

Risk assessment of marine construction projects using Taguchi Loss Function

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ABSTRACT

Today complicated and risky environment makes risk assessment and identification one of the main steps of proper project management and realization of project objectives. Marine construction projects are key and strategic projects, and their specific nature adds to their importance. This study aimed to propose a method for risk assessment and ranking critical risks in marine construction projects in Iran. To this end, the risk assessment team was formed to identify serious marine construction project risks using risk breakdown structure. Afterward, the team defined risk assessment measures. All risks were assessed in each criterion based on the Taguchi loss function. It allowed decision-makers to define a measurable risk threshold for each criterion and assess risks by developing a common language called loss score. Finally, critical risks were determined based on their priority. The results can be used to improve effective risk management, and consequently, project management.

1. Introduction

Maritime, marine exploration and the use of marine food resources have long been of interest to humans. The sea is an essential route for trade, transportation, mineral extraction, energy production, and food supply for humans. It even plays an important role in wars and the security of a country. The largest volume of global trade through the sea, the presence of oil and gas resources in it, and the defense role of the sea have led to the development of knowledge of shipbuilding, maritime, and marine structures. Today, each of these fields is known as a large and advanced industry. They also are taught in universities under different disciplines. Fig. 1 shows activities related to the marine industries [1]. Accordingly, marine affairs and industries play a key and strategic role in many countries.

In recent years, extensive research has been conducted on the risk management of construction and infrastructural projects. . Implementation of construction projects and large marine structures can be considered as important and strategic projects of countries.



Figure 1. Activities pertinent to marine industries

These projects have a special place in the country's economy and security, and recently its importance has increased in Iran. In this research, the main risks of such projects are assessed and ranked based on

previous studies and the opinions of experts and specialists of this field.

By definition, risk is a combination of the severity and the probable frequency of the harm [2]. Risk can be defined as the frequency of a possible event and the consequence of that event's outcome [3].

Projects are growingly challenged with complexity. In fact, project managers need to deal with several and different deeply interrelated parameters, inside and outside the project. Such complexity results in complex risk interactions and a decrease in the effectiveness of the tools that are normally used for risk management [4]. The effective risk management process begins with an effective risk assessment, and it is not possible to manage the risks without completing these steps [5]. The key step in risk assessment process is to evaluate initial risk using a risk scoring system in particular [6]. In addition, literature review demonstrated that the techniques for risk analysis and assessment are categorized into three major categories: (a) qualitative category, (b) quantitative category, and (c) hybrid techniques category (qualitative, quantitative, and semi-quantitative). The category (a) consists of techniques that rely on analytical estimation processes, and abilities of safety managers and engineers. Based on quantitative techniques, the risk is a quantity that it is possible to estimate and represent it using mathematics based on real accidents data recorded at an operation site. The hybrid techniques create notable complexity given their ad hoc character that limits their usability [7]. In the conventional method of risk analysis, the risk is defined as a function of probability and effect. These two factors are important criteria, but there are unlikely events that occur in many cases. Moreover, many likely events never occur in practice, but, unlikely events often occur at an astonishing rate. Thus, probability and effects alone do not cover all aspects of risk analysis [8].

Several studies have been conducted to evaluate and rank the risks of projects, especially construction projects which is discussed in the next section (literature review).

In this study, considering the importance and significant role of Marine construction projects in Iran, an attempt has been made to identify, evaluate, and rank the large and common risks that these projects face. For this purpose, the Risk Breakdown Structure (RBS) has been proposed as a standard and conventional model for project risk identification as well as Taguchi Loss Function (TLF) as an effective and efficient way to assess and prioritizing the risks.

TLF allowed decision-makers to define a measurable risk threshold for each criterion and assess risks by developing a common language called loss score.

Since the TLF simultaneously relies on the experts' judgments and mathematical relationships in the risk assessment process, we can classify it as hybrid risk assessment techniques. Obviously, by recognizing and

prioritizing risks, the risks facing these projects can be managed properly so that such projects can proceed with safe steps towards achieving their objectives.

The rest of the paper is structured as follows: Section 2 reviews the literature. In this section, we studied previous research in order to investigate methods of identifying and classifying risks and techniques used in risk analysis of construction projects. Section 3 presents the research methodology and the proposed framework.

We have made a comparison between the results of the proposed method and one of the most common risk assessment methods known as FMEA in Section 4. Section 5, finally, discusses the results and concludes the paper with recommendations for future research.

2. Literature review

Risk assessment and management as a scientific discipline plays an important role in supporting decision making in practice [9]. Risk assessment, which is an early and crucial stage in the risk management process, involves risk identification and analysis, for which various methods have been introduced [10], [11]. An important key to successful risk analysis is choosing the right risk assessment approach for the considered situation [3].

Jafari and Mohammadi [12], considering the high importance of marine projects as national projects of Iran, assessed the risk of their implementation. They first formed a risk management team and, based on the PMBOK standard and considering EPC contracts, identified and assessed the risk of marine projects in three sections: Engineering, Procurement, and Construction. Mehdikhani [13] by reviewing and comparing project risk assessment and management steps according to PMBOK standard, has proposed a model for the practical implementation of risk management process in marine construction projects and the achievements and experiences of using this model in design, Procurement, and construction stages of marine port projects. He used the FMEA method to identify and rank potential risks in a project and identified five critical risks in marine construction projects. Khatami Firouzabadi et al. [14] determined the main risks within project RBS. Taking into account that project risks have mutual effects on each other, such cause-effect mutual relationships were used to determine the main categories of project risks based on RBS and the fourth edition of project management knowledge guideline using fuzzy DEMATEL method. Their findings indicated that external risk category was the most important category of risks followed by technical, project management, and organizational categories. Golzar et al. [15] proposed a compromise group decision making model based on hesitant fuzzy sets to assess safety risks in shipbuilding projects. Ship building projects rely on heavy equipment and complicated production process and the industry is one

of the most hazardous industries in the world. Therefore, the authors tried to propose a proper model for safety risks assessment and ranking. These risks are the main causes of main damages to product process and human resources. Lambert et al. [16] provided a quantitative method to rank risk factors and used three indices of probability of incidence, potential effect on project, and efficiency and pace of dealing with risks. Vivian and Shen [17] identified and responded to the critical risks of Hong Kong's maritime projects by focusing on active contractors in the construction sector to reduce and control risk that would improve effective project management. The results of the questionnaire and structured interviews showed that "underwater conditions different from bidding assumptions" are the most common risk factors in marine projects, and lack of access to materials, plants, and labor has the greatest impact on risk exposure.

3. Methodology

After the review of previous studies and based on what was stated in the research literature, the general framework presented in this article is illustrated in Figure 2.

The risk assessment methods based on the opinions and judgments of risk experts fall in the studied area and the results of the risk assessment process are obtained from the data entered by them. In fact, they are the decision makers in the studied field. Thus, it would be of particular importance to employ a limited number of experts to increase the reliability of outputs. Therefore, to improve validity of the proposed method results, improbable and judgmental sampling (purposeful) method was used. In the first step, a risk assessment team consisting of 8 managers and experts with sufficient knowledge and expertise and over 10 years of experience in the field of marine construction projects was formed. During the research, their views were used to identify risks and risk assessment criteria and to complete research questionnaires.

Information from library studies and previous research was then provided to the risk assessment team, during which the risks in marine construction projects were identified. The steps in this research are as follows:

3.1. Identifying the risks and defining the RBS

The main methods to identify the risks were brainstorming, document review, Delphi technique, checklist analysis, and assumptions analysis [9]. In addition, there was a need for a systematic and categorized structure to identify the risks. A common approach to put risk categorization in a structure is RBS, which is a hierarchical representation of potential risk sources [18]. After collecting the data using library and literature review, the RBS of marine construction projects was developed and finalized by experts in 3

levels through Delphi technique which is represented as Table 1.

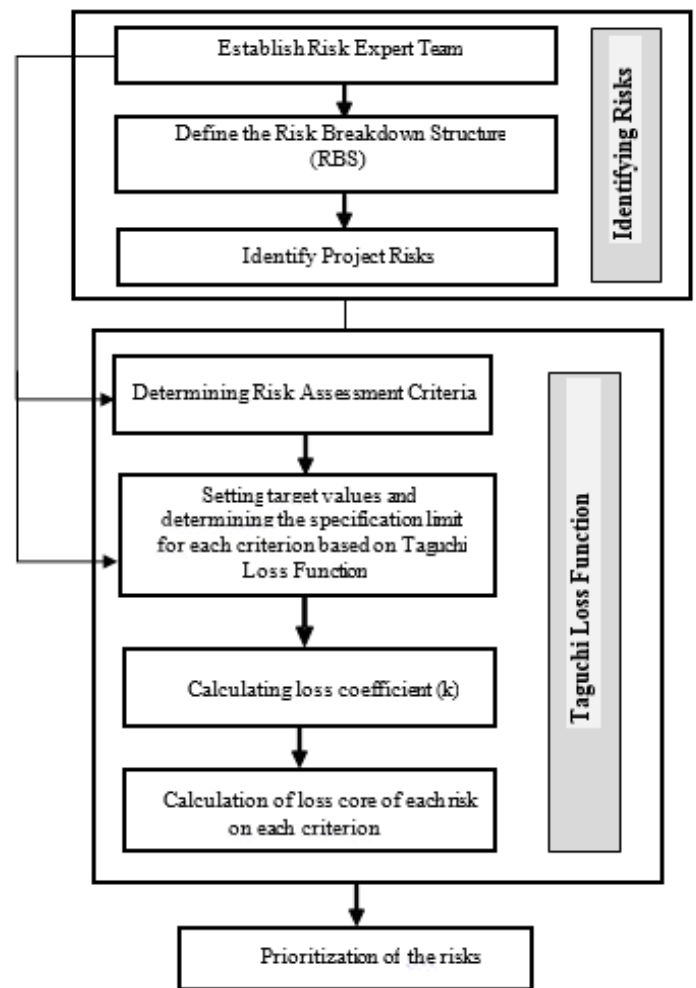


Figure 2. The proposed framework for project risk assessment

3.2. Identification of Risk Assessment Criteria

In order to help with decision-making, risk criteria set standards for evaluating the risks [19]. In conventional risk analysis methods, risk is defined as a function of probability and impact, as two important criteria. However, there exist unlikely events that occur in many cases; yet many probable events never actually happen, and worse is that unlikely events often occur with surprising speed. Thus, probability and impact alone do not cover all aspects of risk analysis [20].

Based on literature review, considering the risk parameters stated in PMBOK 2017, and the risk experts' opinion, the risk assessment criteria were defined in 7 criteria and 3 categories as below:

- Probability: The probability of each risk.
- Impact: The size of impact that puts a risk on one or several project objectives including time, cost, and quality.
 - Impact on Time: The effect of risk is on project timeline.
 - Impact on Cost: The effect of risk is on project planned budget.
 - Impact on Quality: The effect of risk is on expected quality and functionality of project.

Table 1: Marine projects risk breakdown structure

RBS level 0	RBS level 1	RBS level 2	ID
ALL SOURCES OF PROJECT RISK	Technical and Constructional	Changes in project specifications because of inadequate studies	R1
		Design variations	R2
		Complexity of design	R3
		Improper construction methods	R4
		Insufficient experience	R5
		Incompetence sub-contractors	R6
		Poor communication between supervisors and workers	R7
		Inadequate worker safety	R8
	Project Management	Increase in financial and construction costs	R9
		Inappropriate Budget and Financing Plan	R10
		Changes at various levels of management during the implementation of the project	R11
		Inappropriate or inadequate monitoring or control of project activities	R12
		Poor communication between project stakeholders	R13
		Poor site controls	R14
	Resources	Lack of skilled labor	R15
		Exit skilled workers from the project	R16
		Drop in labor productivity	R17
		Equipment breakdown and malfunction	R18
		Unavailability of material and equipment	R19
		Inappropriate storage conditions	R20
	Commercial	Poor performance of suppliers (delivery, transportation, guarantees)	R21
		Slow process of contract	R22
		Customs issues	R23
		Contract disputes	R24
		Fluctuations greater than estimated values	R25
	External	Poor inclement weather conditions	R26
		Increase in costs due to inflation	R27
		Sanctions related issues	R28
		Change in currency rate	R29
		Delay in permits and licenses	R30
		Changes in laws and regulations and code of practices	R31

Table 2. The risk assessment criteria and sub-criteria

The Risk Assessment Criteria							
Category	Probability		Impact		Manageability		
Criteria	Risk probability	Impact on time	Impact on cost	Impact on quality	Manageability and controllability	Risk detectability	Risk connectivity
Symbol	RP	IT	IC	IQ	MC	RD	RC

A 9-point Likert scale was used to assess the risks in the criteria. Even numbers represent intermediate numbers.

Table 3. Risk assessment Criteria scales definition

Scale	Very Low	Low		Medium		High		Very High
	1	2	3	4	5	6	7	8

3.3. Taguchi Loss Function

Taguchi loss function (quality loss function) is a method to measure the loss caused if a product or service fails to meet the standards [21]. The reason for loss occurrence is to achieve a quantitative evaluation of quality loss due to variation [22]. Quality loss occurs when a product fails to remain within the specification limit and becomes unacceptable [23].

Taguchi demonstrated that deviating from the target value of a feature leads to the occurrence of a loss value and the high quality of a feature occurs when this deviation is minimal and when the feature value is equal to the target value, the loss will be equal to zero. In other cases, the resulted loss can be measured using a quadratic function [24]. As the loss function is nonlinear and quadratic, the loss value increases progressively depending on the deviation rate from the target. This allows larger values to be assigned to metrics that show lower deviation from the target value, which will increase the decision-making accuracy.

Three types of functions can be used in this case, namely nominal-is-best, smaller-is-better, and higher-is-better. To have an appropriate function depends on the magnitude and direction of deviations. When the target is at the center of the specification limit, variation or changes are permitted from the both sides of the target value (known as two-sided equal or nominal-is-best loss function) (see Fig. 2). This can be obtained by Eq. (1), where $L(y)$ represents the loss associated with a particular value of the equality character y , m indicates the nominal value of the specification, and k stands for the average loss coefficient (a constant that depends on the cost at the specification limits and the width (e.g., $m \pm \Delta$ of the specification, where Δ represents the tolerance limit). The two other loss functions are one-sided minimum and one-sided maximum specification limit functions, also known as smaller-is-better and larger-is-better loss functions, respectively (see Figs. 3 and 4), which are represented by Eq. (2) and (3), respectively.

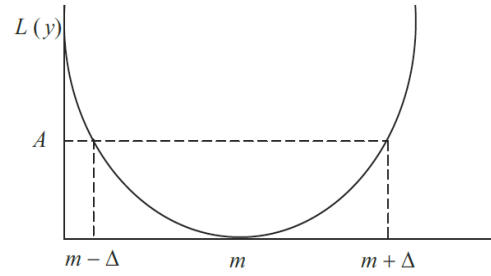


Figure 2. Nominal-is-best loss function

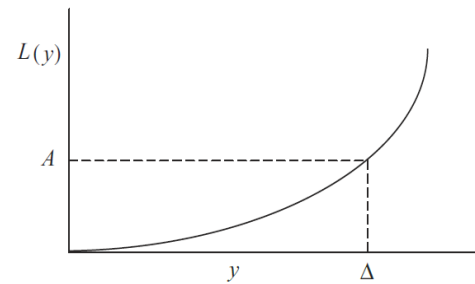


Figure 3. Smaller-is-better loss function

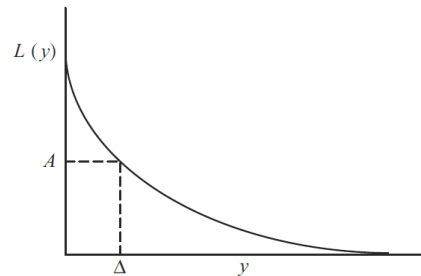


Figure 4. Higher-is-better loss function

We have to specify the optimal value and threshold for each of the criteria in Table 2 to use the TLF in the risk assessment. The range of acceptable deviation from project objectives due to risk effects must be specified for the project team, which is defined by risk

$$L(y) = k(y - m)^2 \tag{1}$$

$$L(y) = k \cdot (y)^2, \quad k = A/\Delta^2 \tag{2}$$

$$L(y) = k/y^2, \quad k = A\Delta^2 \tag{3}$$

thresholds [18].

In this study, we determined the risk thresholds for marine construction projects based on the judgment of experts. It should be noted that the risk thresholds for each of the criteria can vary depending on the requirements and conditions of each project. In general, we tried in this study to make an overall assessment of the risks of such projects by relying on the experiences and expertise of experts in marine

construction projects so that the results obtained would be useful for future projects. The risk assessment steps using the Taguchi loss function are fully described in the following.

Step 1. Target values and specification limit were set as decision variables for risk criteria.

All the criteria in Table 2 are considered as the risk assessment criteria. At first, the function type of each criterion is determined. Then, after exchanging the views of the team members and reaching a consensus, the target and threshold values were determined for each of the risk assessment criteria by taking into account the expected project objectives and requirements, as shown in Table 3. For this purpose, the 9-point Likert scale was used according to the scale given in Table 3.

Step 2. The loss coefficient (k) was calculated.

In order to calculate the loss value, we first determined the loss coefficient (k) value for each criterion using Equation (1), where for each criterion, consumer's tolerance and average quality loss were identified by the risk assessment team. Values used to determine the loss score, including consumer's tolerance (Δ), average loss coefficient (k) and average quality loss (A) are shown in Table 3. In order to have consistency between the criteria, the maximum loss was equal to 100. For example, the loss coefficient of "impact on the cost" criterion was found $k = A/\Delta^2 = 100/(3)^2 = 11.11$. and the loss coefficient of the "risk detectability" criterion was found $k = A\Delta^2 = 100 \times (3)^2 = 900$. Values used to determine the loss score, including consumer's tolerance (Δ), average loss coefficient (k) and average quality loss (A) are shown in the following table:

Table 3. The specification limit and loss coefficient of criteria

Criteria	Type of Taguchi Loss Function	Target Value	Specification Limit	Δ	k
Risk Probability	Lower the better	1	5	4	6.25
Impact on Time	Lower the better	1	4	3	11.11
Impact on Cost	Lower the better	1	4	3	11.11
Impact on Quality	Lower the better	1	3	2	25
Manageability and Controllability	Higher the better	9	5	4	1600
Risk Detectability	Higher the better	9	6	3	900
Risk Connectivity	Lower the better	1	5	4	6.25

Step 3. The loss score of each risk was calculated on each criterion.

After defining (k) values, the loss for each risk criterion was calculated using Equations (1) to (3). For example, the loss score of the risk "Improper

construction methods" (R4) in "impact on quality" criteria is $L(y) = k.(y)^2 = 25 \times (7)^2 = 1225$. The calculations for the risk loss score are shown in Tables 4 and 5.

Table 4. Data related to each risk in each criterion

Criteria Risk	RP	IT	IC	IQ	MC	RD	RC
R1	3	5	3	7	3	3	9
R2	5	4	5	8	6	4	8
R3	6	5	5	5	3	7	8
R4	3	7	5	7	7	7	7
R5	4	4	4	7	6	7	8
R6	3	4	7	6	7	9	6
R7	5	6	1	6	7	8	7
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.
.
R29	8	1	7	2	4	2	7
R30	7	8	5	1	3	3	4
R31	6	5	4	3	2	2	3

Table 5. The risk loss score

Criteria Risk	RP	IT	IC	IQ	MC	RD	RC
R1	56.25	277.77778	100	1225	177.77778	100	506.25
R2	156.25	177.77778	277.77778	1600	44.444444	56.25	400
R3	225	277.77778	277.77778	625	177.77778	18.367347	400
R4	56.25	544.44444	277.77778	1225	32.653061	18.367347	306.25
R5	100	177.77778	177.77778	1225	44.444444	18.367347	400
R6	56.25	177.77778	544.44444	900	32.653061	11.111111	225
R7	156.25	400	11.111111	900	32.653061	14.0625	306.25
.
.
.
R29	400	11.111111	544.44444	100	100	225	306.25
R30	306.25	711.11111	277.77778	25	177.77778	100	100
R31	225	277.77778	177.77778	225	400	225	56.25

Finally, the average of the loss scores for each risk is being regarded as the final loss score, which in fact, is the risk-ranking criterion. The risks, with higher final loss scores compared to others are more important and ranked higher. The final score and the final ranking of the risks are shown in Table 6. The results show that

design variations, lack of skilled labor, improper construction methods, changes in project specifications because of inadequate studies, and unavailability of material and equipment are the five critical risks.

Table 6. The average loss scores and risk ranking

Risk	Final Score	Rank	Risk	Final Score	Rank	Risk	Final Score	Rank
R1	349	4	R12	279	9	R23	238	18
R2	388	1	R13	188	25	R24	172	27
R3	286	8	R14	44	31	R25	245	15
R4	352	3	R15	363	2	R26	276	11
R5	306	6	R16	197	23	R27	236	19
R6	278	10	R17	301	7	R28	182	26
R7	260	12	R18	198	22	R29	241	17
R8	52	30	R19	309	5	R30	243	16
R9	255	14	R20	196	24	R31	227	20
R10	212	21	R21	260	13			
R11	124	29	R22	163	28			

4. Comparing the proposed method with the FMEA method

We made a comparison between the results obtained from the proposed method and one of the most commonly used risk assessment methods known as “Failure Mode and Effects Analysis (FMEA) to evaluate the quality of the results obtained from the Taguchi loss function method. FMEA is a structured method to quantitate the potential effects of error, which makes it possible to prioritize risks aimed at reducing or eliminating the failure modes. To do so, it

uses the calculation of a number called Risk Priority Number (RPN), which is resulted from multiplying the three values of the probability of the event occurring, the severity of the event, and the “probability of risk detection”. The risks with higher RPNs have a higher priority [26].

We used the same data collected from experts given in Table 4 to make this comparison. Thus, the same numbers were directly used for the criteria of the probability of occurrence and probability of risk detection, and the mean of impact on time, impact on

cost, and impact of quality data was considered for the number related to the risk severity criterion. The calculations and rankings of risks based on the FMEA method are shown in table 7. Accordingly, the prioritization of risks is according to Table 8. Hence, the risks of “Increase in costs due to inflation, Poor inclement weather conditions, Complexity of design, Lack of skilled labor, and Sanctions related issues” were identified as 5 high-priority risks, respectively, which are different from the results obtained from the TLF method. The reasons for the differences in the results can be attributed to the use of more criteria as well as employing the risk threshold in the risk assessment process.

Table 7. Data related to each risk in each criterion (FMEA)

Criteria Risk	Probability	Impact	Detectability
R1	3	5	3
R2	5	6	4
R3	6	5	7
R4	3	6	7
R5	4	5	7
R6	3	6	9
R7	5	4	8
.	.	.	.
.	.	.	.
.	.	.	.
R29	8	3	2
R30	7	5	3
R31	6	4	2

Table 8. The RPN and risk ranking

Risk	RPN	Rank	Risk	RPN	Rank	Risk	RPN	Rank
R1	45.00	27	R12	158.67	10	R23	151.67	12
R2	113.33	18	R13	121.33	17	R24	84.00	22
R3	210.00	3	R14	35.00	30	R25	200.00	6
R4	133.00	16	R15	210.00	4	R26	212.33	2
R5	140.00	14	R16	43.33	28	R27	312.00	1
R6	153.00	11	R17	106.67	19	R28	205.33	5
R7	173.33	8	R18	56.00	24	R29	53.33	25
R8	42.00	29	R19	180.00	7	R30	98.00	20
R9	140.00	14	R20	149.33	13	R31	48.00	26
R10	64.00	23	R21	96.00	21			
R11	26.67	31	R22	168.00	9			

5. Discussion and Conclusion

Given the profound role of marine construction projects in economic development and national security, realization of the objectives of such projects is highly important so that most of these projects are considered strategic ones. The project management team is always faced with several risks and a proper model to identify and assess such risks can guarantee the success of such important projects.

For this purpose, RBS and opinions of a risk assessment team were used to find 31 serious risks categorized in five categories of technical, constructional, project management, resources, commercial, and external risks. Then, the critical and sub-critical risks were defined. Subsequently, they were assessed and ranked using TLF.

The results show that design variations, lack of skilled labor, improper construction methods, changes in

project specifications because of inadequate studies, and unavailability of material and equipment are the five critical risks of marine construction projects in Iran.

Also, comparing the results obtained from the proposed method and the FMEA method reveals that the risk prioritization was different in each of them. All experts agreed on the high accuracy and high quality of the results achieved from the Taguchi loss function method due to using further criteria and application of the concept of risk threshold in the risks assessment.

Because of the flexibility of the method and the high collaboration of the risk assessment team during the research process, the results were highly satisfactory and were approved by the experts.

In general, the results can help project managers to achieve project objectives by identifying critical risks of marine construction project which leads to making decisions to prevent, control and respond to them.

It should be noted that in this research, we provided a specific and general framework for the risk assessment of marine construction projects using the Taguchi loss function and its capabilities to achieve more accurate results. Since the definition of the project risk criteria and thresholds varies from project to project, we have to emphasize that the risk assessment process described in this paper should be followed exclusively for each project. Thus, the results obtained from this article are general and can be used to identify important risks in marine construction projects in general without considering the circumstances of a particular project.

Besides, the proposed method is able to be applied to assess and prioritize risks in other projects and sectors. In future research, it is recommended to use theories such as fuzzy logic in order to resolve ambiguity and uncertainty in the views generated by the risk assessment team and thus increase the model accuracy.

Also, risk assessment criteria, depending on the specific conditions and requirements of each project, can have different degrees of importance for the project manager or stakeholders; in such a case, the prioritization of risks will change. Therefore, in future research, we can benefit from the multi-criteria decision-making techniques to determine the importance and weight of the criteria, combine them with the proposed method, and increase the accuracy of the output in prioritizing the risks.

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