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Risk Assessment for Marine Construction Projects

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Claremont Graduate University and California State University-Long Beach
2019

APPROVAL OF THE DISSERTATION COMMITTEE

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Abstract

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Marine-construction projects are becoming increasingly important for the development of the maritime industry. However, such increases are hampered by various risks that can significantly impact growth. Natural forces, political events, administrative and operational mistakes, equipment failures, external attacks such as arson, and economic events are some of the major risks faced by firms in this industry. Researchers have paid little attention on marine-construction risk assessment, despite the importance of such research.

This study sought to develop a generic risk-levels predictor framework, using the integrated definition function model (IDEF0) and the case-based reasoning approach (CBR), to predict levels of risk associated with a new marine-construction project. This framework can be developed through the following three phases: (a) Cases collection: previous marine-construction projects (cases) were investigated for identification, classification, and evaluation of risk factors and triggers, (b) Cases classification: the cases were organized and stored in a marine construction database (MCDB) and compiled into risk-triggers and risk-levels data for each case, (c) Cases reasoning: using the information from previous phases, when risk-triggers data for a new case is entered into a system knowledge database (i.e., a temporary database that keeps the new risks triggers and proposes prediction data for further knowledge and validation) looking for risk-levels prediction, the system searches into the MCDB for known risk-triggers that are similar to the new case. The similar cases are retrieved, and their risk-levels data are used to propose a risk -levels prediction for the new case. Finally, when the proposed prediction is revised and approved by users, the risk-triggers and risk-levels prediction data for the new case are stored in the system knowledge database for further learning. The implementation of the proposed risk-level predictor framework (RLPF) was tested in this study on 10 hypothetical marine construction projects conducted in Saudi Arabia.

The automated systematic approach—the RLPF proposed in this study—can address specific and time-urgent decisions invariably and accurately. Future researchers should use the RLPF to gain knowledge on risk aspects in marine construction projects.

Keywords: risk assessment, marine-construction project, case-based reasoning, risk factors

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Chapter One: Introduction

The marine industry is quite broad; a single research study cannot provide a comprehensive discussion. Marine structures are very important for the development of the maritime industry. All players in this industry rely on ports, harbors, jetties, and other structures to ensure their products move from one location to the other. Marine structures are engineering facilities constructed and installed in coastal zones or open oceans for the exploitation of various marine resources and the maintenance of its continuous operations (Y. Li & Li, 2011). Marine structures can be classified according to their functions and characteristics, their installation on the marine environment, or their purposes and uses. Y. Li and Li (2011) grouped marine structures into three types based on their functions and characteristics: coastal, offshore, and deep-ocean structures, shown in Table 1.

Table 1 *Marine structures classification according to their functions and characteristics*

Coastal structures	Offshore structures	Deep-ocean structures
Breakwater (vertical wall, sloping structure, and composite type)	Fixed structures: jacket platform, tower-type platform (spar platform), and gravity platform	Deep sea manned submersible
Gravity-type piers, pile-foundation piers, and floating piers	Movable structures: jack-up platform, bottom-supported platform, semisubmersible platform, and floating drilling ship	
Seawalls (vertical wall, sloping, and composite)	Complimentary structures: tension-leg platform and guyed-tower platform	
Groins	Mooring system facilities: single-anchor-leg-mooring system and catenary-anchor-leg-mooring system	
Tidal gate	Submarine facilities: subsea pipeline, seabed wellhead template, and submarine tunnel	
Submarine tunnel	Artificial islands: very large floating structures and gravity type artificial islands	

Note. From Environmental and Engineering Geology, Vol. II. Marine Structures and Materials, by Y. Li & L. Li, 2011, Abu Dhabi, United Arab Emirates: Encyclopedia of Life Support Systems, p. 274.

In addition, Y. Li and Li (2011) classified marine structures into fixed, movable (or floating structures), and complimentary structures. Table 2 illustrates the description of these three types of marine structures.

Table 2 *Marine structures classification*

Marine structures	Description	Example
Fixed structures	Fixed on the seabed on a long-term basis using piles or the gravity of structures	Gravity type (breakwater, pier, groin, seawall, concrete platform), jacket platform, submarine pipeline, submarine tunnel, and various types of artificial islands
Movable structures	Can be operated at different locations by the operation of fixing position, floating, sinking, and removal	Floating type (breakwater, and pier), jack-up drilling platform, bottom-supported platform, semisubmersible platform and various types of specially designed boats.
Complimentary structures	Partially fixed by using guyed cable, tension facilities, and universal joints to limit and control the six degrees of freedom of movement induced by various environmental forces. Complimentary structures are vertically anchored and often oriented using flexible members.	Tension-leg platform, guyed-tower platform, and articulated tower platform.

Note. From Environmental and Engineering Geology, Vol. II. Marine Structures and Materials, by Y. Li & L. Li, 2011, Abu Dhabi, United Arab Emirates: Encyclopedia of Life Support Systems, p. 274.

Moreover, different materials such as concrete, stone, timber, and steel have been used to construct marine structures Y. Li and Li (2011). Generally, marine structures need to be designed to resist various loads such as service loads, loads from ships, and loads generated by the impact of sea waves. Thus, according to the purpose of the marine structures, they can be classified as berthing facilities, dry-docking facilities, and coastal-protection structures. Table 3 summarizes each type and its purposes with examples.

Table 3 *Marine structures classification according to their purposes*

Marine structure type	Purposes	Example
Berthing facilities	Provides support for ships, facilitates goods and passenger movements between ships and land transportation. Constructed normal to the shore and parallel to the shore.	Piers (open pier, closed pier, and floating pier), wharves.
Dry-docking facilities	Used to build ships and inspect, maintain, repair, and modify ships	Floating dry dock, graving dry dock, vertical synchronized lifts, and marine railways.
Coastal-protection structures	Provide a barrier between sea waves and structures such as harbors to avoid detrimental effects of sea waves like erosion.	Bulkheads, seawalls, groins, jetties, and breakwaters.

Note. From Environmental and Engineering Geology, Vol. II. Marine Structures and Materials, by Y. Li & L. Li, 2011, Abu Dhabi, United Arab Emirates: Encyclopedia of Life Support Systems, p. 274.

1.1 Characteristics of Marine Construction

When analyzing risks in an industry, it is important to start by defining and explaining the main characteristics of the projects under focus (Hashemi, Mousavi, Tavokkoli-Maghaddam, & Gholipour, 2013). Understanding these characteristics makes it easy to explain the nature of risks and their impact on the affected firms. In this respect, about two thirds of the Earth are covered in water (Tang & Bittner, 2014). Such a percentage of water opens many opportunities, such as developing travel routes, connecting the world, transporting goods, and trade. But making use of two thirds of earth is a challenging task. Building infrastructure on water is quite different from constructing structures on land. The engineers who attempt to do so not only face the general issues of schedules and budget but also must tolerate a list of constraints and problems that have to be solved effectively and efficiently. These problems include the following:

- **Geographic reference**: Engineers must work out methods to ascertain positioning and preserve the position once the structure is constructed.
- **Logistics:** These problems involve the transportation and storage of all necessary materials from land to off-shore sites and the demands of the work force (e.g., housing and nourishment).

- **Protection of crew, materials, and equipment**: Managers must ensure all safety measures from securing building materials to safety of the crew involved in the construction process.
- **Protection of partially completed structures**: This challenge includes shielding all construction from hydro-centered and hydrostatic pressure during all stages of construction until completion.
- **Protection of the environment**: Safety methods must ensure corporate social responsibility in the construction process.
- **Impact on other industries**: Construction damage must be controlled, protecting intimately associated industries like fishing and shipping.

In addition to the above challenges, marine-construction projects are quite costly projects. Undertaking marine-construction projects requires significant amounts of money and only large companies and government entities can afford to sponsor them. Constructing, repairing, or upgrading a port, a harbor, or jetties requires large sums of money that small and medium-sized enterprises cannot afford. Owners of most projects are mostly governments or leading corporations in the country. Moreover, current marine-construction projects require a high level of technology and expertise. Some involve constructing a very delicate structure under or on the water surface with high levels of precision. When undertaking such projects, a team of experts must help at various stages to ensure the desired outcome is achieved.

Moreover, marine-construction projects are prone to natural disasters (Ellis, Sherman, & Shroder, 2015). In many cases, it is almost impossible to avoid consequences of natural disasters when undertaking these projects. Unexpected cases of fire outbreak, major earthquakes, cyclones, or major rainfall can lead to numerous risks and may result in the destruction of the structures being constructed, delays in project-completion time, and financial loss. Because of the nature of most projects, they are often subjected to strict regulatory policies by governments and other relevant authorities.

In sum, the evidence on marine construction suggest that marine construction has the following characteristics:

- Expensive
- Skill intensive
- Vulnerable to natures' abnormalities
- Systematically discouraged through taxes and fees by governments and authorities

1.2 Problem Statement

Marine-construction projects are becoming increasingly important for the development of the maritime industry. However, various risks hamper such increases and significantly impact growth. Natural forces, political events, administrative and operational mistakes, equipment failures, external attacks such as arson, and economic events are some of the main causes of risks that firms face in this industry. In the past, researchers have paid little attention to risk assessment for marine construction projects. In addition, studies on the application of machine learning tools, such as case-based reasoning (CBR) approaches, that predict risk aspects in marine construction industry, were neglected by researchers, despite the importance of such research. This study aims to

i. Identify, classify and evaluate marine construction projects risk factors.
ii. Identify, classify and evaluate marine construction projects risk triggers.
iii. Develop an automated risk-level predictor framework to help decision-makers in the marine-construction industry to predict risk levels for future projects.

1.3 Research Objectives

This study sought to develop a generic risk-levels predictor framework, using the integrated definition function model (IDEF0) and the case-based reasoning approach (CBR), to predict levels of risk associated with a new marine-construction project. This framework can be developed through the following three phases: (a) Cases collection: previous marine-construction projects (cases) were investigated for identification, classification, and evaluation of risk factors and triggers, (b) Cases classification: the cases were organized and stored in a marine construction database (MCDB) and compiled into risk-triggers and risk-levels data for each case, (c) Cases reasoning: using the information from previous phases, when risk-triggers data for a new case is entered into a system knowledge database (i.e., a temporary database that keeps the new risks triggers and proposes prediction data for further knowledge and validation) looking for risk-levels prediction, the system searches into the MCDB for known risk-triggers that are similar to the new case. Similar cases are retrieved, and their risk-levels data are used to propose a risk-levels prediction for the new case. Finally, when the proposed prediction is revised and approved by users, the risk-triggers and risk-levels prediction data for the new case are stored in the system knowledge database for further learning.

1.4 Significance of the Study

According to Gudmestad (2002), failure of a firm to mitigate risks in any industry may lead to serious losses that could force the firm to cease operations. For this reason, this study aimed to explore new approaches to evaluate and predict significant risks, specifically in the marine construction industry. The significance of this study can be highlighted by the followings:

i. The risk factors associated with marine-construction projects are identified, classified, and assessed.

ii. The proposed RLPF acts as a blueprint that companies can use to manage various risks in marine-construction projects as they emerge.

iii. The proposed RLPF provides companies involved in marine-construction projects with skills and knowledge on how to address the various risks they might face.

iv. The proposed RLPF provides policymakers informed decisions when trying to regulate the marine-construction industry.

v. Scholars interested in conducting further studies in the application of the CBR approach in the risk prediction for marine construction also can benefit from this study significantly.

Chapter Two: Literature Review

2.1 Construction Risks

Project risk is the potential threat or problem in the completion of a specific task whose occurrence may affect set project goals (Hulett, 2012). These risks are inherent in all projects, and thus, can never be eliminated fully, although they can be managed efficiently to alleviate impacts to the attainment of project goals (Hulett, 2012). According to Nieto-Morote, and Ruz-Vila (2011), "risk refers to the exposure to economic or financial loss, physical damage, injury, or possible delay, because of the uncertainty associated with pursuing a particular course of action" (p. 1).

One major concern facing the construction industry is risk management (Nieto-Morote & Ruz-Vila, 2011). Risk management is a synchronized set of activities that help a firm overcome consequences in the occurrence of particular calamities (B. Li & Ren, 2009). Risk management is a systematic approach to manage forces that may negatively impact firms when adverse events occur. Effective risk management in an organization is a vital management tasks that can help in achieving success in major construction projects (Ellis et al., 2015). Risk management has become a critical aspect of administrative activities in the construction industry. Researchers have proposed various risk-management approaches. Some of the most well-known methods are Project Risk Analysis and Management (Chapman & Ward, 1997), Risk Analysis and Management for Projects (Institution of Civil Engineers, 2002), Risk Management Solutions (Institute of Risk Management, 2002), and Project Management Body of Knowledge (Project Management Institute, 2008). An efficient risk-management system should bring various major advantages to organizations (Vivian, and Shen, 2012). One major benefit is that a risk-management system should facilitate systematic and objective decision-making in an organization when risk occurs. The system should make it possible to compare the robustness of various projects with specific uncertainties. The system should also enable project managers to rank the relative importance of various immediate risks and should offer an improved understanding of specific projects by identifying risks before they can have a devastating impact on an organization. A risk-management system should also be capable of demonstrating a company's responsibilities to customers. Finally, it should enhance the corporate experience and effective communication.

The construction industry faces greater challenges than other sectors due to long completion periods and high costs (Assaf & Al-Hejji, 2006). Other challenges emanate from the occurrence of unpreventable natural phenomena such as heavy rains and earthquakes. Also, financial shortages create challenges that may cause delays in the execution of a project. Politics play a critical role in the execution of various projects in that politicians are the key policymakers and can stop or delay project execution. Other challenges revolve around the lack of technical expertise by the workforce and poor site controls. Delays in the completion of a project may have adverse financial implications for the contractor due to the imposition of fines and penalties.

The marine-construction industry is unique in numerous ways, but so are the risks, which have the potential to catastrophically affect projects that are being undertaken. It is elementary to discern the high risks associated with marine construction (Tam & Shen, 2012). Usually, handling offshore construction risks requires an additional (and large) amount of funds because considerable delays in time and the quality of the structure may be negatively affected (Gudmestad, 2002). When off-shore construction is underway, it suffers a greater chance of being exposed to potentially damaging risks, specifically, during the time materials and other necessities are being transported to the offshore construction site and when the equipment is being installed.

Most projects in marine construction industry are subjected to numerous risks that may have environmental, financial, health, and many other consequences, if not managed properly. Fire outbreak, explosions, leakages, and accidents that may lead to human injury are common when undertaking such projects. Moreover, risks of delays may result in significant financial consequences. It is difficult to predict some risks and impossible to avoid them completely. For this reason, many firms develop risk management plans. These plans involve identifying risk factors, evaluating predictable consequences on a project's objectives, and creating mitigation plans to overcome the identified risk factors.

One initial step in the risk-management process is risk identification. One must start by identifying the risks to be able to manage them properly. Risk assessments should stress the impact and probability of occurrence. Risks that are likely to occur frequently, and those whose occurrence may have a significant impact on a project, should be prioritized when planning management mechanisms. In contrast, risks that are unlikely to occur and whose impact may have an inconsequential impact should be given less priority. Managers can use various tools and techniques to identify risks, such as documentation reviews, information-gathering techniques, checklists, assumptions analysis, and diagraming techniques.

Through a literature review, numerous marine-construction risk factors were identified. Some of these risks are caused by natural forces such as flooding, cyclones, earthquakes, and massive amounts of rainfall, among other forces, which are directly outside human control. Risk may also align with human error. Gross negligence and violation of set safety rules and procedures may result in a major accident in marine-construction projects. Defects in the equipment or failure of the equipment to function as required may also cause accidents when undertaking such projects. Market forces may also impact a project, such as a sudden increase in the international prices of various materials used in the construction (Bai & Bai, 2014). In such cases, price increases may force a project owner to inject more resources into the project to meet the increased costs of operations. Tam and Shen (2012) stated that "underwater conditions are different from tender assumptions" was the most common risk factor associated with marine projects, and the "unavailability of materials, plant and labor" had the most impact to the project if risk was encountered (pp. 406-407) Inflation is another high-risk factor in major projects, especially when materials need to be imported. In this study, risk factors that affect marine-construction-projects objectives were identified, and list all past risks in Table 4. The risks are stated in no particular order of importance, magnitude, or otherwise.

Table 4 *Identified marine construction risk factors by researchers in the past*

Accidents	Loading/Unloading of material
Bureaucracy of government	Low productivity
Criminal acts	Contractors' lack of experience/trained staff
Delays in documents approval	Manpower unavailability
Ecological damage	Contractor's bankruptcy
Contagious diseases	Poor material selection
Poor site management and supervision	Delay in work/labor permits, licenses
Contractor's financial difficulties	Unreliability of construction equipment
Severe weather condition	Unskilled labor
Design errors	Construction errors
Social/cultural common policy	Breach of agreements between countries
Subcontractors interference	Changes in country laws
Technical problems with vendors/suppliers	Conflicts of government laws
Delay in land/water acquisition or site access	Delay of material supply by vendor/supplier
Environment pollution	Fluctuating currencies exchange rates
Equipment unavailability	Frequent change of subcontractors
Force majeure events	High waves
High/low tide	Improper construction methods implemented
Improper underwater conditions	Inadequate port facilities
Inadequate/unclear definition of project scope	Inappropriate vendor list
Incompetence of subcontractors	Inconsistencies in government policies
Labor strikes	Inflation in material prices more than estimated
Low technical standards	Lack of attention to environmental international laws and regulations
Vendors/suppliers lack of quality	Lack of coordination between project participants

Classification of risks is an important stage in the risk-management process. Many researchers proposed methods to classify risk; for example, Cooper and Chapman (1987) proposed a classification method focused on the nature of risks and their magnitude, dividing risks into two major categories: primary and secondary. Tah et al. (1993) used a hierarchical structure of risks to classify risks according to their origin and to the location of risk impact on a project. Wirba, Tah, and Howes (1996) incorporated the Tah et al. method to classify all possible risks and the Cooper and Chapman method to partition identified risks into primary and secondary levels. Chapman and Ward (1997) presented a comprehensive list of factors gathered from diverse sources and classified these factors in terms of risk origination by contractors, engineers, and clients. These studies focused on the origin of risks (Edwards & Bowen, 1998).

In the present study, risk factors that affect the completion of marine-construction projects were identified. This identification necessitated collecting data from construction professionals, contractors, technical consultants, and project-management experts to ensure a fair collection of project participants and that their views are reflected in this study. The hierarchical structures method was applied to classify various factors into major groups in support of an appropriate methodology.

2.2 Case-Based Reasoning (CBR) and its Applications:

The CBR approach, first introduced by Schank (1982), uses past experiences to solve problems. Past experiences (cases) are stored in a database, known as the case base. Each case is stored by its problem description and solution. When a new problem description is entered (a query), the CBR system retrieves past cases whose problem descriptions are similar to the new problem and uses the past solutions to propose a solution for the query. If proposed solutions fail to solve the problem, these solutions are revised and evaluated until the final solution generated by the system is approved. Finally, the approved solution and the new case are stored in the case base for future knowledge. Because of its ability to create new knowledge in this way, CBR is considered a machine-learning technique. Specifically, CBR is a lazy machine-learning technique because training a CBR system involves merely storing past experiences in a database and learning only happens during query time. In contrast, in rule-based machine-learning techniques, learning happens during training, which involves generalizing information into rules (Kyrilov, 2017).

The main components of the CBR system is augmented in subsequent steps (Núñez et. al., 2004, Figure 1).

Retrieve. The first step is to retrieve similar cases to the query.

Reuse. The retrieved cases are used to propose a solution to the query.

Revise. The problem-solving method used by a CBR-agent adjusts its choices based on the evaluation it receives regarding acceptance criteria. This assessment is provided by either a simulation or through human input.

Retain* or *learn. The information gathered is stored and serves as a record for any problems that may occur in the future. The record stores error-free resolutions and those that yielded unsatisfactory results.

Knowledge base. In general, a case (C) can be represented in the knowledge base as follows (Angelo, 2017):

$$C = (C^d, C^s) \tag{1}$$

Where; C^d is a case problem description, and $(C^d \in D)$, where D is a problem description space, and C^s is a case problem solution, and $(C^s \in S)$, where S is a problem solution space. A query $q \in D$, is a new problem description seeking a solution $s \in S$.

Case retrieval. The process starts by retrieving a set of similar cases $T_q = \{c_1, c_2, \dots, c_k : f(c_i^d, q < \Theta\}$, from the knowledge base, where $f\colon D \times D \to \mathbb{R}$ is a distance measure function between two problem descriptions, $c_1, c_2, \dots, c_k$ are the retrieved cases from the knowledge base, whose problem descriptions are similar to q.

Case reuse. The CBR uses the retrieved cases to learn a function $g: S^k \to S$ that diagnoses a set of k solutions and proposes a solution, $s' = g(R_q)$.

Case revision. At this time, the proposed solution s' is revised and modified until the accepted result is defined as $s^* = h(s')$, where $h : S \to S$ is a function used to revise the proposed solution.

Case retainment. At this step, a new case (q, s^*) is stored in knowledge base.

According to Angelo (2017), the accurate choice of functions $f, g, and\ h$ will guarantee a system's performance and abilities. Depending on the system' domain, these functions can be simple or complex. In some situations, the system may require additional machine-learning techniques to learn these functions. For example, a machine-learning algorithm could be used in the retrieval process to learn the function f to complete the retrieval process more efficiently. In contrast, these functions can be very simple in certain domains. The function g in the reuse process, for example, could be used to simply copy a previous solution. In addition, the CBR system allows humans to learn these functions. For example, the function h in the revision process could be delegated to a human.

CBR has been employed in various diverse fields largely because of its extensively widespread applicability. CBR has been used to attain distinct objectives in the field of environmental sciences, like salvaging information from historical meteorological databases; in the design of sewage-treatment plants, CBR is used to maximize the capability of performance concatenation (Núñez et al., 2004). Additionally, CBR has been used to make well-organized methodical decisions for forest-fire fighting, in the development of case-based conjunctures by rangeland pest-management consultants, and in the case-based delineation of complex engineering procedures (Núñez et al., 2004).

A case was presented under the context of risk assessment to calculate all possible audit risks, in support of auditors who work in diverse settings (Jiang & Wang, 2010). The contemporary version of CBR is much revised from the one that was functional only in discrete and obscure areas of research. With the new developments, the number of fields where CBR can be used to optimize the design process are expanding, and observed in its recent inflation in the number of research papers conducted, both money-oriented and academic. The domains where CBR can be implemented include architectural engineering (Schmitt, 1993), decision support (Deng, 1996), development scheme/agenda (Sycara & Miyashita, 1994), construction consultation and conciliation (Li, 1996), and structural identification and detection (Roddis & Bocox, 1997); these examples prove the utilitarian aptitude of CBR in fields affiliated with engineering and management (all as cited in Chua, Li, & Chan, 2001).

2.3 IDEF0 and its Applications in Construction

The functionality of IDEF0 is grounded in structured analysis and design technique (Karhu, Keitila, & Lahdenper, 1997). However, some modeling techniques belong to the IDEF classification, whereas, the ones associated with a 'zero' (IDEF-0) indicate employment in assembling "function models" (Karhu et al., 1997, pp. 8–9). Researchers use a complex combination of natural and graphic languages to communicate the elucidation of a discrete procedure. Any operations/activities are denoted through boxes. These boxes are intricately connected through arrows that delineate interface and interconnection, shown in Figure 1.

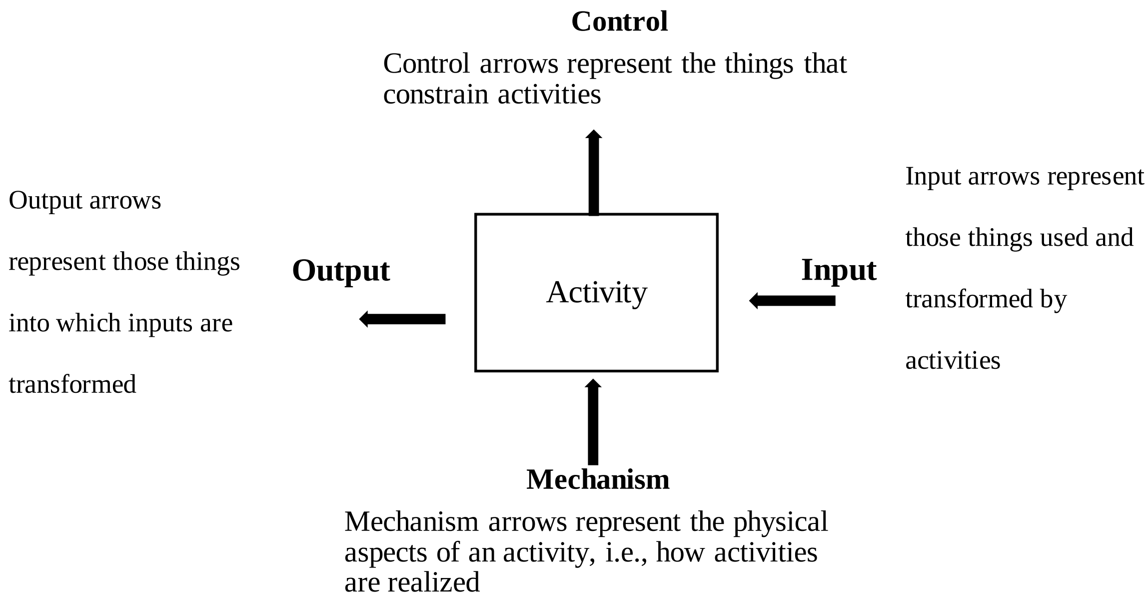


Figure 1. The basic concepts of the IDEF0 method.
Note. Source: *Construction Process Model Generic Present-State Systematization by IDEF0,* by V. Karhu, M. Keitila, & P. Lahdenper, 1997, Espoo, Finland: Technical Research Center of Finland.

IDEF0 models comprise organized representations that compile and systemize diagrams into a ranking order. The diagrams found at the top are considerably less thorough and comprehensive than those at the base. Hence, the IDEF0 model is analogous to a compilation of diagrams structured according to a tree shape.

Sanvido et al. (1990) originated one of the most notorious models that was used to supply open details about architecture to reinforce the planning of any establishment (Karhu et al., 1997). These models assist and support computer-integrated construction and calculate critical success factors for any construction project. Zhong et al. (1994 developed a model similar in nature that added to the features by allowing the user to manipulate the entire building procedure; however, the interface is considerably crude compared to the model developed by Sanvido. Another model, developed by Merendonk and Van Dissel (1989) provides an extensive array of detail and employs the use of various systems, functional and conceptual. The ATLAS model, developed by Nederveen (1995), expounds on architectural and structural design techniques that are specific to points of view, mainly actor-based points of view. These models fall under the sub model category referenced as the "view-type model" (Karhu et al., 1997, p. 16).

This section was elaborated on the data, content, and features offered by these models. Researchers have developed models consistent in nature with those mentioned above to aid in understanding and augmenting recent procedures that require a distinct information system. These models aim to improve specific segments of the building process. For example, Laurikka (1994) employed the IDEF0 as well as other theoretical models to demonstrate the core theory behind the way information systems are scheduled. However, the research that Laurikka conducted aimed to elucidate on the functionality of computer-aided design-based building structures. Information regarding the product model is consolidated in the production scheduling system (Karhu et al., 1997).

Chapter Three: Research Methodology

Marine-construction projects are prone to natural disasters (Ellis et al., 2014). In many cases, it is almost impossible to avoid consequences of natural disasters when undertaking these projects. Cases of unexpected fire outbreak, major earthquakes, cyclones, or major rainfall can lead to a number of risks. These adverse events may result in the destruction of structures, delays as the project is put on hold, and financial loss. Despite these significant consequences, researchers have almost entirely ignored risk factors in marine-construction projects. In the present study, a risk-levels predictor framework for the marine-construction industry was developed. This framework can be developed through the following three phases: : (a) Cases collection: previous marine-construction projects (cases) were investigated for identification, classification, and evaluation of risk factors and triggers, (b) Cases classification: the cases were organized and stored in a marine construction database (MCDB) and compiled into risk-triggers and risk-levels data for each case, (c) Cases reasoning: using the information from previous phases, when risk-triggers data for a new case is entered into a system knowledge database (i.e., a temporary database that keeps the new risks triggers and proposes prediction data for further knowledge and validation) looking for risk-levels prediction, the system searches into the MCDB for known risk-triggers that are similar to the new case. The similar cases are retrieved, and their risk-levels data are used to propose a risk-levels prediction for the new case. Finally, when the proposed prediction is revised and approved by users, the risk-triggers and risk-levels prediction data for the new case are stored in the system knowledge database for further learning.

Accordingly, the methodology adopted for this study was examined under the four broad headings of research design, data collection, population and sampling, and data analysis.

3.1 Research Design

Researchers usually use two general approaches to research: quantitative and qualitative (Kothari, 1985). Both approaches were adopted in this study to generate and analyze data required for the development of the following phases:

1. Cases Collection: the main purposes of this phase were to identify, classify, and assess risk factors and triggers for marine construction projects using methods and techniques to gather and analyze data mentioned below. A literature review and survey methods were conducted to collect data on marine construction industry to identify and classify risk factors and triggers as mentioned in detail in Sec. 3.2. Then, the gathered data was compiled and analyzed to evaluate risk aspects as mentioned in detail in Sec. 3.4.
2. Cases Classification: the main purpose of this phase was to build a marine construction database (MCDB) based on actual data from previous marine construction projects. Due to unavailability of such sensitive data, hypothetical marine construction cases were gathered to build the MCDB for the purpose of this study.
3. Cases Reasoning: the CBR approach was adapted in this phase to perform the reasoning mechanism for the proposed RLPF. Thus, proposed reasoning functions were computed using methods described in Sec. 4.3.

3.2 Data Collection

3.2.1 Literature Review

The main objective of a literature review is to provide readers the state of knowledge and the major problems of the subject area under study (Bell, 1999). A review of the literature also presents critiques of available studies to identify gaps in knowledge. A comprehensive review of related literature from textbooks, professional journals, conference proceedings, academic journals, dissertation reports, magazines, newsletters, and Internet materials, was conducted to gain background knowledge about the marine-construction industry and related issues, specifically risk features. That is, the goal of the literature review was to develop an overall research framework and to prepare an appropriate template for questionnaires survey.

3.2.2 Survey Questionnaires

The survey method was selected in this study to collect data through a questionnaire technique. The selection of this technique was due the following reasons: the survey method is inexpensive compared to other techniques, saves researchers and respondents time, provides privacy for participants, provides respondents with readable and understandable context of questions, and removes interviewer expectations from respondents (Chan, 2011).

In addition, questionnaires are an effective tool in constructing a survey to collect data remotely from respondents, and to sample participants' responses in different locations (Chan, 2011). Generally, researchers design questionnaires to obtain data from participants by choosing a set of answers for each question. Two structured questionnaires were developed in this study to help in obtaining opinions from industry experts who are actively engaged in managing various marine-construction or related projects.

Questionnaire 1 (Marine construction project' risk factors). The International Organization for Standardization/Draft International Standards 31000 (2009) states that risks can be assessed by their probabilities of occurrence and their consequences. An effective method to assess the significance of a risk is the evaluation of the probability of occurrence and potential impact the risk would have on a marine-construction project. Thus, the questionnaire was structured to determine occurrence frequency and the actual impact of identified risks. The primary data collected from the survey questionnaire helped to understand how practitioners in this industry perceived risk factors. The questionnaire had three parts. The first part was designed to capture participants' information such as a participant's role, level of education, and personal experience. The second part of the questionnaire gathered data on the risk factors inherent in the execution of marine projects. In the third part of the questionnaire, data on the impacts of the identified risk factors on project cost, time, and safety was sought.

A 5-point Likert-type scale was employed as a measurement scale to evaluate the frequency of occurrences and the impacts of identified risk factors. In considering occurrence frequency, respondents judged the likelihood of risk occurrence by selecting one of five proposed levels: 1 (very low), 2 (low), 3 (moderate), 4 (high), and 5 (very high). For severity impacts on project time, cost, and safety, respondents judged the degree of loss if a specific risk occurred by selecting one of five options: 1 (very low), 2 (low), 3 (moderate), 4 (high), and 5 (very high).

Questionnaire 2 (Marine construction project' risk triggers). The questionnaire was structured to evaluate the weight of importance of identified marine-construction risk triggers and the similarities of risks caused by these triggers. The questionnaire had three parts as following: the first part collected demographic information from respondents including each respondent's role, work experience, and other related information, the second part was structured to evaluate the importance of the marine-construction project risk triggers in the assessment of risks. The third part explored the similarities of risks caused by risk triggers.

A 5-point Likert-type scale was employed as a measurement scale to rate the weight of the importance of risk triggers by selecting one of the five proposed responses: 1 (very low), 2 (low), 3 (moderate), 4 (high), and 5 (extremely high). Also, a 5-point Likert-type scale was employed as a measurement to rate the similarity of risks caused by risk triggers by selecting one of the five proposed levels: 1 (not at all similar), 2 (slightly similar), 3 (moderate similarity), 4 (highly similar), and 5 (Exactly similar).

3.2.3 Pilot-Survey Questionnaire

To improve the appropriateness and practicality of the survey questionnaires, two pilot-survey questionnaires were developed before launching the above questionnaire surveys in Saudi Arabia. The two pilot surveys were sent to five experts in construction projects and requested to review and comment on the draft survey. The comments obtained from the panel of experts were revised accordingly to increase clarity and suitability of the surveys.

3.3 Research Population and Sample

3.3.1 Research Population

The sample comprised key stakeholders in the marine-construction industry including contractors, owners, and consultants. These stakeholders were drawn from a cross-section of Saudi Arabian cities including Riyadh, Jeddah, Dammam, Jazan, and Thuwal. The specialists for this research were selected because they are well versed in the nature of risks involved during the execution of projects. Therefore, they were able to give accurate and reliable information about the risks that affect the execution of marine projects. Riyadh and Jeddah host major construction firms so were appropriate to select for this study.

3.3.2 Research Samples

The population provided two samples, initially targeting CEOs, project directors, managers, construction directors, managers, and health, safety, and environment directors and managers. The first structured questionnaire survey was conducted from August 2018 to

December 2018. The questionnaires were distributed through e-mail and through the professional online questionnaire platform www.docs.google.com. On the other hand, the second structured questionnaire was conducted from October 2018 to January 2019. The questionnaires were distributed through e-mail and through the professional online questionnaire platform SurveyMonkey.

3.4 Data Analysis

The collected data was accrued and analyzed using the Microsoft Excel and R (Programming language for statistical computing and graphics) software to perform the following descriptive and inferential statistics.

3.4.1 Reliability

To ensure the reliable testing of data, the Cronbach's alpha method was used. Cronbach's alpha is the most common measure of internal consistency reliability. It is most commonly used when researchers use multiple Likert-type questions to form a scale and must determine the reliability of the scale (Hung, Bhagayatulya, & Jacobs 2014). Cronbach's alpha determines the internal consistency or average correlation of items in a survey to measure its reliability. Cronbach's basic equation for alpha (Cronbach, 1951) follows:

$$\alpha = \frac{n}{n-1}\left(1 - \frac{\sum V_i}{V_t}\right) \tag{2}$$

Where,

n = number of questions

V_i = variance of scores on each question

V_t = variance of test scores

3.4.2 Correlation Coefficient

The correlation coefficient measures the strength of association between two variables. The Pearson coefficient method was used in this study to measure the relationship between frequency and the impact of risks. Pearson's r is the most widely used statistic when describing the relationship between variables. The correlation coefficient is computed using the following formula (Levine, Ramsey, & Smidt, 2000).

$$r = \frac{\sum_{i=1}^{n}(X_i - \bar{X})(Y_i - \bar{Y})}{\sqrt{\sum_{i=1}^{n}(X_i - \bar{X})^2}\sqrt{\sum_{i=1}^{n}(Y_i - \bar{Y})^2}} \tag{3}$$

Where,

r = Pearson's coefficient of correlation,

n = Number of data sets,

X_i = Frequency of occurrence of risks,

Y_i = Impact of risk on project objectives,

$\overline{X}$ and $\overline{Y}$ = Mean of frequency and impact data.

3.4.3 Risk Analysis

Data compiled from respondents was analyzed using the multi-attribute analysis method. The multi-attribute analysis method was devised by Mbachu and Nkado (2006) based on the Multi-Attribute Approach of Chang and Ive (2002), Mbachu (2011). The Multi-Attribute Analysis was used and adapted by several researchers (Mbachu & Nkado, 2006, 2007). The analysis involved computing the mean rating (MR) of respondents' ratings, using the following formula:

$$\mathrm{MR} = \sum_{i=1} a_i b_i \tag{4}$$

Where;

a_i: proportions of the responses associated with a rating point,

b_i: Likert-type rating points from 1 (the lowest scale) to 5 (the highest scale).

Risk score. Researchers use a mean rating analysis to evaluate respondents' rating on the rating scale used for the frequency of occurrences and impacts of an identified variable. The risk-score formula used in the calculation was adapted by Mbachu (2011) from the qualitative risk-analysis procedure recommended in the Project Management Body of Knowledge (PMI, 2008).

$$\mathrm{RS_i} = \mathrm{MR(Freq)_i} \times \mathrm{MR(Severity)_i} \quad (5)$$

Where;

$\mathrm{RS_i}$: Risk score for identified risk factor i

$\mathrm{MR(Freq)_i}$: Mean rating of frequency ccurrence for each risk factor i

$\mathrm{MR(Severity)_i}$: Mean rating of severity impact for each risk factor i

Assessing the total severity impacts of identified risk factors. The decision on total-severity impacts of identified risk factors can be taken based on risk attitude decisions. Three decision criteria are based on preference as pessimistic, most likely, and optimistic decisions. In this study, the pessimistic and most likely approaches were conducted using the following formulas:

1. Severity impact based on pessimistic decision yields the following:

$$SI(Pes) = Max[Time\ Impact(TI), Cost\ Impact(CI), Safety\ Impact(SI)] \quad (6)$$

2. Severity impact based on Most-like decision:

$$SI(M) = \frac{TI+CI+SI}{3} \quad (7)$$

Thus, the mean ratings for severity based on most likely and pessimistic decisions were computed as:

$$\mathrm{MR(Severity)} = [\mathrm{MR(Schedule\ impact)} + \mathrm{MR(Cost\ impact)} + \mathrm{MR(Safety\ impact)}]/3$$

$$\mathrm{MR(Severity)} = \mathrm{Max}[\mathrm{MR(Schedule\ impact)}, \mathrm{MR(Cost\ impact)}, \mathrm{MR(Safety\ impact)}]$$

Risk level. An impact-frequency (I-F) chart was used in the risk analysis to enable classification of risk factors based on their risk scores, computed from impact and frequency ratings. The (I–F) chart was designed as shown in Figure 2; it is a modification of the probability and impact matrix of the Project Management Book of Knowledge (PMI, 2008), which classifies the risk level of a risk factor as low, moderate, or high. Moreover, Mbachu (2011) extended the three-band set of risk categories to a five-band set to present solid discrimination of the risks based on risk scores. However, the five classes of risk level were extended in this study to seven categories to provide strong clustering of risks based on their risk scores.

Figure 2 shows a matrix of 5 X 5 rating scales for each dimension of impact and occurrence frequency giving 25 cells as possible intersections. Thus, the risk level for each risk can be computed as:

$$RL_i = \frac{RS_i}{25} \tag{8}$$

Table 6 provides classification of risk levels based on I-F Figure 2.

Severity Impact	5	**(1)** VH CI = 1	**(2)** VH CI = 0.80	**(5)** H CI = 0.60	(9) HM CI = 0.40	(16) LM CI = 0.20
	4	(3) VH CI = 0.8	(4) H CI = 0.64	(7) HM CI = 0.48	(12) M CI = 0.32	(18) LM CI = 0.16
	3	(6) H CI = 0.60	(8) HM CI = 0.48	(11) M CI = 0.36	(14) M CI = 0.24	(21) L CI = 0.12
	2	(10) HM CI = 0.40	(13) M CI = 0.32	(15) M CI = 0.24	(20) L CI = 0.16	(23) VL CI = 0.08
	1	(17) LM CI = 0.20	(19) LM CI = 0.16	(22) L CI = 0.12	(24) VL CI = 0.08	(25) VL CI = 0.04
		Frequency of occurrence				

Figure 2. impact-frequency (I-F) chart.
VH= very high level, H = High, HM = high medium, M = medium, LM = low medium, L= low, VL = very low; CI = critical index.

Table 5 *Classification of criticality index based on the impact-frequency chart*

Level index	Risk class
0.80–1.00	Very High (VH)
0.60–0.79	High (H)
0.50–0.59	Highly Moderate (HM)
0.31–0.49	Moderate (M)
0.20–0.30	Lowly Moderate (LM)
0.10–0.19	Low (L)
0.00–0.09	Very Low (VL)

Chapter Four: The Development of the Risk-Level Predictor Framework

The proposed RLPF in this study uses the CBR approach to perform the cases reasoning mechanism, and the IDEF0 to define the system process shown in Figure 3. The way the system functions is that when managers of a new marine-construction project seek to know significant risks and their levels of riskiness they may face in this project, the system users in charge of the risk evaluation can enter information in the system knowledge database about the new project (case) on the following risk triggers:

- Structure type
- Contract type
- Owner type
- Construction-execution approach
- Site location
- Cost
- Time

Once this information has been registered, the system matches the entered risk triggers with the ones stored in the MCDB, based on the similarity threshold set by the user. The system can then retrieve similar cases in this process. Then, risk-level reports for the retrieved cases are compiled to help propose a new risk prediction report for the new case. The proposed solution is then revised to include a predicted risk-assessment report for the new case. Finally, the new case that includes risk-triggers information and predicted risk-levels is stored in the system knowledge database to help inform future cases, thus updating the system.

This chapter covers the development of Risk-Level Predictor Framework (RLPF), which consists of three phases as: cases collection, classification, and reasoning Figure 4.

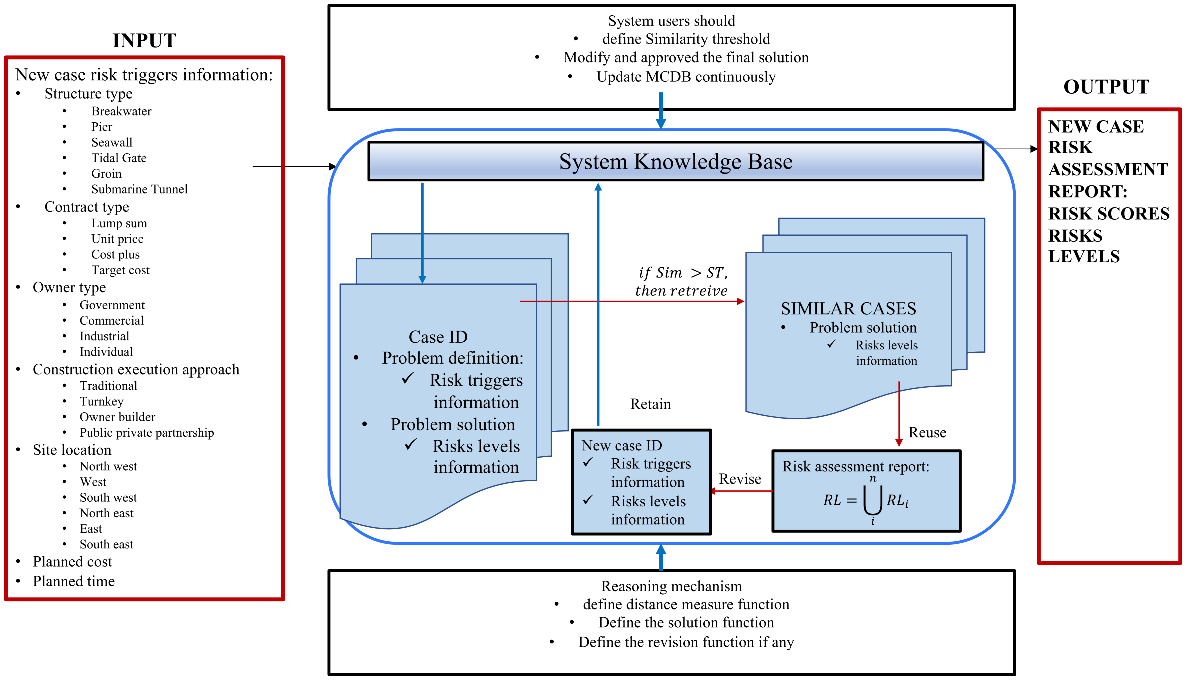


Figure 3. The proposed RLPF process

4.1 Cases Collection

The main objective of this phase is to evaluate the identified risk factors and triggers associated with marine-construction projects using the methodology explained in Chapter 3 and yielding the detailed results presented in Chapter 5.

4.1.1 Risk Identification

To develop a set of risk factors for this study, a list of all possible risks faced in marine construction in the past was tabulated in Table 4. The comprehensive list of risk factors was combined and reduced to 37 questions presented in Survey Questionnaire 1, shown in Table 6. The risks are stated in no particular order of importance, magnitude, or otherwise.

4.1.2 Risk Classification

In this task, the hierarchical structure was used to classify risks according to their origin and the location of the risk impact in the project. A Risk Breakdown Structure was constructed in this research to organize the different categories of project risk as shown in Figure 5. The proposed RBS for the identified risk factors in Figure 6 shows risk groups, risk categories, and risk subcategories at the lowest level. Project risks were categorized based on their source (either internal or external). Internal risks are those generated from project stakeholders and external risks are those risks that come from sources others than the project's stakeholders. Internal and external risks are then classified according to the party who might be the originator of risk events such as owner, designer, contractor, and others initiated at the macro level.

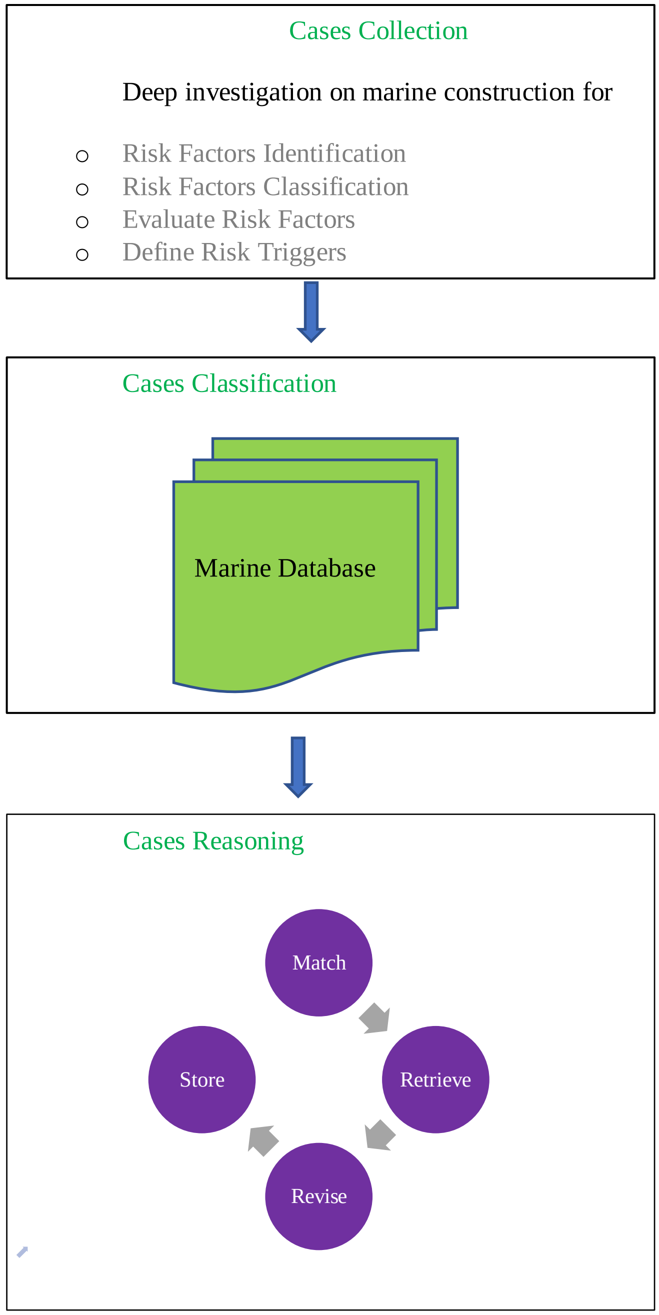


Figure 4. The proposed RLPF development phases

Table 6 *Identified risk factors for questionnaire 1*

Risk ID	Risk factor
RF1	Inadequate/unclear definition of project scope
RF2	Delay in Work/Labor Permits, Licenses
RF3	Delay in Land/Water Acquisition or Site Access
RF4	Lack of coordination between project participants
RF5	Design errors
RF6	Delay in Documents Approval
RF7	Improper Underwater Condition
RF8	Equipment Unavailability
RF9	Contractors' Lack of experience/trained staff
RF10	Unskilled Labor
RF11	Manpower Unavailability
RF12	Low Productivity
RF13	Construction errors
RF14	Accidents
RF15	Contractor's Financial difficulties
RF16	Unreliability of Construction Equipment
RF17	Loading/unloading of material
RF18	Poor site management and supervision
RF19	Frequent change of sub-contractors
RF20	Improper construction methods implemented
RF21	Contractor's Bankruptcy
RF22	Subcontractors interferences
RF23	Incompetence of Subcontractors
RF24	Delay of material Supply by Vendor/supplier
RF25	Technical problems with Vendors/suppliers
RF26	Poor Material Selection
RF27	Laws & Regulations Change
RF28	Inflation for Material Price more than estimated
RF29	Fluctuating currencies exchange rates
RF30	Inconsistencies in government policies
RF31	Sever weather condition
RF32	Environment Pollution
RF33	Ecological Damage
RF34	Social/Culture Common Policy
RF35	Contagious diseases
RF36	Criminal acts
RF37	Bureaucracy of government

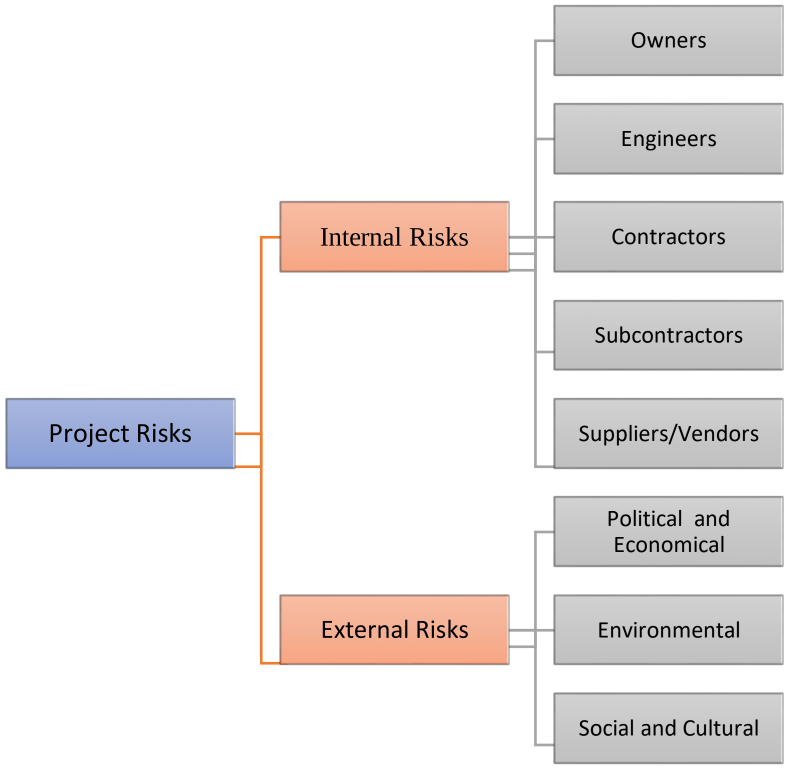


Figure 5. Proposed risk breakdown structure

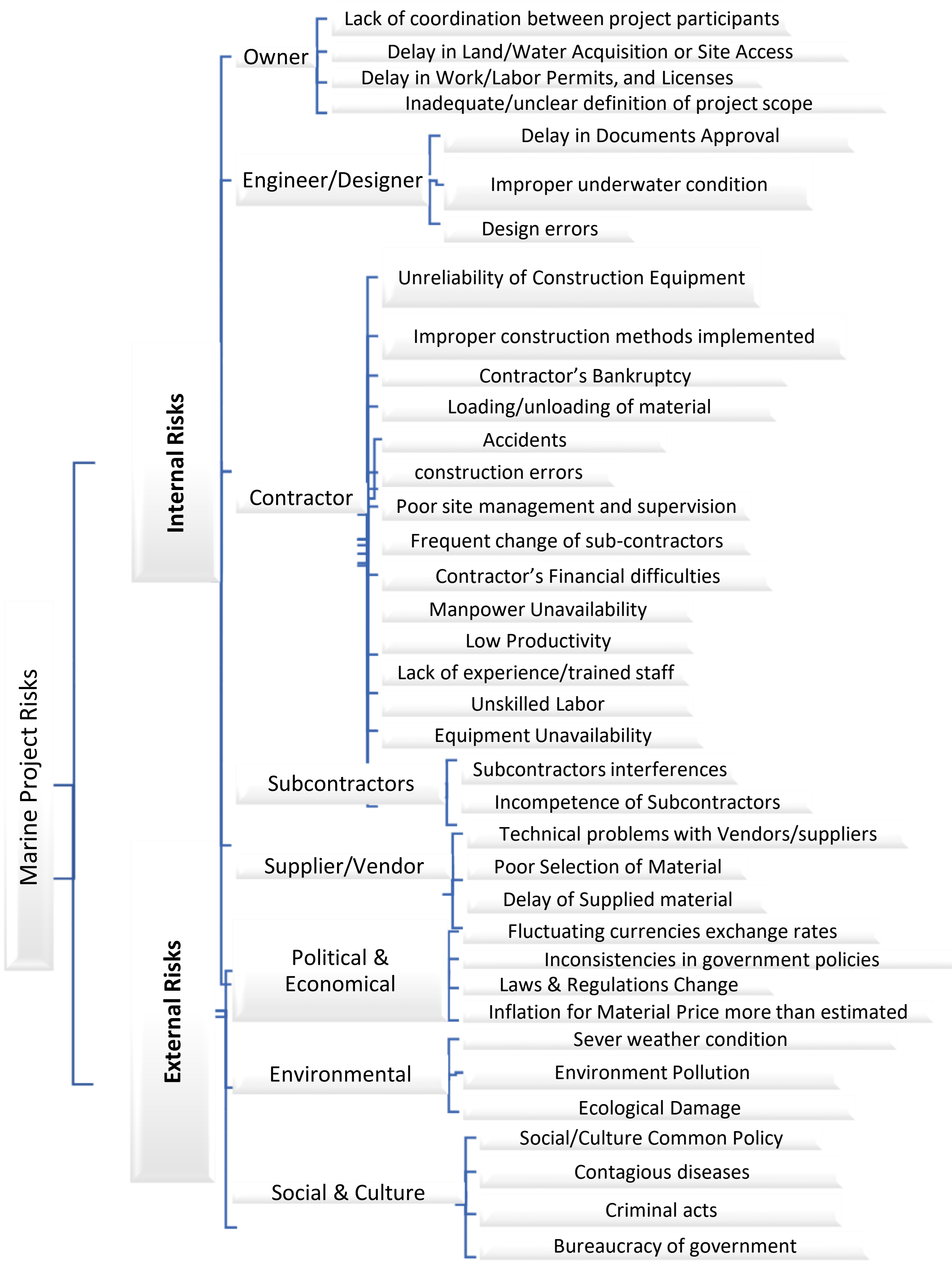


Figure 6. Risk-factors classification

4.1.3 Risk Triggers

In this study data was collected and analyzed using quantitative analysis to identify, classify and evaluate the common risk triggers of marine-construction projects. Seven risk triggers were identified as definite events, facts, or requirements of a marine construction project that may produce risks. The hierarchy structure of the identified risk triggers is proposed in Figure 7. In addition, the weights of importance for the identified risk triggers, and similarity measures of risks produced by each risk trigger in different marine-construction projects were computed. Chapter 5 presents the results.

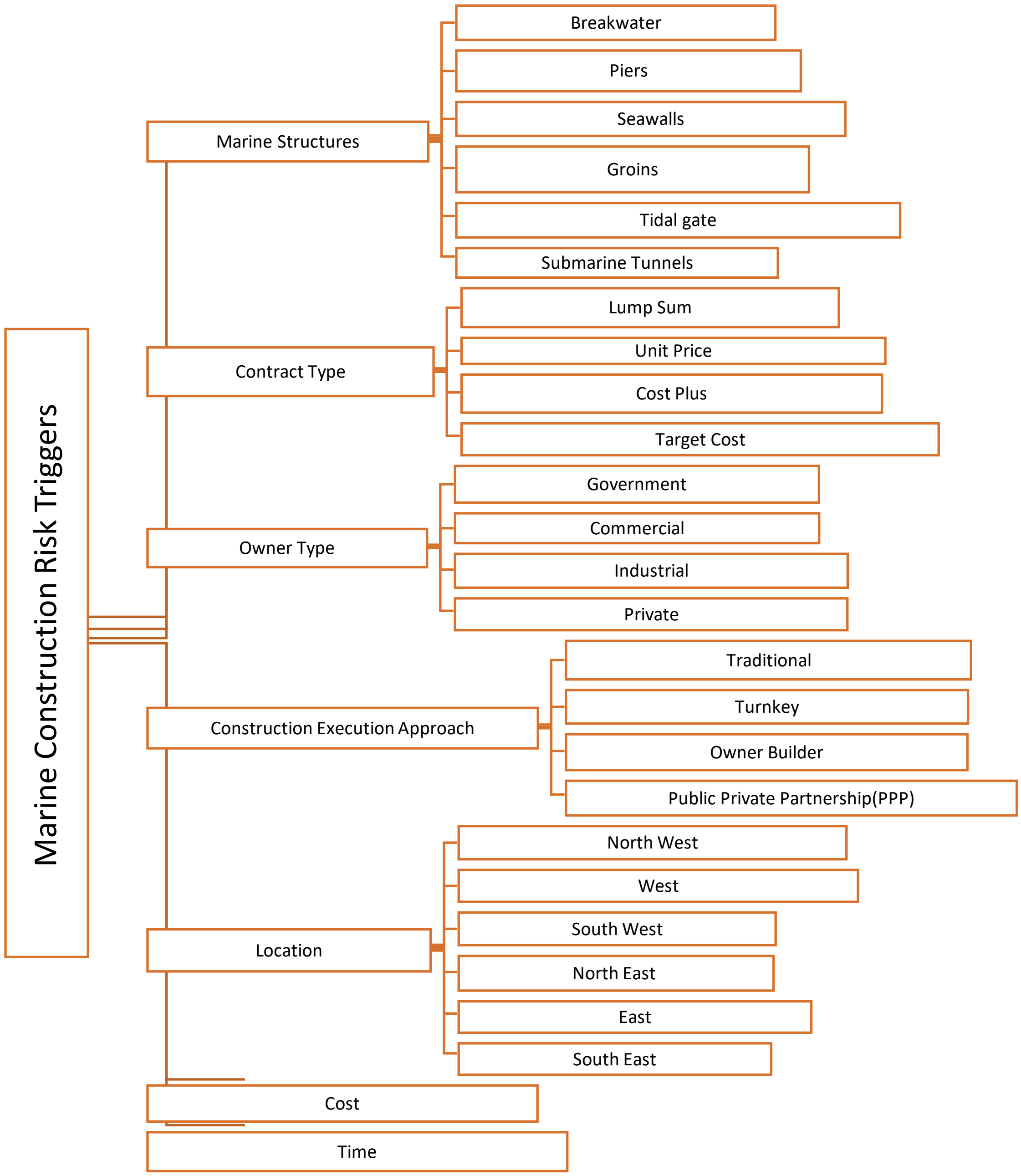


Figure 7. Risk breakdown structure of identified risk triggers in marine-construction projects

Structure types. In offshore construction and marine-operation projects, the main risk normally aligns with damage to or loss of structural elements (Gudmestad, 2002). Thus, the type of structures to be constructed in marine projects can be consider risk triggers. Often, the risks associated with the construction of marine structures are similar. Table 7 shows six types of marine structures identified for this study.

Table 7 *Marine structure types*

Marine structure types
Breakwater
Piers
Seawalls
Tidal Gate
Groins
Submarine Tunnels

Contract type. Currently, the local industry has adopted certain measures to manage risks like changes in contractual arrangement, risk sharing with contractors, and implementing a risk-management system (Tam & Shen, 2012). Accordingly, contract type can be considered a common risk trigger for marine-construction projects. Marine-construction project managers mainly use four types of contracts, shown in Table 8.

Table 8 *Contract types*

Contract types
Lump sum
Unit price
Cost plus
Target cost

Owner type. The most significant risk occurred in design and build, including time and cost overruns (Karim, Rahman, Memmon, Jamil, & Azis, 2013). The major factors responsible for these risks are employer or government delays, lack of information from the employer, difficulty following instructions, conflict of interest, and changes. Generally, most marine-construction projects are owned by governments, commercial firms, industrial firms, or an individual. Thus, risks associated with different marine-construction projects owned by governments, for instance, can be viewed as similar. Table 9 shows four types of marine-construction owners in Saudi Arabia.

Table 9 *Owner types*

Owner types
Government
Commercial
Industrial
Private

Construction execution approaches. Selection of inappropriate construction approach in executing the work is also a risk trigger in marine-construction projects. An inappropriate approach increases the chances of redoing already executed work, which further delays projects. Consequently, some similarities of risks align with each type of construction execution approach. In particular, four common construction-execution approaches were identified, shown in Table 10.

Table 10 *Construction execution approaches*

Construction execution approaches
Traditional
Turnkey
Owner builder
Public–private partnership

Site location. Marine projects constructed along the west or east coasts of Saudi Arabia share common weather conditions such as mean wind height, mean wave speed, and tide height. Thus, marine projects along the two coasts of Saudi Arabia can be classified based on their location as shown in Table 11.

Table 11 *Site locations within two coasts of Saudi Arabia*

Project location at Saudi Arabia coasts
Northwest coast
West coast
Southwest coast
Northeast coast
East coast
Southeast coast

Project cost. According to Westney (2001)With the drilling and development cost of deep-water projects often exceeding $1 billion, owners, partners, and contractors need, more than ever, the ability to:

- set realistic yet reasonable cost and schedule contingencies;
- know the probability of cost overruns and schedule delays;
- know the probability that the sanctioned cost and schedule will be achieved;
- understand the accuracy of a cost estimate or schedule; and
- ensure that project teams identify risks and implement a Risk Mitigation Plan. (p. 1)

As a result, the planned budget to complete marine projects can be considered a risk trigger. For example, marine projects constructed in the same period of time with closed budgets faced almost similar risks.

Project time. Usually, projects constructed in similar time frames faced similar risks related to schedule. Therefore, I considered the execution time of marine projects a risk trigger in this study.

4.2 Case Classification

The main purpose of this phase is to construct a marine construction database (MCDB) that will be used in the cases reasoning mechanism of the RLPF.

4.2.1 Marine Construction Database (MCDB)

A database is a collection of information organized to be easily accessed, managed, and updated. Accordingly, the data gathered from the cases collection phase was compiled and organized to build the MCDB into rows and columns, indexed to make it easier to find relevant information. That is, the rows data represent the number of stored marine construction cases, and the columns data define the identified risk triggers and the most significant risk factors information about stored cases as illustrated in Table 12. Thus, whenever risk-triggers data for a new case is entered in the system knowledge database, the system matches the entered risk triggers with the ones stored in the MCDB, based on the similarity threshold set by the user. Moreover, the MCDB be updated, expanded, or deleted as needed by the system users.

Table 12 *Required information for marine construction database*

	Problem definition Risk triggers							Problem solution Risk levels		
Case ID	RT1	RT2	RT3	RT4	RT5	RT6	RT7	RL1	RL2	RL3

Note. RT = risk triggers, RL = risk levels.

4.3 Case Reasoning

The development of reasoning mechanism for the RLPF consists of the following tasks:

- Define the distance measure function (f), which can be used to retrieve similar cases.
- Define the proposed solution function (g), which can be used to propose a solution.
- Define the final solution function (h), which can be used to revise the proposed solution.

4.3.1 Case Retrieval

The utmost topics in using the CBR approach are how to represent knowledge in the system, how to identify important features, how to select the best old case if more than one match is available, and how to perform the matching process efficiently by applying different policies. However, the system accomplishes this matching in many ways, such as through the nearest-neighbor method, the induction method, the knowledge-based induction method, and the template-retrieval method (Soto & Adey, 2015). Thus, the city block distance was used in this study to measure similarities of risks caused by pairs of quantitative identified risk triggers, (cost and time) using the following formula:

$$Dist(X_o, X_j) = \sum_{i=1}^{n} |x_{0i} - x_{ji}| \times w_i \tag{9}$$

Where, X_o = Existing case, where $o \in (1, k)$; k = number of existing cases

X_j = target (i.e., new) case

x_{oi} = scaled value of the i^{th} risk trigger for the existing case (X_o)

x_{ji} = scaled value of the i^{th} risk trigger for the target case (X_j)

n = number of risk triggers = 7

w_i : weight assigned to the i^{th} risk trigger.

Weights can be evaluated from regression models, connections in the neural network, equal importance, or on expert opinion (Soto & Adey, 2015). In this study, the weights of risk triggers were obtained using the mean rating analysis presented in Chapter 5, using the following formula:

$$w_i = MR_i / \sum_{i=1}^{7} MR_i \tag{10}$$

Moreover, the distance-measure function was applied after normalizing the quantitative risk triggers, such as cost and time, as in the following formula:

$$X_{i,norm} = \overline{X_i} = \begin{cases} \frac{X_i - X_i^{min}}{X_i^{max} - X_i^{min}} \ ; \ \forall \ X_i^{max} > X_i^{min} \\ 0.5 \ ; \ \forall \ X_i^{max} = X_i^{min} \end{cases} \tag{11}$$

Where,

$X_{i,norm}$: Normalized value between 0 and 1

X_i : Raw parameter to be normalized

X_i^{min} : Minimum value for risk trigger X_i (minimum of input or existing)

X_i^{max} : Maximum value for risk trigger X_i (maximum of input or existing)

However, the similarity measure for qualitative risk triggers was defined by the linguistic-conversion variables shown in Table 13. The conversion values were computed by dividing the mean ratings, obtained for the similarity of risks caused by pairs of identified risk-triggers, by the maximum rating (5), to normalize similarity scales between 0 and 1.

Table 13 *Similarity measures for linguistic variables*

Linguistic variable	Conversion value
Not at all similar	0.00–0.20
Slightly similar	0.20–0.40
Moderate similarity	0.40–.60
Highly similar	0.60–0.80
Exactly similar	0.80–1.00

Therefore, the similarity function (f) is:

$$Sim(X_o, X_j) = \left[\sum_{i=1}^{5} Sim(x_{0i}, x_{ji}) \times w_i\right] + \left[\sum_{i=6}^{7} (1 - |x_{0i} - x_{ji}|) \times w_i\right] \qquad (12)$$

4.3.2 Case Reuse

In this process, the union function (g) was used to compile the solutions (risks-levels) from the retrieved cases using the following formula

$$RL_{new} = \cup_{i=1}^{l} RL_i \qquad (13)$$

Where,

$\mathrm{RL_{new}}$: Proposed risks levels for the new case

$\mathrm{RL_i}$: Risks levels associated with a stored case i

$l =$ number of retrieved cases

4.3.3 Case Revised

The proposed solution is then revised and approved by user interventions; otherwise the function (h) will be the same as the proposed function (g). Thus, the final solution includes a prediction of risk assessment for the new marine construction case.

4.3.4 Case Retained

Finally, the information about the new case's risk triggers and predicted risks-levels is saved into the system knowledge database to inform future cases, thus updating the MCDB.

Chapter Five: Implementation and Results

The specific objectives of this research are: 1) to assess risks associated with marine-construction projects; 2) to predict risks-levels that new marine projects may face. In this chapter, data collected through questionnaire surveys were analyze using basic descriptive and inferential statistical tools. The findings of the analysis provided information on risk assessments for marine-construction projects, evaluation of marine-construction risk-triggers, and implications for the RLPF.

5.1 Results of the Questionnaire Survey on Risk Assessment in Saudi Arabia

A total of 40 questionnaires was distributed through e-mail and through the professional online questionnaire platform www.docs.google.com. These questionnaires targeted professionals in the Saudi Arabian marine-construction industry. 25 valid responses were received, resulting in a response rate of 62.5%.

5.1.1 Reliability Analysis

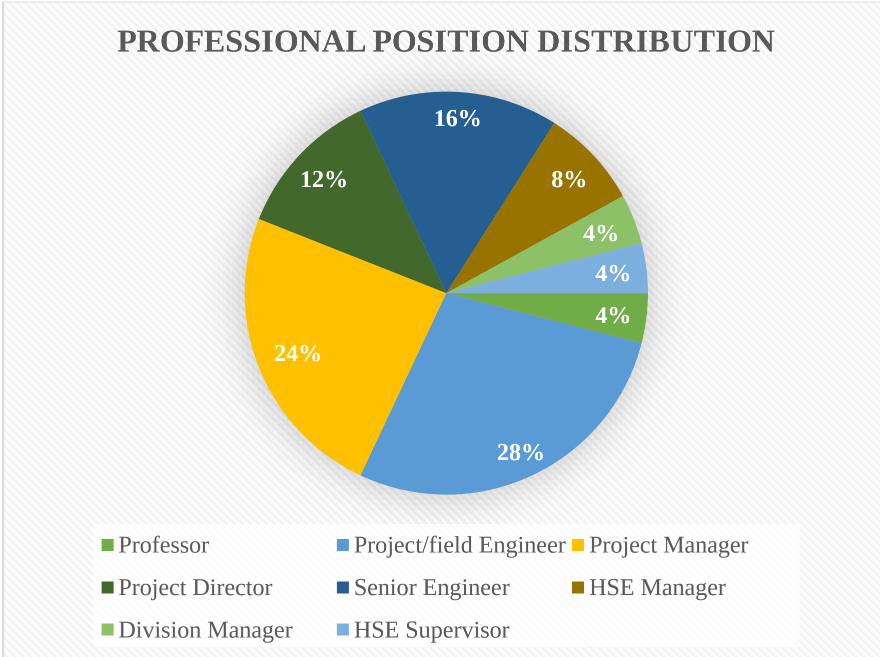
Reliability and internal consistency checks were carried out using Cronbach's α on the 37 constructs in the questionnaire to assess their suitability for analysis. α values greater than 0.7 is regarded as sufficient (Karim, et, al, 2013). Cronbach's coefficient α was 0.910, which was higher than the 0.7 threshold and thus indicated the reliability of the 5-point measurement scale at the 5% significance level.

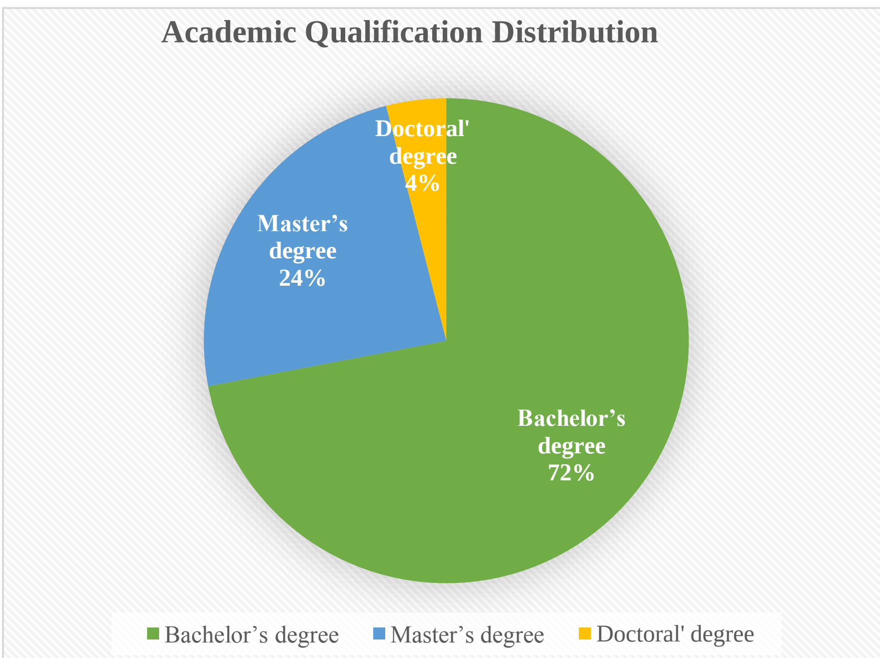
5.1.2 Respondents Profile

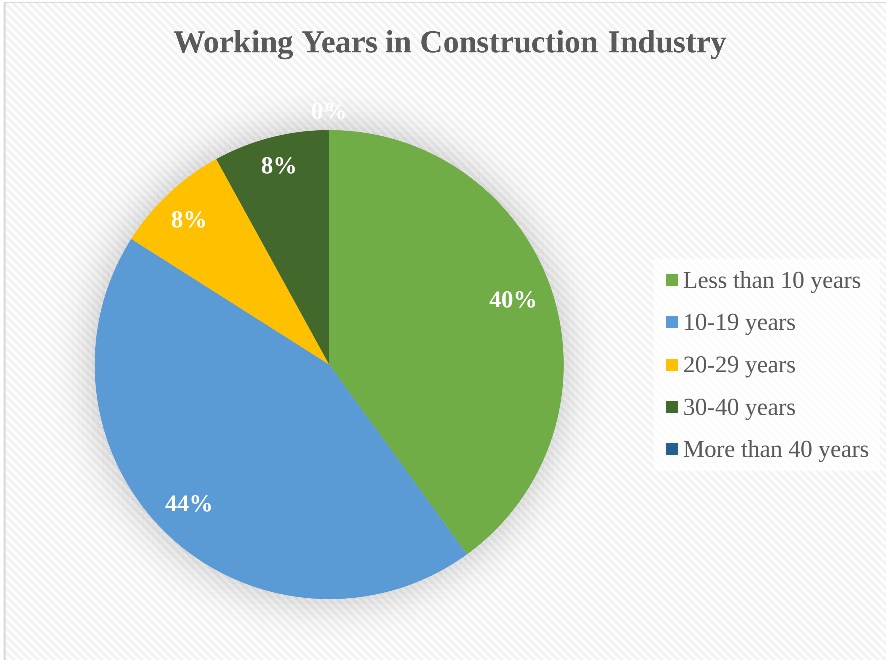
Table 14 and Figure 8 show a profile of respondents to the questionnaire survey. A reasonable spread of responses emerged across the major professions including 24% responses from project managers, 12% responses from project directors, and 8% from health, safety, and environmental managers. The results also indicated a diverse set of academic backgrounds among usable responses received, as almost 72% had bachelor’s degree whereas 24% had a master’s degree.

Table 14 *Respondents profile distribution*

Metrics	Frequency	Proportions %
Professional position		
Professor	1	4
Project/field Engineer	7	28
Project Manager	6	24
Project Director	3	12
Senior Engineer	4	16
HSE Manager	2	8
Division Manager	1	4
HSE Supervisor	1	4
Total	25	100
Academic qualification		
Bachelor’s degree	18	72
Master’s degree	6	24
Doctoral’ degree	1	4
Total	25	100
Years of experience in construction industry		
Less than 10 years	10	40
10–19 years	11	44
20–29 years	2	8
30–40 years	2	8
More than 40 years	0	0
Total	25	100
Working number of marine construction projects		
Less than 5 Projects	19	76
5–9 Projects	3	12
10–14 Projects	2	8
15–20 Projects	0	0
More than 20 Projects	1	4
Total	25	100
Contract types mostly used in marine construction projects		
Lump sum	20	80
Unit price	3	12
Cost plus	0	0
Target cost	2	8
Total	25	100


PROFESSIONAL POSITION DISTRIBUTION
16%
12%
8%
4%
4%
4%
24%
28%
Professor
Project/field Engineer
Project Manager
Project Director
Senior Engineer
HSE Manager
Division Manager
HSE Supervisor


Academic Qualification Distribution
Doctoral' degree 4%
Master’s degree 24%
Bachelor’s degree 72%
Bachelor’s degree
Master’s degree
Doctoral' degree



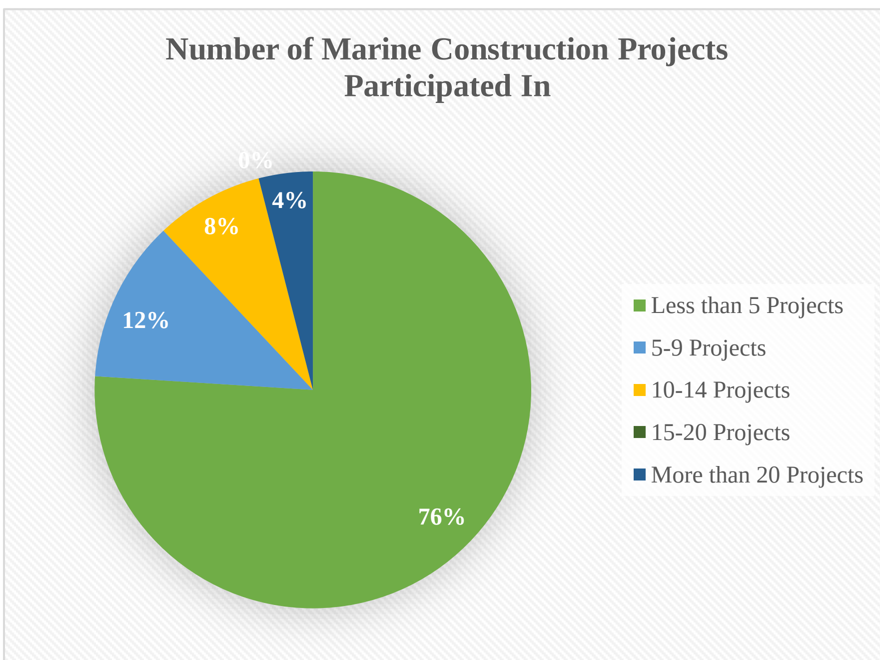


Figure 8. Demographic frequencies.

5.1.3 Analysis of the Occurrence Frequency of Identified Risk Factors

To assess the frequency of occurrence of the risk factors, data were generated from 25 responses and analyzed using R software. Mean ratings provided by respondents, standard deviations, skewness, kurtosis, standard errors, and ranking of occurrence for the 37 identified risk factors appear in Table 15.

5.1.4 Analysis of the Impacts of Identified Risk Factors

Findings on this section provide mean ratings of respondents, standard deviations, skewness, kurtosis, and standard errors for the impacts of identified risk factors on project safety, cost, and schedule, shown in Tables 16, 17, and 18.

The total severity impact of identified risk factors was calculated, as stated in Chapter 3, as

$$SI(Pes) = Max[Time\ Impact(TI), Cost\ Impact(CI), Safety\ Impact(SI)]$$

Table 19 shows ranking of the most severe risk factors on project objectives, based on pessimistic decisions.

5.1.5 Correlation Analysis

Correlations between frequency of occurrences and impacts of the identified risk factors are presented in Table 20.

Table 15 *Risks occurrence frequency*

	MR	*SD*	Skew	Kurtosis	Rank of occurrence
RF10	3.48	1.05	0.05	-1.27	1
RF9	3.36	1.22	-0.28	-0.96	2
RF11	3.32	0.90	0.03	-0.98	3
RF2	3.28	1.06	-0.14	-0.83	4
RF12	3.24	0.93	-0.16	-0.07	5
RF7	3.20	1.12	-0.03	-1.14	6
RF25	3.20	0.91	0.25	-0.91	7
RF15	3.08	1.08	-0.53	-0.61	8
RF1	3.04	1.14	0.09	-0.83	9
RF4	3.04	0.93	-0.07	-0.64	10
RF8	3.04	1.21	-0.35	-0.94	11
RF13	3.00	0.96	0.00	-0.81	12
RF24	3.00	0.96	0.00	-0.81	13
RF6	2.96	0.84	0.07	0.28	14
RF16	2.96	0.89	0.07	-0.24	15
RF3	2.92	1.08	0.15	-0.73	16
RF23	2.92	0.91	-0.17	-1.23	17
RF5	2.88	0.93	-0.08	-0.05	18
RF20	2.88	1.09	-0.33	-0.71	19
RF26	2.88	1.17	0.22	-0.70	20
RF37	2.84	1.18	0.15	-1.08	21
RF14	2.76	1.27	0.32	-1.05	22
RF18	2.76	1.09	-0.10	-0.82	23
RF31	2.72	1.46	0.24	-1.40	24
RF32	2.72	1.34	0.29	-1.25	25
RF19	2.56	1.26	0.11	-1.36	26
RF22	2.52	0.92	0.10	-0.95	27
RF27	2.52	1.12	0.29	-0.87	28
RF28	2.44	0.96	-0.11	-1.10	29
RF30	2.44	1.26	0.37	-1.27	30
RF33	2.44	1.08	0.24	-0.62	31
RF17	2.40	1.04	0.47	-0.30	32
RF34	2.36	1.11	0.34	-0.70	33
RF29	2.32	0.99	0.11	-1.16	34
RF21	2.28	1.02	0.13	-1.26	35
RF35	1.96	1.21	1.03	-0.17	36
RF36	1.60	1.00	1.30	0.21	37

Table 16 *Safety impacts of risk factors*

Safety Impacts of Risk Factors					
Risk ID	Mean	*SD*	Skew	Kurtosis	*SE*
RF1	2.80	1.19	0.23	-0.64	0.24
RF2	2.48	1.36	0.18	-1.57	0.27
RF3	2.44	1.23	0.85	-0.23	0.25
RF4	2.56	1.47	0.22	-1.65	0.29
RF5	2.52	1.45	0.60	-1.14	0.29
RF6	2.08	1.29	0.87	-0.39	0.26
RF7	3.12	1.39	-0.20	-1.20	0.28
RF8	2.48	1.36	0.47	-0.99	0.27
RF9	3.76	1.01	0.00	-1.42	0.20
RF10	3.64	1.29	-0.47	-0.9	0.26
RF11	2.68	1.41	0.21	-1.37	0.28
RF12	2.44	1.42	0.50	-1.15	0.28
RF13	2.80	1.26	0.48	-0.88	0.25
RF14	3.84	1.31	-0.99	-0.09	0.26
RF15	2.04	1.02	0.38	-1.26	0.20
RF16	3.32	1.49	-0.39	-1.32	0.30
RF17	2.40	1.29	0.27	-1.36	0.26
RF18	3.32	1.28	-0.24	-0.90	0.26
RF19	2.88	1.27	0.10	-1.12	0.25
RF20	3.24	1.42	-0.32	-1.17	0.28
RF21	2.40	1.26	0.46	-0.82	0.25
RF22	2.64	1.29	0.21	-1.20	0.26
RF23	3.24	1.27	-0.08	-0.85	0.25
RF24	1.88	1.05	0.84	-0.65	0.21
RF25	2.20	1.22	0.55	-0.93	0.24
RF26	3.16	1.46	-0.19	-1.38	0.29
RF27	2.08	1.29	0.98	-0.25	0.26
RF28	1.64	0.91	1.04	-0.21	0.18
RF29	1.44	0.77	1.78	2.76	0.15
RF30	2.04	1.31	0.90	-0.41	0.26
RF31	3.60	1.26	-0.46	-0.82	0.25
RF32	3.08	1.58	-0.19	-1.59	0.32
RF33	3.32	1.41	-0.29	-1.17	0.28
RF34	2.08	1.38	1.05	-0.26	0.28
RF35	3.12	1.45	-0.28	-1.30	0.29
RF36	3.16	1.55	-0.19	-1.48	0.31
RF37	1.88	1.09	1.15	0.61	0.22

Table 17 *Schedule impacts of identified risk factors*

Schedule Impacts of identified risk factors					
Risk ID	Mean	*SD*	Skew	Kurtosis	*SE*
RF1	3.76	0.83	0.02	-0.95	0.17
RF2	3.56	1.00	-0.51	-0.11	0.20
RF3	3.56	1.12	-0.31	-0.78	0.22
RF4	3.56	1.16	-0.68	-0.32	0.23
RF5	3.68	1.41	-0.74	-0.89	0.28
RF6	3.68	1.11	-0.44	-0.59	0.22
RF7	3.16	1.18	-0.44	-0.92	0.24
RF8	3.68	1.35	-0.52	-1.06	0.27
RF9	3.28	1.02	-0.10	-0.58	0.20
RF10	3.32	1.31	-0.05	-1.26	0.26
RF11	3.80	1.15	-0.56	-0.66	0.23
RF12	3.76	1.16	-0.46	-0.80	0.23
RF13	3.72	1.17	-0.36	-0.91	0.23
RF14	3.48	1.26	-0.55	-0.62	0.25
RF15	3.36	1.41	-0.54	-0.98	0.28
RF16	3.20	1.15	-0.37	-0.55	0.23
RF17	2.64	1.32	0.34	-1.05	0.26
RF18	3.64	1.15	-0.41	-0.82	0.23
RF19	3.72	1.10	-0.36	-0.60	0.22
RF20	3.40	1.44	-0.37	-1.22	0.29
RF21	3.60	1.38	-0.56	-0.98	0.28
RF22	3.20	1.08	-0.19	-0.44	0.22
RF23	3.52	1.05	-0.26	-0.45	0.21
RF24	3.96	1.02	-0.38	-1.26	0.20
RF25	3.36	1.22	-0.28	-0.96	0.24
RF26	3.36	1.32	-0.23	-1.00	0.26
RF27	3.28	1.10	0.36	-1.26	0.22
RF28	3.00	1.04	0.43	-0.48	0.21
RF29	2.40	1.08	0.34	-0.55	0.22
RF30	3.00	1.50	0.07	-1.53	0.30
RF31	3.40	1.26	-0.51	-0.75	0.25
RF32	2.80	1.38	0.16	-1.21	0.28
RF33	3.00	1.41	0.00	-1.32	0.28
RF34	2.44	1.29	0.74	-0.61	0.26
RF35	2.40	1.29	0.49	-0.94	0.26
RF36	2.88	1.56	0.13	-1.55	0.31
RF37	2.84	1.25	0.17	-1.00	0.25

Table 18 *Cost impacts of the identified risk factors*

Cost Impacts of identified risk factors					
Risk ID	Mean	*SD*	Skew	Kurtosis	*SE*
RF1	3.56	0.96	0.11	-1.10	0.19
RF2	3.08	1.00	0.09	-0.63	0.20
RF3	3.08	1.19	-0.15	-0.85	0.24
RF4	2.92	1.32	0.04	-1.04	0.26
RF5	3.48	1.42	-0.42	-1.26	0.28
RF6	3.00	1.35	0.10	-1.19	0.27
RF7	3.16	1.18	-0.30	-0.75	0.24
RF8	3.48	1.26	-0.31	-0.98	0.25
RF9	3.20	1.08	-0.38	-0.65	0.22
RF10	3.40	1.19	-0.34	-0.77	0.24
RF11	3.32	1.31	-0.26	-1.06	0.26
RF12	3.56	1.23	-0.33	-1.18	0.25
RF13	3.72	0.98	0.04	-1.31	0.20
RF14	3.36	1.35	-0.45	-0.93	0.27
RF15	3.36	1.38	-0.45	-1.07	0.28
RF16	3.36	1.15	-0.22	-0.58	0.23
RF17	2.52	1.29	0.34	-1.11	0.26
RF18	3.32	1.22	-0.20	-0.96	0.24
RF19	3.48	1.16	-0.18	-1.01	0.23
RF20	3.28	1.24	-0.14	-1.10	0.25
RF21	3.56	1.39	-0.48	-1.05	0.28
RF22	3.08	1.19	-0.15	-0.85	0.24
RF23	3.04	1.02	-0.08	-0.30	0.20
RF24	3.28	1.21	0.02	-1.29	0.24
RF25	3.08	1.15	0.32	-1.03	0.23
RF26	3.52	1.23	-0.37	-0.79	0.25
RF27	3.12	1.13	0.28	-0.95	0.23
RF28	3.60	1.19	-0.23	-1.06	0.24
RF29	3.00	1.41	0.17	-1.32	0.28
RF30	2.84	1.43	0.27	-1.34	0.29
RF31	3.40	1.32	-0.52	-1.05	0.26
RF32	2.96	1.49	-0.01	-1.49	0.30
RF33	3.20	1.47	-0.18	-1.33	0.29
RF34	2.28	1.21	0.84	-0.24	0.24
RF35	2.40	1.19	0.37	-1.01	0.24
RF36	2.80	1.47	0.26	-1.39	0.29
RF37	2.72	1.21	0.25	-1.04	0.24

Table 19 *Ranking of severity impact of identified risk factors*

Ranking of severity impact of identified risk factors					
Risk ID	MR (T1)	MR (CI)	MR (SI)	SI (Pes)	Rank
RF24	3.960	3.280	1.880	3.960	1
RF14	3.480	3.360	3.840	3.840	2
RF11	3.800	3.320	2.680	3.800	3
RF9	3.280	3.200	3.760	3.760	4
RF12	3.760	3.560	2.440	3.760	5
RF1	3.760	3.560	2.800	3.760	6
RF13	3.720	3.720	2.800	3.720	7
RF19	3.720	3.480	2.880	3.720	8
RF8	3.680	3.480	2.480	3.680	9
RF5	3.680	3.480	2.520	3.680	11
RF6	3.680	3.000	2.080	3.680	10
RF10	3.320	3.400	3.640	3.640	12
RF18	3.640	3.320	3.320	3.640	13
RF31	3.400	3.400	3.600	3.600	14
RF21	3.600	3.560	2.400	3.600	16
RF28	3.000	3.600	1.640	3.600	15
RF2	3.560	3.080	2.480	3.560	17
RF4	3.560	2.920	2.560	3.560	18
RF3	3.560	3.080	2.440	3.560	19
RF26	3.360	3.520	3.160	3.520	21
RF23	3.520	3.040	3.240	3.520	20
RF20	3.400	3.280	3.240	3.400	22
RF16	3.200	3.360	3.320	3.360	25
RF25	3.360	3.080	2.200	3.360	23
RF15	3.360	3.360	2.040	3.360	24
RF33	3.000	3.200	3.320	3.320	26
RF27	3.280	3.120	2.080	3.280	27
RF22	3.200	3.080	2.640	3.200	28
RF7	3.160	3.160	3.120	3.160	29
RF36	2.880	2.800	3.160	3.160	30
RF35	2.400	2.400	3.120	3.120	31
RF32	2.800	2.960	3.080	3.080	32
RF30	3.000	2.840	2.040	3.000	33
RF29	2.400	3.000	1.440	3.000	34
RF37	2.840	2.720	1.880	2.840	35
RF17	2.640	2.520	2.400	2.640	36
RF34	2.440	2.280	2.080	2.440	37

Note. MR = mean rating, T1 = time(schedule) impact, CI = cost impact, SI = safety impact, Pes = pessimistic.

Table 20 *Correlation between occurrence and impacts of risk factors*

Risk occurrence	Safety impact	Schedule impact	Cost impact
RF1	-0.086	-0.343	-0.097
RF2	0.279	-0.232	-0.258
RF3	0.311	-0.030	0.037
RF4	0.195	0.055	-0.132
RF5	0.235	0.033	0.045
RF6	**0.542**	-0.104	-0.109
RF7	0.198	0.006	0.037
RF8	0.369	0.136	0.096
RF9	0.275	0.083	0.132
RF10	0.319	-0.056	-0.026
RF11	0.348	0.104	0.050
RF12	0.297	0.133	0.243
RF13	0.297	-0.111	-0.044
RF14	0.276	-0.003	0.271
RF15	**0.414**	**0.446**	**0.428**
RF16	-0.021	0.013	-0.189
RF17	0.248	-0.012	0.148
RF18	0.325	0.360	**0.406**
RF19	-0.086	0.238	-0.049
RF20	**0.422**	0.322	0.271
RF21	0.136	0.024	0.031
RF22	0.341	0.269	0.227
RF23	0.415	0.002	-0.041
RF24	-0.041	0.341	0.252
RF25	0.037	0.381	0.340
RF26	0.207	-0.052	0.103
RF27	0.171	0.349	0.113
RF28	0.284	-0.041	0.233
RF29	**0.520**	**0.538**	0.238
RF30	0.141	0.396	0.201
RF31	0.277	0.222	0.384
RF32	**0.444**	**0.485**	**0.517**
RF33	**0.478**	0.326	0.334
RF34	**0.441**	0.377	**0.417**
RF35	-0.021	0.197	0.098
RF36	0.124	0.207	0.283
RF37	0.211	0.378	0.142

Note. Bolded numbers indicate a strong relationship between the occurrence of RF6 and its impact on safety; thus, as the occurrence happens, a commensurate impact on safety also occurs.

5.1.6 Risk Analysis

Table 21 shows the findings of risk analysis as risk scores, risk-criticality index, and risk level for identified risk factors.

5.2 Results of the Questionnaire Survey on Risk Triggers for Marine-Construction Projects in Saudi Arabia

A total of 30 questionnaires was distributed through e-mail and through the professional online questionnaire platform SurveyMonkey and received 22 responses, resulting in a response rate of 73.3%.

5.2.1 Reliability Analysis

Cronbach's coefficient α for rating the weights of marine-construction project risk triggers was .80, indicating reliability of the 5-point measurement scale at the 5% significance level. Additionally, Cronbach's coefficient α's to rate the similarity of risks caused by pairs of marine-structure type, contract type, owner type, execution approach, and project' location were 0.97, 0.87, 0.89, 0.94, and 0.97, respectively, indicating the reliability of the 5-point measurement scale at the 95% confidence interval, show in Table 22.

5.2.2 Respondents Profile

Table 23 presents a profile of respondents for the questionnaire survey. A reasonable spread of responses across the major professions included 36% responses from project managers, 9% responses from project directors, and 23% from project field engineers. The results also indicated a diverse set of professional experience in the construction industry among usable responses received, as almost 36% had working experience less than 5 years in the construction industry, 28% had working experience between 16 and 20 years, and 9% had working experience of more than 20 years. However, almost 72% of respondents participated in less than five marine-construction projects, whereas 9% of respondents participated in more than 20 marine-construction projects.

Table 21 Assessment of risk factors in marine construction project

Risk ID	Description	Source	RS	CI	Class	Rank
RF10	Unskilled labor	Contractor	12.667	0.5067	HM	1
RF9	Lack of experience/trained staff	Contractor	12.634	0.5053	HM	2
RF11	Manpower unavailability	Contractor	12.616	0.5046	HM	3
RF12	Low productivity	Contractor	12.182	0.4873	M	4
RF24	Delay of material supply by vendor/supplier	Supplier/Vendor	11.880	0.4752	M	5
RF2	Delay in work/labor permits, licenses	Owner	11.677	0.4671	M	6
RF1	Inadequate/unclear definition of project scope	Owner	11.430	0.4572	M	7
RF8	Equipment Unavailability	Contractor	11.187	0.4475	M	8
RF13	Construction errors	Contractor	11.160	0.4464	M	9
RF6	Delay in documents approval	Engineer/Designer	10.893	0.4357	M	10
RF4	Lack of coordination between project participants	Owner	10.822	0.4329	M	11
RF25	Technical problems with vendors/suppliers	Supplier/Vendor	10.752	0.4301	M	12
RF5	Design errors	Engineer/Designer	10.598	0.4239	M	14
RF14	Accidents	Contractor	10.598	0.4239	M	13
RF3	Delay in land/water acquisition or site access	Owner	10.395	0.4158	M	15
RF15	Contractor’s financial difficulties	Contractor	10.349	0.4140	M	16
RF23	Incompetence of subcontractors	Sub-Contractor	10.278	0.4111	M	17
RF26	Poor material selection	Supplier/Vendor	10.138	0.4055	M	18
RF7	Improper underwater condition	Engineer/Designer	10.112	0.4045	M	19
RF18	Poor site management and supervision	Contractor	10.046	0.4019	M	20
RF16	Unreliability of construction equipment	Contractor	9.946	0.3978	M	21
RF31	Severe weather conditions	Environment	9.792	0.3917	M	23
RF20	Improper construction methods implemented	Contractor	9.792	0.3917	M	22
RF19	Frequent change of subcontractors	Contractor	9.523	0.3809	M	24
RF28	Inflation for material price more than estimated	Politics/Economics	9.000	0.3600	M	25
RF32	Environment pollution	Environment	8.378	0.3351	M	26
RF27	Laws and regulations change	Politics/Economics	8.266	0.3306	M	27
RF21	Contractor’s bankruptcy	Contractor	8.208	0.3283	M	28
RF33	Ecological damage	Environment	8.101	0.3240	M	29
RF22	Subcontractors’ interferences	Sub-Contractor	8.064	0.3226	M	30
RF37	Government bureaucracy	Social/Culture	7.928	0.3171	M	31
RF30	Inconsistencies in government policies	Politics/Economics	7.320	0.2928	LM	32
RF29	Fluctuating currency exchange rates	Politics/Economics	6.960	0.2784	LM	33
RF17	Loading/unloading of material	Contractor	6.336	0.2534	LM	34
RF35	Contagious diseases	Social/Culture	6.115	0.2446	LM	35
RF34	Social/cultural common policy	Social/Culture	5.758	0.2303	LM	36
RF36	Criminal acts	Social/Culture	5.056	0.2022	LM	37

Note. MR = mean rating, SI = safety impact, Pes = pessimistic decision, RS = risk score, CI = risk criticality index, RF = risk factor.

Table 22: Reliability test results for rating the similarity scales for pairs of risk triggers

Risk Trigger	Cronbach's coefficient α
Structure type	0.97
Contract type	0.87
Owner type	0.89
Construction execution approach	0.94
Site location	0.97

Table 23 *Respondents profile*

Respondents Profile		
Category	Frequency	Proportion %
Professional occupation		
CEO	1	4.55
Project Director	2	9.09
Project Manager	8	36.36
Project Engineer	5	22.73
Other	6	27.27
Total	22	100.00
Working years in construction industry		
1–5 Years	8	36.36
6–10 Years	4	18.18
11–15 Years	2	9.09
16–20 Years	6	27.27
> 20 Years	2	9.09
Total	22	100.00
Number of marine construction projects participated in		
1–5 Projects	17	77.27
6–10 Projects	2	9.09
11–15 Projects	1	4.55
16–20 Projects	0	0.00
> 20 Projects	2	9.09
Total	22	100.00

5.2.3 Evaluation of Risk Triggers in Marine Construction Projects

Table 24 shows the mean of respondents' ratings and relative weights on the importance of the identified risk triggers. Results showed that the most important risk triggers are time, with a weight of 0.1554, and site location, with a weight of 0.1502; least important was the owner type, with a weight of 0.1237. Structure type and execution approach had the same weight of importance as 0.1467.

Table 24 *Relative weights for risk triggers in marine construction projects*

Relative Weights for Risk Triggers in Marine Construction Projects		
Risk trigger	Mean rating	Relative weight %
Structure Type	3.38	14.67
Contract Type	3.08	13.37
Owner Type	2.85	12.37
Construction Execution Approach	3.38	14.67
Location	3.46	15.02
Time	3.58	15.54
Cost	3.31	14.37

5.2.4 Similarity Measures of Qualitative Risk Triggers

In the third part of the questionnaire survey, respondents were asked to measure the similarity of risks caused by pairs of marine-structure types, contract types, owner types, construction-execution approaches, and locations on the two coasts of Saudi Arabia. Tables 25 through 29 present mean ratings for similarity measures between risk triggers. Tables 30 through 34 show the results obtained from normalizing the mean ratings of similarity measures for risk triggers.

5.3 Implementation of the Risk-Level Predictor Framework (RLPF):

Access to raw data on constructed marine projects in Saudi Arabia was difficult because of data sensitivity. This section illustrates an example of predicting risk levels for a new marine-construction project. For this purpose, the MCDB was populated with 10 hypothetical cases with the help of marine project managers experienced in risk assessment. Table 35 summarizes the risk-trigger information for a new case. The three most similar cases are summarized in Table 36. The final risk assessment proposed for the new case is presented in Table 37.

Table 25 *Mean ratings of similarity measures between pairs of marine structure types*

MR of similarity of risk caused by pairs of MSTs	
Marine structure types	MR (similarity)
(Breakwater, pier)	3.18
(Breakwater, seawall)	2.91
(Breakwater vs groin)	3.36
(Breakwater, tidal gate)	3.20
(Breakwater, submarine tunnel)	3.40
(Pier, seawall)	2.64
(Pier, groin)	3.09
(Pier, tidal gate)	2.82
(Pier, submarine tunnel)	3.27
(Seawall, groin)	3.27
(Seawall, tidal gate)	3.00
(Seawall, submarine tunnel)	3.45
(Groin, tidal gate)	3.18
(Groin, submarine tunnel)	3.09
(Tidal gate, submarine tunnel)	3.20

Note. MR = mean rating.

Table 26 *Mean ratings of similarity measures between pairs of contract types*

MR of similarity of risk caused by pairs of CTs	
Contract types	MR (similarity)
(Lump sum, unit price)	3.55
(Lump sum, cost plus)	3.00
(Lump sum, target cost)	3.09
(Unit price, cost plus)	2.73
(Unit price, target cost)	3.00
(Cost plus, target cost)	3.27

Note. MR = mean rating.

Table 27 *Mean ratings of similarity measures between pairs of owner types*

MR of similarity of risk caused by pairs of OTs	
Owner types	MR (similarity)
(Government, commercial)	3.00
(Government, industrial)	3.18
(Government, private)	3.55
(Commercial, industrial)	3.45
(Commercial, private)	2.55
(Industrial, private)	2.55

Note. MR = mean rating, OTs = owner types

Table 28 *Mean ratings of similarity measures between pairs of execution approaches*

MR of similarity of risk caused by pairs of EAs	
Construction execution approach	MR (Similarity)
(Traditional, turnkey)	2.64
(Traditional, owner builder)	2.64
(Traditional, public–private partnership)	3.09
(Turnkey, owner builder)	3.00
(Turnkey, public–private partnership)	3.09
(Owner builder, public–private partnership)	2.73

Note. MR = mean rating, EAs = Execution approaches

Table 29 *Mean ratings of similarity measures between pairs of site locations*

MR of similarity of risk caused by pairs of Site Locations	
Location on the coast of Saudi Arabia	MR (Similarity)
(Northwest, west)	2.36
(Northwest, southwest)	2.55
(Northwest, northeast)	3.00
(Northwest, east)	2.91
(Northwest, southeast)	2.64
(West, southwest)	2.64
(West, northeast)	2.64
(West, east)	2.82
(West, southeast)	2.91
(Southwest, northeast)	2.20
(Southwest, east)	2.45
(Southwest, southeast)	2.27
(Northeast, east)	2.64
(Northeast, southeast)	3.00
(East, southeast)	2.91

Note. MR = mean rating.

Table 30 *Normalized similarity scales between structure types*

Normalized Similarity Scales Between Structure Types	
Marine structure types	Similarity scale
(Breakwater, pier)	0.64
(Breakwater, seawall)	0.58
(Breakwater, groin)	0.67
(Breakwater, tidal gate)	0.64
(Breakwater, submarine tunnel)	0.68
(Pier, seawall)	0.53
(Pier, groin)	0.62
(Pier, tidal gate)	0.56
(Pier, submarine tunnel)	0.65
(Seawall, groin)	0.65
(Seawall, tidal gate)	0.60
(Seawall, submarine tunnel)	0.69
(Groin, tidal gate)	0.64
(Groin, submarine tunnel)	0.62
(Tidal gate, submarine tunnel)	0.64

Table 31 *Normalized similarity scales between contract types*

Normalized Similarity Scales Between CT	
Contract types	Similarity scale
(Lump sum, unit price)	0.71
(Lump sum, cost plus)	0.60
(Lump sum, target cost)	0.62
(Unit price, cost plus)	0.55
(Unit price, target cost)	0.60
(Cost plus, target cost)	0.65

Table 32 *Normalized similarity scales between owner types*

Normalized Similarity Scales Between OTs	
Owner types	Similarity scale
(Government, commercial)	0.60
(Government, industrial)	0.64
(Government, private)	0.71
(Commercial, industrial)	0.69
(Commercial, private)	0.51
(Industrial, private)	0.51

Table 33 *Normalized similarity scales between construction execution approaches*

Normalized Similarity Scales Between EAs	
Construction execution approach	Similarity scale
(Traditional, turnkey)	0.53
(Traditional, owner builder)	0.53
(Traditional, public–private partnership)	0.62
(Turnkey, owner builder)	0.60
(Turnkey, public–private partnership)	0.62
(Owner builder, public–private partnership)	0.55

Table 34 *Normalized similarity scales between site locations*

Normalized Similarity Scales Between Site Locations	
Location on the coast of Saudi Arabia	Similarity scale
(Northwest, West)	0.47
(Northwest, southwest)	0.51
(Northwest, northeast)	0.60
(Northwest, east)	0.58
(Northwest, southeast)	0.53
(West, southwest)	0.53
(West, northeast)	0.53
(West, east)	0.56
(West, southeast)	0.58
(Southwest, northeast)	0.44
(Southwest, east)	0.49
(Southwest, southeast)	0.45
(Northeast, east)	0.53
(Northeast, southeast)	0.60
(East, southeast)	0.58

Table 35 *Risk triggers information of a new case*

Risk triggers	Value
Structure type	○ Groin
Contract type	○ Lump sum
Owner type	○ Commercial
Execution approach	○ Owner Builder
Site location	○ North east
Cost	○ SR 100 Million
Time	○ 16 months

Table 36 *Most similar cases to the new case*

Case ID	Similarity	Risk assessment report
001	73.39%	
002	81.22%	(RF31; 0.3917; M), (RF10;0.5067; HM), (RF9;0.5053; HM)
003	76.00%	(RF12;0.4873; M), (RF11; 0.5046; HM), (RF10;0.5067; HM)
004	75.51%	(RF25; 0.4301; M), (RF11; 0.5046; HM), (RF12;0.4873; M)
005	75.18%	
006	75.14%	
007	74.84%	
008	71.05%	
009	73.02%	
010	75.11%	

Note. RF = risk factor.

Table 37 *Predicted risk levels of the new case*

Risk ID	**Description**	**Source**	**Critical index**	**Risk level**
RF9	Contractors' lack of experience/trained staff	Contractor	0.5053	HM
RF10	Unskilled labor	Contractor	0.5067	HM
RF11	Manpower unavailability	Contractor	0.5046	HM
RF12	Low productivity	Contractor	0.4873	M
RF25	Technical problems with vendors/suppliers	Supplier/Vendor	0.4301	M
RF31	Severe weather conditions	Environment	0.3917	M

011	Groin	Lump Sum	Commercial	Owner Builder	North East	100 M	16 Mo	RF9	RF10	RF11

Chapter Six: Discussion and Conclusion

6.1 Conclusion

According to the conducted risk assessment:

- The top five critical risks that associated with the marine construction projects in Saudi Arabia are presented in Table 38.

Table 38: The most critical risk factors in marine-construction projects in Saudi Arabia.

	Description	Source	RS	CI	Risk-Level
1	Unskilled labor	Contractor	12.667	0.5067	HM
2	Lack of experience/trained staff	Contractor	12.634	0.5053	HM
3	Manpower unavailability	Contractor	12.616	0.5046	HM
4	Low productivity	Contractor	12.182	0.4873	M
5	Delay of material supply by vendor/supplier	Supplier/Vendor	11.880	0.4752	M

Note. RS = Risk Score, CI = Critical Index.

- The most risk factors frequently occurred in marine construction projects in Saudi Arabia are tabulated in Table 39.

Table 39 The most risks frequently occurred in marine-construction projects in SA

	Description	Source
1	Unskilled labor	Contractor
2	Lack of experience/trained staff	Contractor
3	Manpower unavailability	Contractor
4	Delay in work/labor permits, licenses	Owner
5	Low productivity	Contractor

- The top risk factors that have sever impacts on project' safety, schedule, and cost if they occurred are shown in Tables 40, 41, and 42 respectively.

Table 40 The top influential risks on Project' safety

	Description	Source
1	Accidents	Contractor
2	Lack of experience/trained staff	Contractor
3	Unskilled labor	Contractor
4	Poor site management and supervision	Contractor
5	Unreliability of construction equipment	Contractor

Table 41 The top influential risks on project' schedule

	Description	Source
1	Delay of material supply by vendor/supplier	Supplier/Vendor
2	Manpower unavailability	Contractor
3	Inadequate/unclear definition of project scope	Owner
4	Low productivity	Contractor
5	Construction errors	Contractor

Table 42: The most influential risks on Project' cost

	Description	Source
1	Construction errors	Contractor
2	Inflation for material price more than estimated	Politics/Economics
3	Contractor’s bankruptcy	Contractor
4	Low productivity	Contractor
5	Inadequate/unclear definition of project scope	Owner

By using the RLPF, the system obtained similar cases for a new case in this study. Although the number of similar cases was low, this was just due to there being only 10 cases currently in the MCDB. Once a large variety of cases can be gathered and managed in the MCDB, the output quality of the RLPF will improve.

In the future, using the RLPF will help construction managers evaluate new projects by relying on the history of recorded marine construction projects. This system will help managers predict and assess risks more accurately and effectively, and will be useful for them to reduce risks, which will have a positive impact on the marine construction economy? Finally, the RLPF will continue growing in accuracy and efficiency as more cases are introduced.

6.2 Limitations

The main limitation to this project is that the successive use of the proposed system and the output quality of the system mainly depends on having many previous cases stored and the level of good construction and management of the case base. Another limitation is the limited amount of data available to construct the MCDB due to the sensitivity of the required data and the cost to obtain such data. Finally, the scope of this study is limited to a small number of participants in Saudi Arabia. Future research should replicate the results of the system using a larger sample size.

6.3 Recommendations for Future Research

Future research studies may focus on developing similar risk-assessment models for marine-construction projects using different risk triggers than those identified here, increasing the number of risk triggers, or decreasing them to compare and contrast risks associated with marine-construction projects. The developed RLPF is applicable to other industries, in addition to marine construction, to evaluate risk levels in new projects.

6.4 Contribution to the Body of Knowledge

Marine construction projects are a very important aspect of infrastructure development, however risks associated with these projects may delay or cease these projects. In the past researchers have paid little attention to risks prediction for marine construction projects. This study identified, classified, and ranked risk factors associated with marine construction. With a risk-score value assigned to each risk, managers now have a roadmap to mitigate project risks and the possibility to develop contingency plans only for the tasks that have the highest risk factors.

In many circumstances, the application of classical risk assessment methodologies did not provide satisfactory results due to incomplete risk data or the high level of uncertainty involved in the risk data available. It was therefore essential to develop a new risk-analysis method to predict risks levels associated with new projects based on accurate and reliable stored data of previously constructed marine projects. Moreover, few researchers have assessed risks using CBR and no risk assessment for marine-construction projects specifically has been implemented to date. This paper presents a generic risk-level predictor framework that helps decision-makers in the marine-construction industry predict risk levels associated with a new project. The approach allows users to modify and adjust the evaluation of risk factors in marine construction based on information learned about risk assessment in similar projects.

Moreover, predicting the levels of risks associated with a new marine-construction project is a time- and effort-consuming process. The systematic approach—the risk-level predictor framework proposed in this study—can consistently and efficiently address even specific and time-urgent decisions. Using the RLPF to help decision-makers predict and assess risk in marine-construction projects is meaningful. Additional research should attend to this area. The risk-assessment methodology in this study integrates risk assessment from previous projects with the CBR approach to present an effective and appropriate prediction of risks based on similarities of constructed projects.

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