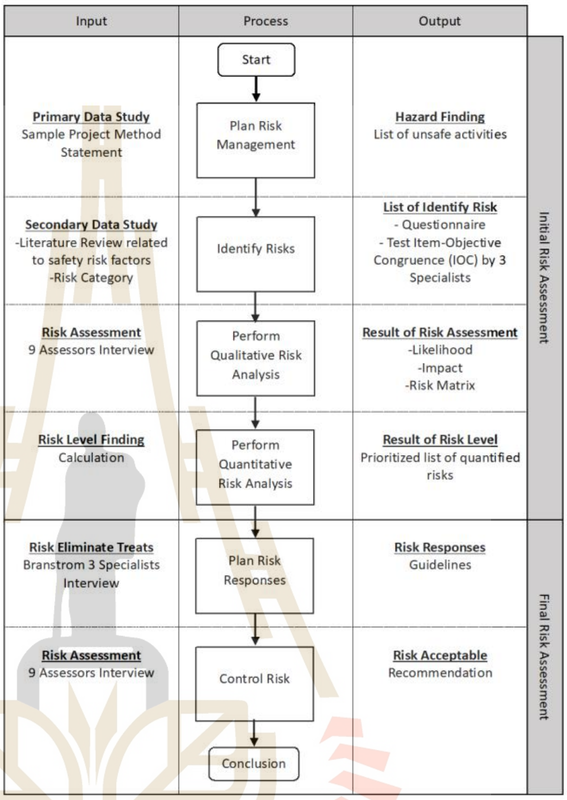

Figure 1. Research methodology.

In this research, two groups of people will assist in completing the study: a group of specialists and a group of assessors performing risk assessments.

(1) Specialist Group:

- Number of Participants: 3
- Experience: More than 10 years of direct experience working in dredging and reclamation.
- Role: This group will help check the risk assessment checklist in the "Identify Risks" step and provide opinions on responses to risks in the "Plan Risk Responses" step. This information is shown in **Table 1**.

Table 1. Specialist group demographic information.

Position	**Frequency**	**% of Total**
Senior Manager	1	33.33
Senior Engineer	1	33.33
Project Manager	1	33.33
Discipline	Frequency	% of Total
Civil Engineering	3	100
Total Work Experience	Frequency	% of Total
35 or more	1	33.33
30–35	1	33.33
25–29	1	33.33
Dredging and Reclamation Work Experience	Frequency	% of Total
25 or more	1	33.33
20–24	1	33.33
15–19	1	33.33
Education level	Frequency	% of Total
Postgraduate	2	66.67
Undergraduate	1	33.33

Table 2. Risk assessor group demographic information.

Position	**Frequency**	**% of Total**
Manager	4	44.44
Project Engineer	3	33.33
Inspector	2	22.22
Discipline	Frequency	% of Total
Civil Engineering	7	77.78
occupational health and safety	2	22.22
Total Work Experience	Frequency	% of Total
30 or more	3	33.33
20–29	4	44.44
10–19	2	22.22
Dredging and Reclamation Work Experience	Frequency	% of Total
10 or more	3	33.33
6–9	4	44.44
3–5	2	22.22
Education level	Frequency	% of Total
Postgraduate	2	77.78
Undergraduate	7	22.22

(2) Risk Assessor Group:
- Number of Participants: 9.
- Experience: More than 5 years of direct experience working in dredging and reclamation.

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- Role: This group will help evaluate the risk in each factor in the "Perform Qualitative Risk Analysis" step and the "Control Risks" step, which is the final step in the risk assessment process. This information is shown in **Table 2.**

The following will explain in detail the study of each step of safety risk management in dredging and reclamation work.

2.1. Plan risk management

First of all, it is worth mentioning that this paper applied risk management to the case study of the Map Ta Phut Industrial Port Phase 3 Development Project, situated in Rayong province, Thailand. The methodology steps began with a plan for risk management and the development of a systematic risk categorization. This step involved a primary data collection of the method statement of the case study project from the field investigation and observation to preliminarily identify hazardous activities and compile the list of unsafe practices. Concurrently, the secondary data was gathered from a comprehensive literature review to pinpoint and delineate the various risks inherent in dredging and reclamation work. The findings from these two steps were subsequently utilized in the development of a semi-structured interview questionnaire for assessor opinions evaluation on risk identification.

The analysis of primary data has provided insights into the processes involved in dredging and filling, as outlined in **Figure 2**. This depiction highlights five sequential steps as placing a revetment for reclamation boundary definition, installing a silt curtain for controlling silt spread and ensuring environmental protection, constructing a silt pond for drainage, conducting dredging operations to excavate seabed sand, conveying it through a floating pipeline, and finally transporting the dredged sand to the land reclamation area. These steps elucidate activities that inherently entail certain safety risks.

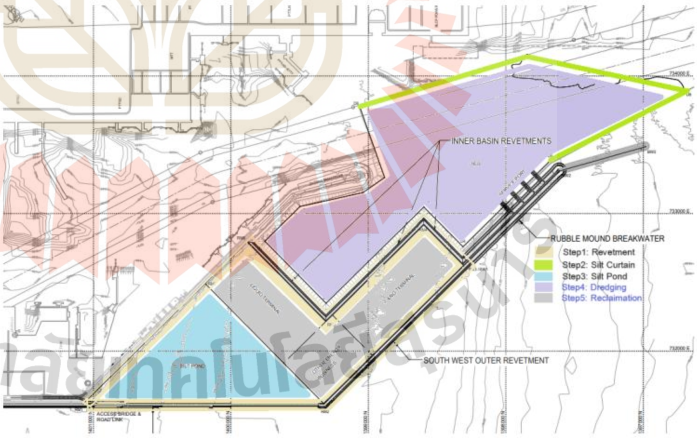

Figure 2. Work sequence and method statement of sample project.

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2.2. Identify risks

Subsequently, an examination of secondary data pertaining to safety in dredging and reclamation work was conducted, as illustrated in **Table 3**. This comprehensive review delineates specific risk factors such as noise, crashes, pipe movement, lifting falls, diving, slips, and uncertain sea conditions within the context of dredging and reclamation operations, offering valuable insights into potential safety challenges.

Table 3. Summary of dredging and land reclamation safety risk factors.

Past study	Safety risk factor
Cruickshank and Cork (2005)	Noise, crash, pipe moving, lifting fall, diving, slip, and uncertain sea.
Holle et al. (2005)	Lightning.
Daniel (2011)	Heavy machine, fire, and diving.
Bugg et al. (2018)	Hazard during remove dredging sand.
Gunduz and Laitinen (2018)	Fall from scaffolding, work lighting, fire, and noise.
Rizki (2018)	Ship collision, and workers fall into the sea.
Ma et al. (2020)	Noise from the dredger machine disturbs.
Mahapatra and Kushwaha (2020)	Collision, falling, lifting fall, lighting, noise, and toppling.
Sevryugina and Apatenko (2020)	Vehicle of reclamation crashed by the breaker's imperfection.

Table 4 presents the identification of risk factors, organized into 7 categories and 22 sub-factors. These categories encompass a range of risks, including as:

- Contact with moving machinery, poses a significant risk due to the continuous operation of dredging machinery, increasing the likelihood of operator injury or harm.
- Struck by moving objects is heightened in areas with water and land traffic, particularly in temporary traffic zones, increasing the risk of accidents.
- Strike against something fixed or stationary underscores the potential damage to stationary objects when adequate protection measures are lacking.
- Injuries while handling, lifting, or carrying often result from inadequate knowledge or understanding of proper work practices, leading to frequent accidents.
- Slips, trips, or falls on the same level underscores the unfamiliar working environment, contributing to frequent accidents.
- Falls from height presents a significant risk due to the differences in working surfaces and poses a considerable threat to worker safety.
- Weather hazards, highlight the potential hazards posed by natural disasters, which can escalate if work continues unabated.

This categorization derives from a synthesis of findings in both primary and secondary data studies, forming the framework for a semi-structured interview questionnaire designed to assessor's opinions on risk identification. The subsequent evaluation of the index of item objective congruence by 3 specialists ensures alignment with research objectives, enhancing the robustness of the questionnaire. The unanimous evaluation results affirm the accuracy of the questionnaire in risk identification.

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Table 4. Risk factors identification.

Item	Risk Identification
Contact with Moving Machinery	
(1)	The operator was injured in contact with the running dredger.
(2)	Noise from the dredger machine disturbs operator.
Struck by Moving Objects	
(1)	Dredger collides with cargo/fishing boat.
(2)	Vehicle of reclamation crashed by the driver's negligence.
(3)	Vehicle of reclamation crashed by the breaker's imperfection.
(4)	Dredging sand overlaps the workers.
(5)	Dredging sand conveying pipe fall on worker while connecting.
Strike against Something Fixed or Stationary	
(1)	Dredger collides with a pier or embankment.
(2)	Fire on dredger.
(3)	Diver was tied up by curtain cable.
(4)	Insufficient working light.
Injuries while Handling, Lifting, or Carrying	
(1)	Crane is unstable and fall on the workers.
(2)	Failure of lifting gear leading to heavy loads fall on workers.
Slips, Trips, or Falls on Same Level	
(1)	Operators slip on the dredger.
(2)	Worker were sedimented by quicksand at the silt pond.
Falls from Height	
(1)	Dredger operators fall into the sea.
(2)	General workers fall into the sea.
(3)	Operator/worker fall from temporary scaffolding.
(4)	Operators fall from dredger's ladder.
(5)	Vehicle of reclamation falls into the sea.
Weather hazards	
(1)	Storm, strong wind blows dredger.
(2)	Lightning in land reclamation open space.

2.3. Perform qualitative risk analysis

In this step, face-to-face interviews were conducted with 9 experts. After the identification of risks in the preceding phase, a structured questionnaire was developed to involve experts in the risk assessment process. Both the likelihood and impact of each risk were classified into 5 score levels. To ensure the reliability of subjective evaluations among the experts, the risk measurement and assessment index were initially established based on procedure outlines the risk management of Nanyang Technological University (2023), as illustrated in **Table 5**.

Table 5. Risk assessment index.

Score level	1: Very Low	2: Low	3: Moderate	4: High	5: Very High
Likelihood	One per ten years	One per five years	One per three years	One per year	Likely to occur many times per year
Impact	No injury	Injury at least 3 days of hospitalization	Injury at least 10 days of hospitalization	Injury at least 30 days of hospitalization	Fatality

Table 6. Initial risk assessment.

Item	Initial Risk Assessment	
	Likelihood	Impact
A		
(1)	4	4
(2)	4	4
B		
(1)	4	4
(2)	3	3
(3)	3	3
(4)	3	3
(5)	3	3
C		
(1)	3	3
(2)	3	3
(3)	2	2
(4)	3	3
D		
(1)	3	5
(2)	4	4
E		
(1)	4	3
(2)	2	4
F		
(1)	3	5
(2)	3	5
(3)	3	4
(4)	3	4
(5)	2	5
G		
(1)	4	5
(2)	2	5

The subjective evaluation on the likelihood of incidents and the severity of the impact among all 9 assessors were gathered and averaged. Then, the results of initial risk assessment representing the likelihood, the impact, and the risk exposure level were concluded in **Table 6**. The scores presented in the table, ranging from 1 to 5, indicate the frequency of likelihood in the second column and denote the level of impact in the third column of the table.

ISO 31000 (PECB, 2018) recommends using a risk matrix as a tool for assessing and prioritizing risks based on their likelihood and impact. This tool helps visualize the severity of each risk, assisting in the decision-making process for risk management. By prioritization risks into different levels, it becomes easier to identify which risks require immediate attention and which can be monitored over time.

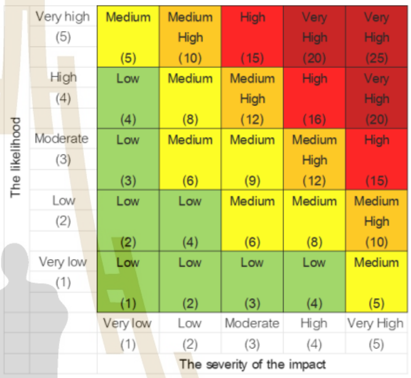

Figure 3. Risk matrix (Modified from Lehner, 2021).

In this research, the scale under ISO 31000, as shown in **Figure 3**, was applied to propose a risk matrix and scoring system for risk prioritization based on the likelihood and impact scores. Risk levels were arranged into five categories as follows: Low, Moderate Medium, Medium High, High, and Very High.

Based on the results of the qualitative risk analysis, values for both the Likelihood and Impact of various risks were obtained. These values have been plotted onto a risk matrix, which visually represents the risk level for each identified risk factor. The risk levels are prioritized and displayed in **Figure 4**.

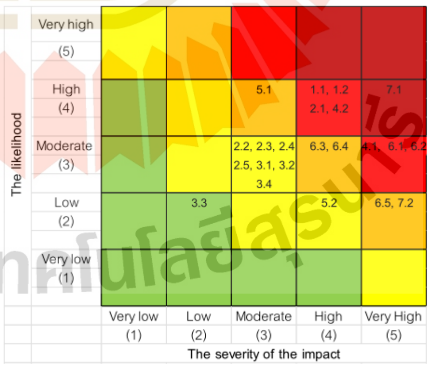

Figure 4. Initial risk assessment matrix.

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2.4. Perform quantitative risk analysis

In this quantitative risk analysis process, a prioritized list of quantified risks based on the numerical analysis conducted is presented. The likelihood and impact values from the previous steps were multiplied to obtain the risk priority values. These values help in determining which risks need immediate attention and which can be monitored over time. The calculation items and the resulting prioritized list are detailed in **Table 7**.

This table enables stakeholders to focus on the most critical risks first, ensuring efficient allocation of resources for risk mitigation and management.

Table 7. Prioritized list of quantified risks.

Item	Likelihood Value	Impact Value	Risk Priority Value (Likelihood × Impact)	Priority Level
A				
(1)	4	4	16	High
(2)	4	4	16	High
B				
(1)	4	4	16	High
(2)	3	3	9	Medium
(3)	3	3	9	Medium
(4)	3	3	9	Medium
(5)	3	3	9	Medium
C				
(1)	3	3	9	Medium
(2)	3	3	6	Medium
(3)	2	2	4	Low
(4)	3	3	9	Medium
D				
(1)	3	5	15	High
(2)	4	4	16	High
E				
(1)	4	3	12	Medium High
(2)	2	4	8	Medium
F				
(1)	3	5	15	High
(2)	3	5	15	High
(3)	3	4	12	Medium High
(4)	3	4	12	Medium High
(5)	2	5	10	Medium High
G				
(1)	4	5	20	Very High
(2)	2	5	10	Medium High

2.5. Plan risk responses

The risk response is planned based on the identified risks and assessments to develop appropriate risk management strategies. The strategies are proposed on the prevention, mitigation, and control measures to minimize or eliminate safety risks. A panel discussion was conducted through a brainstorming session involving interviews with 3 specialists. The aim was to exchange ideas and collaboratively analyze the causes of risk events in each factor. The outcome of this discussion was the establishment of a comprehensive guideline designed to avoid, mitigate, and reduce risk levels. The primary focus of this guideline is to effectively control operational safety risks in dredging and reclamation operations.

This phase constitutes an essential risk response strategy aimed at mitigating potential hazards in the workplace. To this end, specialists were interviewed using a series of brainstorming questions designed to elicit insights and recommendations for addressing each identified risk factor. Through this collaborative process, measures to reduce or avoid risks were explored and documented, resulting in the creation of a comprehensive work manual. **Table 8** delineates the responses to safety risks in dredging and reclamation work, showcasing the concerted efforts to enhance workplace safety and minimize potential incidents.

Table 8. Proposed guidelines.

Item	Risk Rating Level	Risk Response	Guidelines for Risk Control
A			
(1)	High	Avoid & mitigate	Before repairing, the machine must be stopped and must have protective equipment and safety guard.
(2)	High	Avoid & mitigate	Provide operators with suitable hearing protection such as earmuffs or earplugs and controls to reduce noise levels at the source.
B			
(1)	High	Avoid	Equip the dredger and cargo/fishing boats with advanced navigation aids and technologies, such as radar, VHF radios, GPS, and AIS.
(2)	Medium	Avoid & mitigate	Enforce speed limits, safe driving practices and implement a system for monitoring driver behavior.
(3)	Medium	Avoid	Conduct post-operation inspections of breakers to assess their condition before and after use.
(4)	Medium	Avoid	Designate exclusion zones around the dredging area to keep workers at a safe distance from the sand discharge and implement warning signals.
(5)	Medium	Avoid & mitigate	Establish control zones around the area where the sand conveying pipe is being connected and Require workers to wear safety fall protection equipment.
C			
(1)	Medium	Avoid & mitigate	Install collision avoidance systems on the dredger to detect and alert the crew of potential collisions with piers or embankments.
(2)	Medium	Avoid & mitigate	Install effective fire detection and alarm systems on the dredger to provide early warning in case of a fire outbreak and install fire extinguishers.
(3)	Low	Avoid	Equip the curtain cables with an emergency release mechanism that can be activated immediately in case a diver becomes entangled.
(4)	Medium	Avoid & mitigate	Install backup lighting systems, such as battery-powered emergency lights or backup generators.

Table 8. (*Continued*).

Item	Risk Rating Level	Risk Response	Guidelines for Risk Control
D			
(1)	High	Avoid	Assess and ensure that the ground where the crane is positioned is stable and capable of supporting the crane's weight and the loads it lifts.
(2)	High	Avoid	Ensure that all materials to be lifted are properly rigged and securely attached to the crane's hook or lifting device.
E			
(1)	Medium High	Avoid	Ensure that the dredger's decks have non-slip surfaces or anti-skid coatings and require operators to wear appropriate footwear with slip-resistant soles.
(2)	Medium	Avoid & mitigate	Establish safe work perimeters around the silt pond and clearly mark them with warning signs and provide workers with appropriate life vests.
F			
(1)	High	Avoid & mitigate	Provide dredger operators with appropriate personal protective equipment, including life jackets or personal floatation devices (PFDs).
(2)	High	Avoid & mitigate	Install safety lanyards and tethers on vessels or work platforms to secure general workers when working near the water's edge and provide worker's life jackets.
(3)	Medium High	Avoid & mitigate	Proper scaffolding design and provide operators and workers with appropriate personal fall protection equipment, such as harnesses and lanyards.
(4)	Medium High	Avoid & mitigate	Equip the ladder with non-slip steps or rungs to enhance grip and prevent slipping and provide operators with safety harnesses.
(5)	Medium High	Avoid	Implement a traffic management plan that includes clear instructions on vehicle routes and areas where vehicles need to slow down and install guardrails/barriers.
G			
(1)	Very High	Avoid	Implement an early warning system to alert personnel of potential storms or strong winds include provisions for securing and evacuating the dredger if necessary.
(2)	Medium High	Avoid	Instruct workers to stay away from tall objects, metal structures, avoid using electronic, and stop working and enter a safe area during lightning storms.

2.6. Control risk

The final step involves controlling risks through a comprehensive final assessment, which includes conducting interviews with 9 assessors to tackle the identified risks. This process aims to verify the guidelines for reducing risk levels effectively.

To ensure the validity of the findings, a follow-up questionnaire was conducted with the same nine assessors who participated in the initial survey. This phase included a thorough final risk assessment to verify the effectiveness of the deployed risk response methods in minimizing risks. As a result, the overall risk levels were reduced to a level deemed acceptable. **Table 9** presents an exhaustive evaluation of the identified risks and their respective levels, both prior to and after the implementation of risk response methods.

While **Figure 5** depicts the risk matrix obtained from this phase. The outcomes derived from the final column in table indicate that the risk assessment was at a low level. This implies that it falls within an acceptable risk range.

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Table 9. Final risk assessment.

Item	Initial Risk Rating			Final Risk Rating		
	Risk Assessment		Risk Assessment	Risk Assessment		Risk Assessment
	Likelihood	Impact		Likelihood	Impact	
A						
(1)	4	3	High	1	1	Low
(2)	4	3	High	2	1	Low
B						
(1)	4	5	High	2	2	Low
(2)	3	5	Medium	1	1	Low
(3)	3	5	Medium	1	1	Low
(4)	3	4	Medium	2	1	Low
(5)	3	3	Medium	1	1	Low
C						
(1)	3	4	Medium	1	1	Low
(2)	3	5	Medium	1	2	Low
(3)	2	5	Low	1	1	Low
(4)	3	3	Medium	1	1	Low
D						
(1)	3	5	High	1	2	Low
(2)	4	4	High	2	2	Low
E						
(1)	4	3	Medium High	1	1	Low
(2)	2	4	Medium	1	1	Low
F						
(1)	3	5	High	1	1	Low
(2)	3	5	High	1	1	Low
(3)	3	4	Medium High	1	2	Low
(4)	3	4	Medium High	1	1	Low
(5)	2	5	Medium High	1	2	Low
G						
(1)	4	5	Very High	2	1	Low
(2)	2	5	Medium High	1	1	Low

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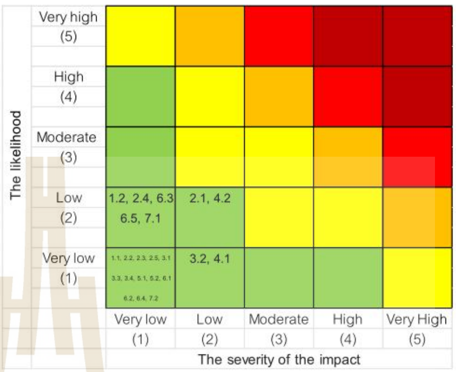

Figure 5. Final risk assessment matrix.

3. Discussion

When comparing the results of this study with past research, several consistent themes emerge, indicating the ongoing relevance and importance of addressing safety risks in dredging and reclamation work as.

Contact with moving machinery, previous studies by Cruickshank and Cork (2005) and Daniel (2011) have also emphasized the dangers associated with heavy machinery in dredging operations, aligning with the findings of this study.

Struck by moving objects, similar to Bugg et al. (2018) and Rizki (2018), this study highlights the risk of collisions involving dredgers and other vehicles during material handling, reinforcing the importance of safety protocols in such environments.

Strike against something fixed or stationary. consistent with past research by Cruickshank and Cork (2005), this study identifies the risk of collisions with fixed structures, such as piers or embankments, as well as fires on dredgers, underscoring the persistent hazards in these operations.

Injuries while handling, lifting, or carrying, findings from Holle et al. (2005) and Mahapatra and Kushwaha (2020) align with this study's identification of risks associated with unstable cranes and lifting gear failure, highlighting ongoing challenges in ensuring safe lifting practices.

Slips, trips, or falls on the same level, the concerns raised by Daniel (2011) regarding slip and fall incidents are consistent with the findings of this study, emphasizing the need for vigilance in preventing accidents on slippery surfaces.

Falls from height, similar to Holle et al. (2005), this study identifies the risk of falls from elevated surfaces, including into the sea, underscoring the continued importance of fall protection measures.

Weather hazards, the identification of weather-related hazards, such as storms and lightning during land reclamation, corresponds with past research by Cruickshank and Cork (2005), highlighting the ongoing challenges posed by adverse weather conditions.

However, while past research has addressed certain risk factors, this study

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acknowledges its limitations in comprehensively covering all inherent risks in dredging and reclamation work. By identifying and compiling new risk factors and evaluating the reliability of the questionnaire, this study aims to bridge this gap and provide a more comprehensive understanding of safety risks in these operations. The proactive measures formulated in response to the identified risks, along with subsequent assessments indicating risk mitigation to acceptable levels, contribute valuable insights and guidelines for future work in this reducing the potential for safety risks in dredging and reclamation work.

The risk assessment methodology employed involved several key steps, including qualitative and quantitative analyses, to ensure effective risk management. Methodology Overview:

1) Qualitative analysis
    - Risk Identification: Risks were identified through sample project method statement study and literature review related to safety risk factors.
    - Likelihood and Impact Assessment: Likelihood and impact values were assigned to each identified risk and subsequently plotted on a risk matrix.
2) Risk matrix utilization
    - The use of a risk matrix was instrumental in visualizing and prioritizing risks based on their likelihood and impact. This approach facilitated the identification of the most critical risks requiring immediate attention.
3) Quantitative analysis
    - Risk Priority Value Calculation: Likelihood and impact values were multiplied to obtain a risk priority value for each risk. This quantitative measure further aided in the prioritization process.
4) Risk response development
    - Specialist Brainstorming: A brainstorming session with specialists was conducted to develop guidelines aimed at reducing identified risks.

By conducting this comprehensive final assessment and mitigation process, it was ensured that the proposed strategies were both practical and effective in minimizing risks. This robust approach not only validated the effectiveness of the risk response methods but also provided a clear path for future risk management improvements in other dredging and reclamation work. Including construction in other marine infrastructure project.

While this research provides valuable insights, it is essential to acknowledge its limitations. The study's focus on specific projects introduces potential constraints stemming from variations in topography, weather conditions, and design specifics, as well as differences in dredging and reclamation technologies. The findings, therefore, may not universally apply to all contexts within these domains. To address this limitation, future studies could adopt a more extensive approach, encompassing a diverse range of projects and locations. Such an inclusive strategy, involving rigorous data collection, risk analysis, and assessment, could contribute to the creation of a substantial database. This, in turn, would facilitate the development of advanced technologies in risk management, promising heightened accuracy in risk assessments and significantly benefiting occupational health and safety practices.

The results of this study highlight the critical importance of addressing safety risks in dredging and reclamation. By following a detailed risk management process

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aligned with the guidelines of the Project Management Institute (PMI), which is an internationally recognized authority in project management, and incorporating insights from sample projects and personnel with direct experience in this field, this study provides comprehensive guidelines for managing safety risks in dredging and reclamation. Construction companies engaged in dredging and reclamation can apply the findings of this study to enhance their safety protocols. Implementing the recommended measures will not only protect workers but also contribute to the sustainable success and long-term viability of construction projects in the marine construction sector. The research offers further guidance on effective risk management practices, which will enable the industry to achieve higher safety standards and promote a culture of continuous improvement in workplace safety.

4. Conclusion

Aligned with Project Management Institute (PMI) guidelines, this study meticulously follows a structured risk management process, plan risk management and identification stages. The risk identify covers seven main categories and twenty-two sub-risk factors through qualitative and quantitative assessments. Expert evaluations identify safety risks in dredging and reclamation as notably high and very high, leading to proactive risk response strategies, validated by industry experts. Emphasizing adherence to safety protocols and international standards, the study concludes with a final expert assessment, indicating low or acceptable risk levels. Serving as a crucial reference for decision-makers, the study underscores the significance of proactive risk awareness in ensuring the sustainable progress of dredging and reclamation projects.

This research study stands as a valuable guide for proactive safety control practices in dredging and reclamation work, providing a comprehensive overview of potential risks and hazards inherent in the job. The study not only identifies these risks but also offers clear guidelines for their mitigation, thereby reducing overall risk. Its exemplary nature makes it a valuable resource for decision-makers involved in managing safety in similar types of work. The insights gained from this study can be directly applied to enhance safety measures, making it an instrumental tool for fostering a secure work environment in dredging and reclamation projects.

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APPENDIX B

Safety Guideline for Marine Infrastructure Construction Projects

(Developed from Risk Analysis Findings in Dredging, Reclamation, and Deep Seaport Construction)

A Introduction

This guideline is developed based on the results of a doctoral study titled "Safety Risk Analysis in Marine Infrastructure Construction Projects."

The purpose is to support construction stakeholders in identifying, analyzing, and managing key safety risks during dredging, land reclamation, and deep seaport construction.

B Objective of the Guideline

1) To reduce safety risks to an acceptable level.

2) To serve as a practical tool for engineers, project managers, and safety officers.

3) To promote a culture of safety in high-risk marine infrastructure environments.

C Scope

Applicable to:

1) Dredging operations
2) Land reclamation
3) Deep seaport construction works (e.g., quay walls, jetty piling, caissons, etc.)
4) Covers risk management during construction phase only.

D Key Risk Categories Identified

This appendix summarizes the primary risk categories identified from the comprehensive analysis of dredging, land reclamation, and deep seaport construction activities. Each category includes examples of hazardous scenarios observed during field operations or reported in previous studies.

1) Contact with Moving Machinery

- 1.1) Operator injured by operating dredger.
- 1.2) Noise from dredger causes operator distraction or fatigue.

2) Struck by Moving Objects

- 2.1) Dredger collides with cargo/fishing boats.
- 2.2) Reclamation vehicles crash due to driver error or mechanical failure.
- 2.3) Sand or conveying pipes accidentally fall or strike workers.

3) Striking Fixed or Stationary Objects

- 3.1) Dredger collides with pier or embankment.

3.2) Fire incidents onboard dredgers.

3.3) Divers entangled in silt curtain cable.

3.4) Poor lighting leads to tripping or collisions.

4) Injuries from Lifting and Carrying

4.1) Crane instability or gear failure causes dropped loads.

4.2) Workers struck by falling objects during lifting operations.

5) Slips, Trips, and Falls (Same Level)

5.1) Slippery surfaces on dredgers.

5.2) Workers sink into soft soil or quicksand near silt ponds.

6) Falls from Heights

Operators/workers fall into the sea or from scaffolding, ladders, or equipment. Vehicles fall from embankments or unstable platforms into water.

7) Weather-Related Hazards

7.1) Storms and strong winds destabilize marine equipment.

7.2) Lightning in open reclamation areas poses electrocution risk.

7.3) Additional Risks in Deep Seaport Construction

8) Structural Instability

8.1) Platform collapse, temporary structure failure, or unstable cranes.

8.2) Instability in working platforms or lifting zones.

9) Equipment and Tool Hazards

9.1) Explosions during gas cutting.

9.2) Grinder malfunction causes injury.

9.3) Electric shock during welding.

10) Water-Related Risks

10.1) Wave impact destabilizing working platforms.

10.2) Workers fall into steel pile holes or sea.

10.3) Vessel collision in confined marine work zones.

11) Diving-Specific Risks

11.1) Physical stress or decompression illness.

11.2) Equipment failure (oxygen supply, regulators, etc.).

11.3) Entanglement with cables, nets, or marine objects.

11.4) Poor visibility and failure of underwater communication.

11.5) Strong currents pose risk to diver safety.

11.6) Dangerous marine life encounters.

E Safety Control Measures

This section outlines the essential safety control measures recommended to mitigate the identified risks in dredging, land reclamation, and deep seaport construction works. The measures align with standard safety practices and are tailored to marine construction environments.

1) Machinery Operation Safety

Conduct regular maintenance of dredgers and heavy machinery.

1.1) Install physical barriers and emergency stop switches.

1.2) Train operators on safe start-up and shutdown procedures.

1.3) Provide hearing protection and noise-reducing measures.

2) Mobile Equipment and Collision Prevention

2.1) Designate separate zones for machinery, vehicles, and personnel.

2.2) Install proximity alarms and visual warning systems.

2.3) Conduct traffic control training and enforce speed limits.

2.4) Inspect and maintain vehicles and brake systems regularly.

3) Fixed Structure and Fire Safety

3.1) Use navigation aids (e.g., buoys, lights) to prevent dredger collisions.

3.2) Install fire detection and suppression systems on marine equipment.

3.3) Use flame-retardant materials and ensure availability of fire extinguishers.

3.4) Improve worksite lighting for night or low-visibility operations.

4) Lifting and Material Handling

4.1) Use certified lifting gears and conduct regular inspections.

4.2) Implement crane stability assessments before lifting.

4.3) Enforce exclusion zones under suspended loads.

4.4) Train riggers and signalers on lifting operations.

5) Fall and Trip Prevention

5.1) Use anti-slip mats and maintain cleanliness of walkways.

5.2) Install guardrails and toe boards on elevated platforms.

5.3) Enforce the use of fall protection systems (harnesses, lifelines).

5.4) Cover or barricade excavation holes and steel pile openings.

6) Weather Hazard Management

6.1) Monitor weather forecasts daily and establish weather emergency protocols.

6.2) Suspend marine operations during storms, strong currents, or lightning.

6.3) Secure all floating equipment in advance of high winds.

7) Electrical and Welding Safety

7.1) Ground all electrical equipment and provide GFCIs (Ground Fault Circuit Interrupters).

7.2) Conduct hot work permit checks before welding or gas cutting.

7.3) Provide PPE such as welding masks, gloves, and flame-resistant clothing.

8) Diving Operations Safety

8.1) Perform pre-dive health checks and dive planning.

8.2) Use checklists for equipment inspection and air supply control.

8.3) Maintain continuous diver-supervisor communication.

8.4) Avoid diving during strong underwater currents or poor visibility.

8.5) Have a standby rescue diver and emergency response plan in place.

9) Safety Culture and Supervision

9.1) Conduct daily toolbox meetings and pre-task briefings.

9.2) Appoint dedicated safety officers for marine activities.

9.3) Promote hazard reporting and near-miss investigations.

9.4) Regularly audit safety performance and update procedures.

F Checklists for Site Implementation

F1) Daily Risk Assessment Checklist

No.	Checklist Item	Yes / No / N/A	Remarks
1	Pre-start safety briefing conducted with all team members?	☐ / ☐ / ☐	
2	Weather and sea condition assessed and deemed safe?	☐ / ☐ / ☐	
3	Access ways, walkways, and ladders are free from obstructions and slips?	☐ / ☐ / ☐	
4	Dredger, cranes, and lifting equipment inspected and certified?	☐ / ☐ / ☐	
5	Diving activities reviewed and pre-dive checklist completed?	☐ / ☐ / ☐	
6	Electrical and welding equipment inspected and grounded?	☐ / ☐ / ☐	
7	Fall protection and PPE properly worn by all personnel?	☐ / ☐ / ☐	
8	Traffic management plan in place and vehicle checks completed?	☐ / ☐ / ☐	
9	Hot work permit and fire safety checks in place (if applicable)?	☐ / ☐ / ☐	
10	Emergency equipment (lifebuoys, extinguishers, first aid kit) available and accessible?	☐ / ☐ / ☐	
11	Communication devices tested and functional (radios, dive comms)?	☐ / ☐ / ☐	
12	Environmental controls (e.g. silt curtain, noise barriers) installed properly?	☐ / ☐ / ☐	
13	Designated Safety Officer present at the worksite?	☐ / ☐ / ☐	
14	Any new hazards identified today? (If yes, specify in Remarks)	☐ / ☐ / ☐	
15	Risk mitigation actions implemented for any identified hazards?	☐ / ☐ / ☐	

F2) Equipment Inspection Checklist

No.	Equipment / Item	Checklist Criteria	Pass	Fail	N/A	Remarks
1	Crane / Lifting Gear	Inspection Certificate Valid	☐	☐	☐	
		Load Limit Clearly Marked	☐	☐	☐	
		No Oil Leaks or Deformation	☐	☐	☐	
		Wire Rope/Cable Intact	☐	☐	☐	
2	Dredger	Navigation and engine checked	☐	☐	☐	
		Hydraulic systems functioning	☐	☐	☐	
		Safety devices working	☐	☐	☐	
3	Scaffolding / Platforms	Properly leveled and secured	☐	☐	☐	
		Guardrails and toeboards in place	☐	☐	☐	
4	Power Tools (e.g., Grinders, Welders)	Cables intact / no exposure	☐	☐	☐	
		Plug, socket, and grounding inspected	☐	☐	☐	
		Properly stored after use	☐	☐	☐	
5	Diving Equipment	Air tank pressure checked	☐	☐	☐	
		Regulator and mask functioning	☐	☐	☐	
		Communication system working	☐	☐	☐	
		Backup equipment available	☐	☐	☐	
6	Life Saving Equipment	Life vests and buoys available	☐	☐	☐	
		Fire extinguisher in place and charged	☐	☐	☐	
		First aid kit stocked	☐	☐	☐	
7	Temporary Structures	Stable and not overloaded	☐	☐	☐	
		No damage or corrosion	☐	☐	☐	

F3) Dive Operation Safety Checklist

No.	Checklist Criteria	Pass	Fail	N/A	Remarks
Pre-Dive Preparation					
1	Dive plan reviewed and approved by dive supervisor	☐	☐	☐	
2	Weather and sea condition checked and acceptable	☐	☐	☐	
3	Emergency response plan available and briefed	☐	☐	☐	
4	Medical fitness certificate valid (diver)	☐	☐	☐	
5	Dive team briefing completed	☐	☐	☐	
6	Standby diver designated and ready	☐	☐	☐	
Diving Equipment					
7	Air supply tanks fully charged and tested	☐	☐	☐	
8	Regulators, masks, and valves inspected and operational	☐	☐	☐	
9	Dive suits and weight belts in good condition	☐	☐	☐	
10	Communications system tested and functional	☐	☐	☐	
11	Backup air source (bailout bottle) available	☐	☐	☐	
Site & Platform Safety					
12	Dive platform stable and secure	☐	☐	☐	
13	Entry/exit point safe and accessible	☐	☐	☐	
14	Clear water visibility assessed	☐	☐	☐	
15	No entanglement hazards (cables, debris)	☐	☐	☐	
16	Communication with surface team maintained	☐	☐	☐	
Post-Dive					
17	Diver debriefing completed	☐	☐	☐	
18	Diver checked for fatigue or DCS symptoms	☐	☐	☐	
19	Dive log updated with time, depth, conditions	☐	☐	☐	
20	Equipment cleaned and stored properly	☐	☐	☐	

F4) Weather and Sea Condition Monitoring Checklist

No.	Checklist Criteria	Morning	Afternoon	Evening	Remarks
Weather Conditions					
1	Cloud coverage observed and recorded	☐	☐	☐	
2	Rainfall detected or forecasted	☐	☐	☐	
3	Wind speed measured and within safe limits	☐	☐	☐	
4	Wind direction noted and consistent with forecast	☐	☐	☐	
5	Lightning detected or warning issued	☐	☐	☐	
Sea Conditions					
6	Wave height measured and within safe operating limits	☐	☐	☐	
7	Tidal level recorded according to schedule	☐	☐	☐	
8	Current speed and direction assessed	☐	☐	☐	
9	Visibility on sea surface acceptable	☐	☐	☐	
10	Swell direction not causing instability to floating equipment	☐	☐	☐	
Decision Criteria					
11	Conditions safe for marine construction work	☐	☐	☐	
12	Stop-work order needed based on weather/sea alerts	☐	☐	☐	
13	Emergency measures briefed and ready	☐	☐	☐	
Documentation & Reporting					
14	Forecast from Meteorological Department reviewed	☐	☐	☐	
15	Records filed in weather monitoring logbook	☐	☐	☐	

F5) Emergency Response Readiness Checklist

No.	Checklist Criteria	Status (Yes/No)	Remarks
Personnel Preparedness			
1	Emergency Response Team (ERT) roster updated and present on site	☐ Yes ☐ No	
2	All personnel briefed on emergency procedures	☐ Yes ☐ No	
3	Contact list of emergency services (hospital, fire, coast guard) visibly posted	☐ Yes ☐ No	
Emergency Equipment Readiness			
4	First Aid kits checked and fully stocked	☐ Yes ☐ No	
5	Life vests, lifebuoys, and rescue ropes available and accessible	☐ Yes ☐ No	
6	Fire extinguishers inspected and functional	☐ Yes ☐ No	
7	Emergency lighting operational	☐ Yes ☐ No	
8	Communication tools (radio, phone) tested and working	☐ Yes ☐ No	
Evacuation Plan and Access Routes			
9	Evacuation map posted in work area	☐ Yes ☐ No	
10	Emergency exits and assembly points clearly marked and unobstructed	☐ Yes ☐ No	
11	Access routes for ambulance/rescue boat accessible	☐ Yes ☐ No	
Emergency Drills and Training			
12	Last emergency drill conducted within past 30 days	☐ Yes ☐ No	
13	Dive emergency and drowning protocols reviewed with dive team	☐ Yes ☐ No	
Documentation			
14	Emergency readiness log updated	☐ Yes ☐ No	
15	Any issues reported and corrective actions recorded	☐ Yes ☐ No	

G Sample Safety Protocols

1) Safe Lifting Operation – Standard Operating Procedure (SOP)

1.1) Objective

To ensure the safe planning and execution of lifting operations in construction areas to prevent accidents, injuries, or equipment damage.

1.2) Scope

Applies to all lifting activities using cranes, hoists, forklifts, or other mechanical lifting equipment in dredging, reclamation, and port construction sites.

1.3) Responsibilities

1.3.1) Site Engineer / Supervisor: Approves lifting plans, supervises operations

1.3.2) Lifting Operator: Operates equipment following procedures and instructions

1.3.3) Signalman / Rigger: Communicates and assists in proper rigging and movement

1.3.4) Safety Officer: Conducts inspections and enforces compliance with this SOP

1.4) Procedure

Step 1: Pre-Lift Planning

1) Conduct a Lifting Risk Assessment
2) Define the weight, center of gravity, and dimensions of the load
3) Select appropriate lifting equipment and accessories
4) Inspect all slings, shackles, hooks, and cranes
5) Develop a Lifting Plan, approved by a qualified engineer

Step 2: Pre-Operation Checks

1) Conduct a Toolbox Talk with involved personnel
2) Verify weather conditions are safe (no strong wind, lightning, or rain)
3) Ensure area is cordoned off with warning signs
4) All lifting equipment must have a valid inspection certificate
5) Ensure load path is free of obstructions

Step 3: Lifting Execution

1) Appoint a signalman for clear communication
2) Perform a test lift to check balance and rigging
3) Lift slowly and steadily without sudden movements
4) Never stand under suspended loads
5) Maintain constant communication during lifting

Step 4: Post-Lift Actions

1) Secure the load properly in designated area
2) Inspect lifting gear for any signs of damage
3) Complete post-operation checklist/report
4) Report any near-miss or incident to Safety Officer

1.5 PPE Requirements

1.5.1) Safety helmet

1.5.2) Safety gloves

1.5.3) Steel-toe boots

1.5.4) High-visibility vest
1.5.5) Eye and hearing protection (as needed)

1.6 Emergency Procedures

1.6.1) In case of equipment failure: Stop operations immediately
1.6.2) If an injury occurs: Alert first aid team and follow site emergency plan
1.6.3) For dropped load: Evacuate area and report incident

1.7 Documentation

1.7.1) Daily Lifting Checklist
1.7.2) Lifting Plan Approval Form
1.7.3) Incident/Near Miss Report (if applicable)
1.7.4) Emergency Evacuation in Marine Sites
1.7.5) Underwater Work SOP
1.7.6) Electrical Work Near Water SOP

2) Electrical Work Near Water – Standard Operating Procedure (SOP)

2.1) Objective

To prevent electric shock, short circuits, or fire hazards associated with electrical operations near water.

2.2) Scope

This SOP applies to all installation, repair, inspection, or testing of electrical systems in environments such as coastal construction sites, piers, vessels, or any wet or damp conditions.

2.3) Responsibilities

2.3.1) Electrical Supervisor: Plan and oversee the operations.
2.3.2) Qualified Electricians: Perform tasks according to safety standards.
2.3.3) Safety Officer: Inspect site conditions and verify compliance with safety requirements.

2.4) Procedure

Step 1: Pre-Work Assessment

1) Inspect the site to ensure protection from splashing or flooding.
2) Ensure isolation of power sources with Ground Fault Circuit Interrupters (GFCI) or Residual Current Devices (RCD).
3) Use waterproof cables and connectors (minimum IP65 rated).

4) Prepare additional electrical ground fault protection devices.

Step 2: During Work

1) Never touch electrical tools with wet hands or while standing on a wet surface.

2) Do not use damaged or frayed wires and cords.

3) Use insulated mats or dry working platforms.

4) Avoid using non-GFCI AC-powered tools in wet areas.

Step 3: Post-Work

1) Turn off the power and unplug equipment after use.

2) Clean and dry equipment thoroughly before storage.

3) Immediately report any irregularities or damages.

4) Record tasks and inspections in the daily work log.

2.5 Required Personal Protective Equipment (PPE)

2.5.1) Insulated gloves

2.5.2) Rubber-soled or dielectric safety boots

2.5.3) Waterproof or chemical-resistant coveralls

2.5.4) Safety goggles or face shields to protect from water splashes

2.6 Emergency Procedures

2.6.1) In case of electric shock: disconnect the power and avoid direct contact with the victim.

2.6.2) Call emergency services and perform CPR if necessary.

2.6.3) Use Class C fire extinguishers for electrical fires.

2.6.4) Report all incidents to the site manager immediately.

2.7 Documentation

2.7.1) Electrical Work Permit Form

2.7.2) Pre-Task Job Safety Analysis (JSA)

2.7.3) Daily Electrical Equipment Inspection Checklist

2.7.4) Emergency Contact List

2.7.5) Incident Report Form (if applicable)

3) Electrical Work Near Water – Standard Operating Procedure (SOP)

3.1 Purpose

To ensure the safe execution of electrical tasks in environments near or exposed to water, minimizing the risk of electric shock, equipment failure, and injury.

3.2 Scope

Applicable to all electrical installation, maintenance, and inspection tasks performed in or around marine environments, including docks, vessels, underwater operations, and land reclamation zones.

3.3 Responsibilities

3.3.1) Project Manager: Approves and enforces this SOP on all relevant sites.

3.3.2) Electrical Supervisor: Ensures pre-task planning and inspection.

3.3.3) Qualified Electricians: Execute work using approved methods and PPE.

3.3.4) Safety Officer: Verifies compliance with safety regulations and inspects site readiness.

3.4 Procedure

3.4.1 Pre-Work Preparations

1) Conduct a Job Hazard Analysis (JHA) specific to the location and task.

2) Ensure all electrical systems are GFCI/RCD protected.

3) Inspect all tools and equipment for waterproof ratings (IP65 or higher).

4) Set up dry working platforms or insulated mats above wet surfaces.

5) Secure the work area to avoid unauthorized access.

3.4.2 Work Execution

1) Prohibit use of electrical equipment with exposed wires or signs of damage.

2) Operators must wear insulated gloves and rubber-soled boots at all times.

3) Keep all electrical connectors elevated and dry.

4) Do not work barefoot or with wet hands.

5) Maintain constant communication with the Safety Officer.

3.4.3 Post-Work Activities

1) De-energize circuits and unplug tools before leaving the area.

2) Store electrical equipment in dry, secure locations.

3) Report any faults or malfunctions immediately.

4) Log task completion and inspection results in the daily report.

3.5 Personal Protective Equipment (PPE)

3.5.1) Electrical-rated gloves

3.5.2) Dielectric safety boots

3.5.3) Waterproof overalls

3.5.4) Safety helmet with face shield

3.5.5) Insulated tools

3.6 Emergency Response

3.6.1) In case of electric shock: disconnect power immediately using insulated tools.

3.6.2) Do not touch the victim with bare hands—use non-conductive material.

3.6.3) Call emergency services and administer first aid or CPR if trained.

3.6.4) Report the incident to the Site Manager and document in the Incident Log.

3.7 Required Forms & Records

3.7.1) Electrical Work Permit

3.7.2) Daily Equipment Inspection Checklist

3.7.3) Job Hazard Analysis (JHA)

3.7.4) Emergency Contact Sheet

3.7.5) Incident Report Form

H Implementation and Monitoring

1) Appointment of Safety Risk Champions

1.1) Definition: A Safety Risk Champion is a designated individual responsible for overseeing the implementation of safety protocols within each phase of work (e.g., dredging, reclamation, pile driving, diving operations).

1.2) Responsibilities:

1.2.1) Monitor adherence to the site-specific risk control measures.

1.2.2) Act as the first point of contact for safety-related queries.

1.2.3) Lead daily and weekly safety briefings.

1.2.4) Coordinate with the Safety Officer and Project Manager to report risk-related issues or improvements.

1.3) Selection Criteria:

1.3.1) Must have relevant experience in the operation phase.

1.3.2) Should be trained in hazard identification, emergency response, and communication.

1.3.3) Must be empowered to stop work if unsafe conditions are observed.

2) Weekly Toolbox Meetings

2.1) Purpose:

2.1.1) To reinforce safety awareness.

2.1.2) To share lessons learned, near misses, and incident prevention strategies.

2.2) Conducted by: Safety Risk Champion or Safety Officer.

2.3) Format:

2.3.1) Duration: 15–30 minutes.

2.3.2) Location: Near the work area in a safe and controlled environment.

2.3.3) Content:

1) Highlight current safety risks.

2) Discuss recent incidents or close calls.

3) Review changes in weather, tides, or equipment conditions.

4) Remind teams about key procedures or PPE requirements.

5) Collect feedback from workers for continual improvement.

3) KPI-Based Monitoring System

Key Performance Indicators (KPIs) should be established to measure the effectiveness of safety risk management. Suggested KPIs include:

KPI	Target	Monitoring Frequency
Number of Toolbox Meetings Conducted	1 per week	Weekly
Near Misses Reported	>3 per month (encouraged reporting culture)	Monthly
Corrective Actions Implemented	100% within 7 days	Weekly
Number of Safety Inspections Completed	At least 2 per week	Weekly
Compliance with PPE Usage	>95% observed compliance	Daily

3.1) Review Mechanism:

3.1.1) A weekly safety summary report should be compiled by the Safety Officer.

3.1.2) Results should be reviewed during site coordination meetings.

3.1.3) Trends should be analyzed monthly to refine safety strategies.

4) Continual Improvement

4.1) Periodically audit the safety system to identify gaps.

4.2) Encourage open feedback from all site personnel.

4.3) Update safety protocols as site conditions and project phases evolve.

J Conclusion

This safety guideline has been developed to provide structured, practical, and comprehensive support for managing safety risks in dredging, reclamation, and deep seaport construction operations. It is not merely a static reference document but is designed to be a living document—meant to evolve through continual updates based on real-world experience and feedback from field operations.

J1 Key Takeaways:

1) The risk categories and control measures provided here address both common and critical safety hazards observed in marine construction environments.

2) The checklists, standard operating procedures (SOPs), and monitoring strategies outlined in this guideline aim to improve proactive risk identification and prevention.

3) By appointing Safety Risk Champions, conducting regular toolbox meetings, and applying KPI-based tracking, this guideline promotes accountability and continuous safety engagement at all levels.

J2 Future Outlook:

1) With the advancement of construction technology and digital tools, this guideline can serve as a foundational framework for integrating AI-based systems.

2) Future enhancements may include:

2.1) Predictive risk analytics using historical incident data.

2.2) Real-time hazard alerts through IoT and sensor-based monitoring.

2.3) AI-supported decision-making tools for risk prioritization and mitigation planning.

Such innovation will enable data-driven safety management and allow project teams to respond to risks faster, smarter, and more effectively, further protecting workers and ensuring project success.

This document should be regularly reviewed and revised based on:

1) Field experience,

2) Near miss and incident reports,

3) Feedback from site personnel and safety experts, and

4) Technological advancements.

BIOGRAPHY

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