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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.

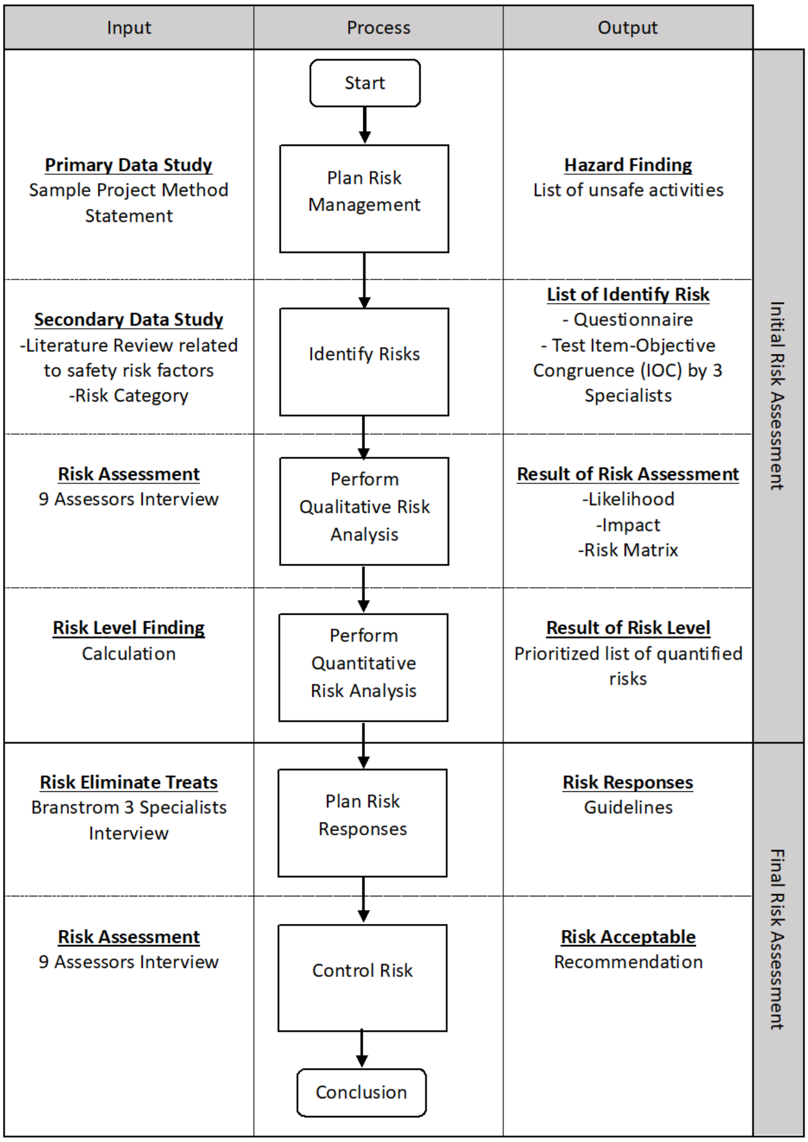

Figure 1. Research methodology.

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.

- 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.

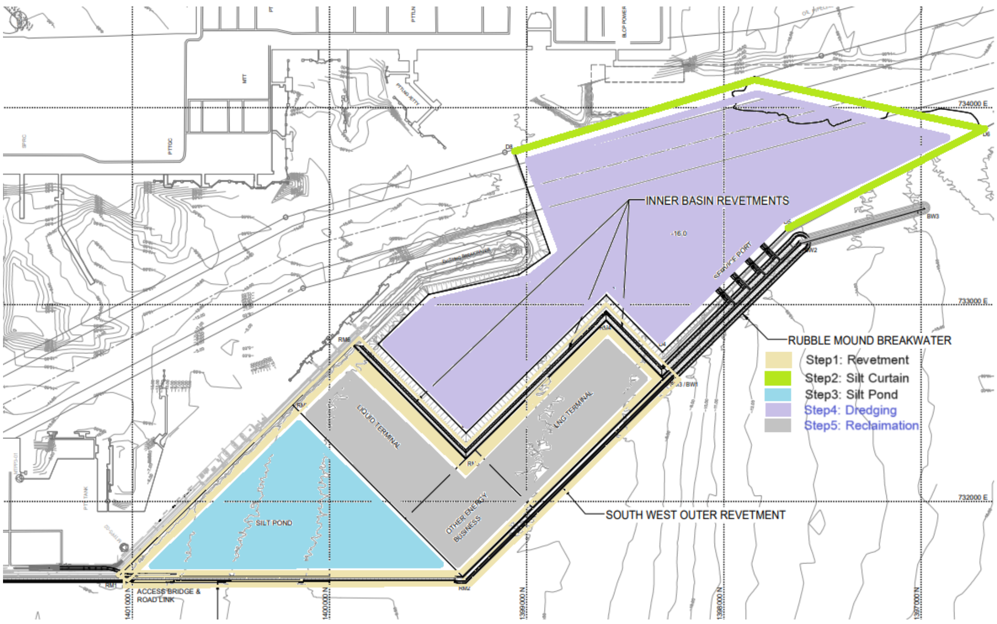

Figure 2. Work sequence and method statement of sample project.

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.

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.

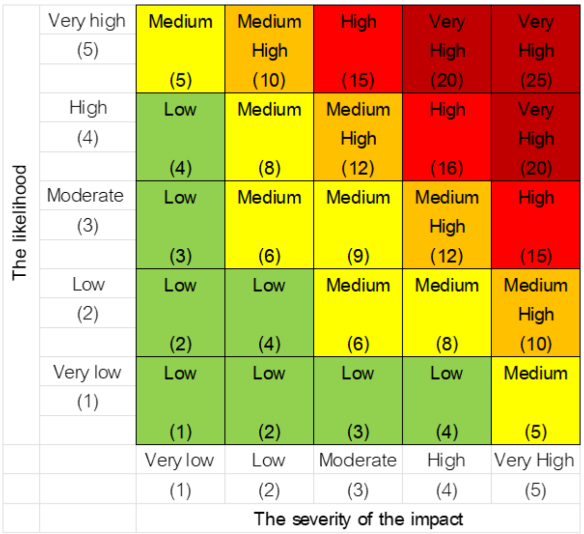

Figure 3. Risk matrix (Modified from Lehner, 2021).

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**.

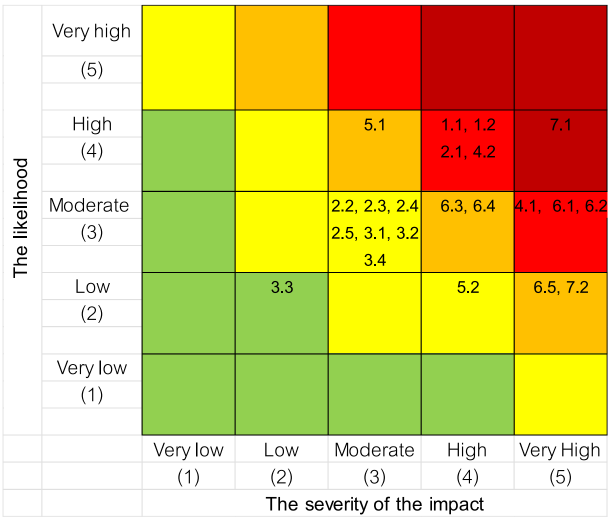

Figure 4. Initial risk assessment matrix.

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.

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

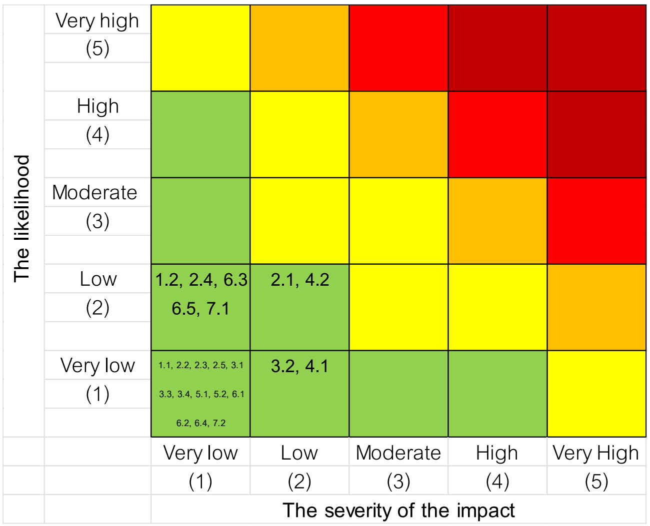

Figure 5. Final risk assessment matrix.

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 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 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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