Proposing the Use of Failure Mode and Effect Analysis (FMEA) as Risk Assessment Tool in Construction

Wahbi Albasyouni, Ibrahim Abotaleb, Khaled Nassar

Abstract: ***This research aimed to improve the analysis of risks in construction projects in Egypt through proposing the implementation of FMEA as a risk assessment tool. First, an extensive literature review was conducted to identify the relevant risks in the Egyptian construction industry. Second, a questionnaire survey was conducted to assess the perceived impact, probability, and detection of the identified risk factors by experts working in the construction sector in Egypt. Third, an analysis of these risks was carried out using traditional PMI's risk assessment, FMEA, and the integration of fuzzy logic with FMEA fundamentals. The results demonstrated that FMEA and risk management are similar in various aspects, but FMEA has an additional dimension to PMI's risk analysis, specifically "detection". Such dimension affects how risks are managed and plays a significant role in developing better strategies for controlling and detecting risks. This added depth provides more insights into the project, enabling construction parties to make better preparations and informed decisions for their projects. The findings indicated that FMEA has significant potential in the construction industry when properly applied. The findings of this research aim to promote the application of FMEA as an enhancement to the currently applied PMI's risk management practice, thereby improving efficiency, visualisation, and ultimately decision-making.***

Keywords: Risk Management in Construction, Risk Assessment, Failure Mode Effect Analysis, Risk Priority Number, Fuzzy FMEA

I. INTRODUCTION

The construction sector plays a significant role in developing and improving the economy of any country. The complexity of construction projects is increasing with the addition of new methods and technologies that are an extra burden on projects to be completed on time, on budget, and with proper quality [12]. Nevertheless, the general perception about the construction industry is that it lacks efficiency and is unable to complete projects on time, within budget, and to the required quality standards.

Manuscript received on 17 October 2023 | Revised Manuscript received on 31 October 2023 | Manuscript Accepted on 15 November 2023 | Manuscript published on 30 November 2023
*Correspondence Author(s)
Wahbi Albasyouni*, PhD Student, Department of Civil Engineering, Newcastle University, United Kingdom. Email: W.i.m.albasyouni2@newcastle.ac.uk, ORCID ID: 0000-0003-0615-8549
Ibrahim Abotaleb, Associate Professor, Department of Construction Management, The American University in Cairo, Egypt. Email: ibrahimsalah@aucegypt.edu
Khaled Nassar, Professor, Department of Construction Management, The American University in Cairo, Egypt. Email: knassar@aucegypt.edu

It is well known that any construction project typically faces potential risks that can directly and indirectly affect its overall performance. The size and complexity of the project could increase the likelihood of risks and uncertainties. Therefore, risk management applications and practices are implemented to ensure the success of construction projects and the adequate management and control of risks. Failure Mode and Effects Analysis (FMEA) is a systematic process for identifying and managing potential failures and errors in any process, system, or project. FMEA can be used to identify and assess risks, ranking them according to their importance and significance. This is accomplished by evaluating the Risk Priority Number (RPN) of each risk. RPN can be used to estimate the importance of a risk based on its impact, occurrence, and detection [4]. Failure Mode and Effects Analysis (FMEA) was initially introduced in 1949 by the U.S. Army and used to improve its military operations [6]. NASA then used FMEA at the beginning of 1963 to improve their reliability needs and optimise their safety analysis [4]. Since then, this technique has kept on developing until being used in various industries, such as the aerospace sector, mechanical sector, and the construction sector [6]. In addition, [5] presented FMEA design as an alternative to the standard technique that was used in design practices. Additionally, risk FMEA was also employed and presented to assess risks in the construction industry. Other methods, such as the Risk Priority Number (RPN), were also presented. This technique is used to examine the impact of any risk by considering severity rates, occurrence rates, and detection rates. The critical FMEA is another form which concentrates only on the multiplication of the effects and severity [6]. Furthermore, another approach of using FMEA is through fuzzy analysis; it was recommended for its usefulness in assessing time delays and estimating the projected time to complete the project [9]. FMEA is sensible in assessing the reliability of any element while evaluating the possibility of failures in any process and component [11]. This paper proposes the adoption of FMEA as a method for risk management and assessment of construction projects.

II. LITERATURE REVIEW

Multiple studies have studied the adoption of FMEA in the construction sector [8]. presented a study on demonstrating a decision-making criterion based on FMEA as a risk assessment method. That paper aimed to present a multi-criteria decision-making approach using FMEA.

Multiple benefits and advantages are related to this approach, but mainly relative to estimating the severity, occurrence, and detection of risks based on their cost impact and significance [1]. investigated occupational and safety hazards in construction projects using probabilistic fuzzy analysis. Due to the significant development in the construction sector in developing countries, the annual percentage of occupational accidents is increasing. Therefore, the presence of a hazard management process with proper vision can help in determining and ranking the most possible risks and the required preventive measures. Thus, this study presents the use of fuzzy probabilistic FMEA to assess occupational hazards in construction projects. The presented fuzzy model provides multiple data analysis for accidents on site. The model was applied to 4 different construction projects. By using an intensive validation procedure, the model analyzed and prioritized the risks that are considered the causes of hazards [15]. proposed a cost based FMEA for analyzing life cycle cost and failure mode of equipment. The primary objective of the study was to enhance and improve the reliability of the design, aiming to achieve a practical approach that can accomplish the assigned goals and expectations. Estimating the cost impact of failures modes from the design phase can help in cutting costs [18]. proposed the usage of FMEA as a tool for risk management in the planning of construction projects. The purpose of the research was to integrate FMEA into the planning stage to identify potential risks that could impact the project's performance and workflow. The author stressed on the lack of sufficient studies about the implementation of FMEA in the construction sector and specifically in the planning phase [17]. also discussed the potential of FMEA as a risk evaluation approach. FMEA can be valuable in reducing risk losses and providing a proper and reasonable preventive approach in construction projects [2]. discussed the possibility of using a composite FMEA for the risk assessment of construction projects. The researcher introduced the idea of integrating FMEA, the method of Pairwise comparison, and Markov Chain to develop a tool for risk assessment. This tool can support the project management individuals in gathering reliable data to decide accurate and efficient corrective measures. To conduct the present research, the study's research methods are categorised into five stages, each revolving around the different steps necessary to achieve the research objectives.

[3] used fuzzy FMEA to evaluate safety risks in construction projects. The study combined fuzzy logic and FMEA to improve the process of assessing hazards and risks in projects. Likewise, [10] analyzed the risks of elevated metro rail projects in India using fuzzy FMEA. The approach was valuable in identifying potential dangers associated with these types of construction projects and proved to be effective. Another way of implementing FMEA was to analyze construction delay, which was previously shown by [16]. Delay was evaluated based on the occurrence of risks, the impact of these risks on the project’s delay, and the ability to handle and resolve the risks before they caused any delay. Fuzzy FMEA was able to estimate the percentage of delay in the project with an error rate that is less than 20% [7]. developed a hybrid approached to prioritize failure modes based on the concept of FMEA. The findings demonstrated that the proposed method could expose critical failure models and their correlation. The author concluded that this approach is efficient for ranking and prioritising risks. On the other hand, [13] investigated the empirical and theoretical concept of FMEA and its contribution to risk analysis in the construction sector in Indonesia. It helps in decision-making for stakeholders, practitioners, and managers.

III. METHODOLOGY

The methodology of this paper was divided into various phases. The initial phase of this research involved a comprehensive literature review to identify the risks commonly faced in construction projects and discuss previous studies that have utilised FMEA as a risk assessment tool. The literature included electronic resources, textbook reviews, journals, publications, thesis papers, and other sources of data. A questionnaire survey was conducted to assess the current impact and likelihood of risks in the construction sector in Egypt. Then, interviews were conducted with experts to evaluate the collected risks and select only the most significant ones applicable to the construction sector in Egypt. The primary source of data in this research was a questionnaire survey. Due to the COVID-19 pandemic that began in 2020, this survey was structured to be completed online. Various professional parties, including contracting and consulting companies, were invited to participate in the survey, and 221 responses were gathered; however, only 214 were considered valid. Participants were asked to provide their opinion about the impact, probability, and detection of each risk factor faced in the Egyptian construction sector.

Risks were assessed using multiple methods. The initial one followed the risk management process proposed by PMI, which essentially involves assessing the impact and probability of each risk. Then, FMEA was the next approach used to prioritise risks, utilising the risk priority number. The third approach was the fuzzy FMEA, which involved some sort of simulation and accurate estimation of figures. Fuzzy logic enables the generation of flexible and valuable reasoning that considers uncertainties and inaccuracies.

The next stage of the study was to determine the level of alignment of participants' responses. One of the most common problems in any research is comparing tendencies across different values or groups. One of the most common statistical tools for examining such a comparison is known as the t-test. The primary objective of this tool is to determine the mean, examine variations within samples, and provide evidence regarding the central tendency in mean values. This research primarily focused on engineers and parties working in the construction sector in Egypt. The majority of participants in this survey are contractors, consultants, and owners. The idea of applying a t-test is to determine if there is a difference in mean values between contractors, consultants, and owners. Hence, the means for impact, probability, and detection were compared to indicate whether there are any differences between owners and contractors.

Retrieval Number: 100.1/ijitee.L975011121223
DOI: 10.35940/ijitee.L9750.11121223
Journal Website: www.ijitee.org

Published By:
Blue Eyes Intelligence Engineering
and Sciences Publication (BEIESP)

The previous steps helped in analysing risks using different methods and approaches. However, it was essential to validate the accomplished results by determining the applicability of FMEA in the construction industry. Hence, it is crucial to consider the opinions of engineers who participated in the initial questionnaire survey to gauge their views on the necessity of FMEA in the construction sector. The basic structure of this survey was primarily based on determining participants' opinions about the efficiency and simplicity of the risk management process proposed by PMI and FMEA, as well as indicating the potential for using FMEA in future construction projects.

IV. RESULTS

A. Survey Results:

The survey included 221 participants; however, some responses were not validated and were excluded from the results, leaving 214 validated and accurate responses from experienced engineers working in various positions and companies in Egypt. The first part of the questionnaire collected demographic information about respondents, including their age, the company they are currently working with, and the number of years of experience. Then, respondents were asked to evaluate the impact, occurrence, and detection of risks on a scale of 1 to 10 (1 represents the lowest impact, probability, and ability to detect the risk, while 10 indicates the highest impact, probability, and difficulty in detecting the risk).

B. Level of Alignment:

This section presents the results of a t-test conducted to examine the variances in means between consultants, owners, and contractors for all project risks, in terms of impact, probability, and detection. There were no significant variations in responses between contractors and owners. It initially investigated the level of alignment between contractors and consultants using the t-test. However, the number of contractors participating in the questionnaire survey was much higher than that of consultants, but the only variation observed was in the occurrence of variation orders. Consultants thought that it had fewer occurrences than contractors. Table 1 shows the p-values for contractors and consultants.

Table 1. Results of p-values (Cont: Contractor, and Cons: Consultant)

Risks	Impact			Occurrence			Detection		
	Mean		P-value	Mean		P-value	Mean		P-value
	Cont	Cons		Cont	Cons		Cont	Cons	
Cash flow problems	8.46	8.04	0.198	6.54	6.24	0.44	5.85	5.88	0.94
Delay in giving payments by the owner	7.85	7.4	0.189	6.78	6.32	0.24	5.93	5.96	0.93
Changes in the prices of resources	7.67	7.46	0.55	6.4	6.18	0.58	5.87	5.86	0.97
Poor coordination with all parties during the design stage	7.28	7.44	0.68	6.67	6.38	0.499	5.34	5.87	0.24
Variation order	7.04	6.54	0.18	7.37	6.56	0.041	6.3	5.94	0.42
Poor planning of work and activities	7.79	7.79	0.76	5.94	6.08	0.72	5.45	5.77	0.46
Late delivery of materials to the site	7.84	7.63	0.52	5.93	5.95	0.95	5.99	5.69	0.46
Poor cost estimation	8.02	7.52	0.17	5.53	5.56	0.94	5.46	5.7	0.59
Inexperienced Contractor	7.92	7.8	0.69	5.45	5.2	0.51	5.91	5.76	0.72
Poor production rate from labourers	7	7.02	0.97	6.19	5.74	0.2	5.99	5.52	0.27
Design errors	7.86	7.26	0.1	5.38	5.44	0.95	5.44	5.54	0.94
Shortage of materials	7.58	7.2	0.28	5.67	5.22	0.24	5.95	5.68	0.51
Poor supervision of work	6.99	7.04	0.89	5.75	5.48	0.44	5.6	5.22	0.35
Shortage of skilled labourers	6.62	6.8	0.85	6	5.6	0.71	5.48	5.24	0.68
Delay in the delivery of equipment	7.15	7.36	0.58	5.48	5.26	0.56	5.45	5.72	0.54
Poor quality of work	6.67	6.56	0.75	5.375	5.58	0.59	5.57	5.9	0.45
Wrong estimation of quantities	6.66	6.3	0.37	5.61	5.56	0.89	5.27	5.2	0.86
Error in the construction stage	7.3	6.68	0.11	4.75	4.68	0.84	5.86	5.86	0.43
Safety accidents on site	6.7	6.38	0.41	5.17	5	0.66	5.57	5.05	0.21

C. Risk Assessment (PMI) Results:

Each respondent in the survey was asked to provide a specific value for the impact and probability of risks that ranged from one to ten. The average values were calculated based on the number of respondents (214 in this case) to determine a specific average weight for both impact and probability, as shown in the table below. The multiplication of both values can obtain the significance rate, which is then used to rank the most critical risk factors according to this process. Table 2 presents the impact, probability, and significance values for all risks based on the results of the questionnaire survey.

Table. 2. Risk Assessment Results

Risk	Impact	Probability	Significance
Cash flow problems	8.3	6.4	53.0
poor planning of work and activities	7.8	5.9	45.6
Late delivery of materials to the site	7.7	5.9	45.5
Safety accidents on site	6.4	5.0	32.0
Inexperienced contractor	7.8	5.3	41.5
Error in the construction stage	7.0	4.6	32.3
Poor quality of work	6.6	5.4	35.6
Poor production rate from the labourers	6.9	5.9	40.8
Shortage of skilled labour	6.8	5.7	38.2
Delay in the delivery of equipment	7.1	5.2	36.6
Shortage of materials	7.3	5.4	39.2
Poor cost estimation	7.8	5.4	41.8

Delay in giving payments by the owner	7.5	6.6	49.5
Variation order	6.7	6.9	46.0
Design errors	7.5	5.3	40.1
Wrong estimation of quantities	6.4	5.5	35.1
Poor coordination with all parties during the design stage	7.2	6.5	46.7
Changes in the prices of resources	7.5	6.3	47.2
Poor supervision of work	6.9	5.6	38.4

The higher the significance rate, the more critical this factor is on construction projects. The top-ranked factors, based on their significance values, were cash flow problems, delay in payment by the owner, poor planning of work and activities, and late delivery of materials to the site. The significance value depends mainly on the impact and probability values. As indicated earlier, Figure 1 shows the most critical risks with the highest significance values. Most of these risks had an average significance rate that ranged between 40% and 50%. The reason for having a close range was primarily due to the high population in the questionnaire survey, with an average taken among 214 survey respondents.

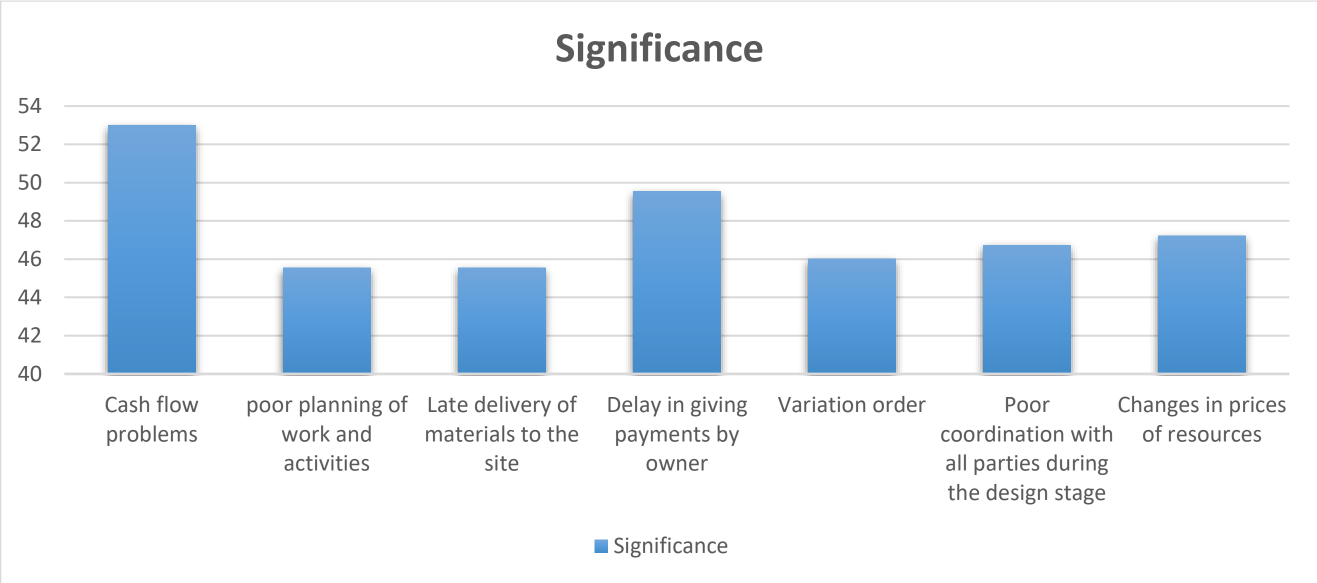

Fig.1. Risk Factors with a Significance Rate Higher than 40

D. Failure Mode Effect Analysis:

To apply the concept of FMEA, the most common tool used in this context is the risk priority number. It is pretty similar to PMI's risk assessment, but the additional factor in this case was estimating the likelihood of detecting each risk. Hence, the probability and impact will remain the same, but the risk priority number will also include the detection rate. Thus, Table 3 shows the results of applying the risk priority number tool. Hence, the ranking of risks for both techniques remained the same, considering that most survey respondents thought the detection rate to be average, as detecting risks in any project depends on factors such as experience, qualification, and others.

Table 3. Risk Priority Number Results (FMEA)

Risk	Severity	Occurrence	Detection	RPN
Cash flow problems	8.3	6.4	5.7	302.8
Delay in giving payments by the owner	7.5	6.6	5.7	282.2
Changes in the prices of resources	7.5	6.3	5.9	278.8
Variation order	6.7	6.9	6.0	277.4
Late delivery of materials to the site	7.7	5.9	5.8	263.5
Poor coordination with all parties during the design stage	7.2	6.5	5.5	257.4
poor planning of work and activities	7.8	5.9	5.4	248.5
Inexperienced contractor	7.8	5.3	5.8	239.8
Poor production rate from the labourers	6.9	5.9	5.7	232.0
Poor cost estimation	7.8	5.4	5.4	227.4
Shortage of materials	7.3	5.4	5.7	224.7
Design errors	7.5	5.3	5.4	214.7
Poor supervision of work	6.9	5.6	5.3	204.8
Shortage of skilled labour	6.8	5.7	5.2	201.6
Delay in the delivery of equipment	7.1	5.2	5.4	199.4
Poor quality of work	6.6	5.4	5.6	199.6
Wrong estimation of quantities	6.4	5.5	5.2	183.0
Error in the construction stage	7.0	4.6	5.5	177.1
Safety accidents on site	6.4	5.0	5.3	169.6

Retrieval Number: 100.1/ijitee.L975011121223
DOI: 10.35940/ijitee.L9750.11121223
Journal Website: www.ijitee.org

Published By:
Blue Eyes Intelligence Engineering and Sciences Publication (BEIESP)

E. Fuzzy FMEA:

The use of fuzzy FMEA has been relatively limited in the literature, especially in the construction industry. It is still based on applying the risk priority formula that concentrates on the occurrence, severity, and detection of risks. In this case, O represents the probability of occurrence, S is the severity, and D is the probability of not detecting risks. The values of O, S, and D were obtained from a questionnaire survey conducted among engineers in the construction field. The values assigned for each factor ranged from 1 to 10, as known in the traditional FMEA; however, the only difference was that the detection became a range of values, from 1 to 10. Each factor was divided into three parameters: low, medium, and high. To overcome all these limitations, the researcher followed some guidelines provided by [14] including the following:

- Fuzzyfication: It involves redefining the membership function in terms of occurrence, severity, and detection to obtain a fuzzy RPN.
- Indicate the most suitable fuzzy rules to obtain the best output needed, as all combinations are involved in some groups to define a fuzzy rule. For instance, if the occurrence is very high, the severity is also very high, and the detection is very high, the fuzzy RPN therefore turns out to be very high.

For the conventional FMEA, risk assessment was performed by multiplying the occurrence, severity, and detection to obtain a risk priority number. The assessment was also considered qualitative and subjective as it depends mainly on the opinion of single or multiple parties. Hence, analysing the RPN using fuzzy logic was the most suitable option, employing a 'Mamdani' (min and max) approach. Mamdani is a standard inference system in fuzzy logic, represented by minimum and maximum attributes. Table 4 presents the criteria used for severity, occurrence, and detection, along with the category of each input.

Table 4. The Numerical Indication for Severity, Occurrence, and Detection, Including Their Categories

Score			Category
Severity	Occurrence	Detection	
1	1	1	VL
2,3	2,3	2,3	L
4,5,6	4,5,6	4,5,6	M
7,8	7,8	7,8	H
9,10	9,10	9,10	VH

Hence, these numerical indicators were then used as input variables in the membership functions, which were divided into three inputs: severity, occurrence, and detection, as shown in Figure 2.

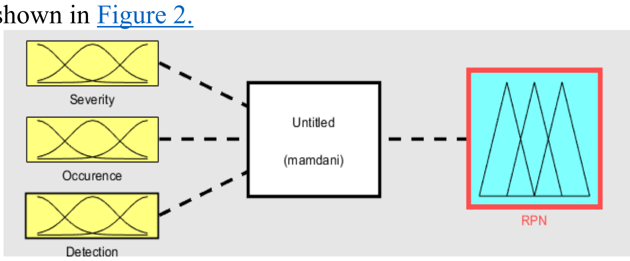

Fig. 2. Setting up the Input and Output for Fuzzy RPN

Table 5 presents the criteria for each category, the type of curves used, and the range of parameters. Each parameter had to include a particular curve type and specific regional parameters. It should start from zero as the initial point in the analysis, and end with 10 as the highest value in the study.

Table 5. Used Parameters for the Membership Function of the Input Variable [14]

Category	Type of curve	Parameter used
Very Low (VL)	Trapezoidal	(0, 0, 1, 2.5)
Low (L)	Triangle	(1, 2.5, 4.5)
Medium (M)	Trapezoidal	(2.5, 4.5, 5.5, 7.5)
High (H)	Triangle	(5.5, 7.5, 9)
Very High (VH)	Trapezoidal	(7.5, 9, 10, 10)

For the outputs, it was pretty similar, but this time it focused mainly on the RPN values, which are the result of multiplying severity, occurrence, and detection. Therefore, the output was divided into several categories, starting from zero, which represents the lowest value, and 1000, representing the highest RPN value, as shown in Table 6.

Table 6. Used Parameters for the Membership Function of the Output Variable [14]

Category	Type of curve	Parameter used
Very Low (VL)	Trapezoidal	(0, 0, 25, 75)
Very Low to L (VL-L)	Triangle	(25, 75, 125)
Low (L)	Triangle	(75, 125, 200)
Low to Medium (L-M)	Triangle	(125, 200, 300)
Medium (M)	Triangle	(200, 300, 400)
Medium to High (M-H)	Triangle	(300, 400, 500)
High (H)	Triangle	(400, 500, 700)
High to Very High (H-VH)	Triangle	(500, 700, 900)
Very High (VH)	Trapezoidal	(700, 900, 1000, 1000)

The real values used for the severity, occurrence, and detection were initially obtained from the questionnaire survey results. The analysis of the survey was conducted using Microsoft Excel. Still, the application of Fuzzy RPN was facilitated by the MATLAB software program, which contains a fuzzy logic toolbox that aids in providing the necessary analysis.

Table 7 shows the results of risk factors after applying fuzzy logic. The initial step was to insert the severity, occurrence, and detection values, and then indicate the fuzzy RPN value, along with the category to which this risk belongs, ranging from very low to very high risk.

Published By:
Blue Eyes Intelligence Engineering
and Sciences Publication (BEIESP)

Table 7. Results of Fuzzy RPN and Risk Categories

Risk	Severity	Occurrence	Detection	RPN	Fuzzy RPN	Category
Cash flow problems	8.3	6.4	5.7	302.8	441	M-H
Delay in giving payments by the owner	7.5	6.6	5.7	282.2	442	M-H
Changes in the prices of resources	7.5	6.3	5.9	278.8	465	M-H
Variation order	6.7	6.9	6.0	277.4	426	M-H
Late delivery of materials to the site	7.7	5.9	5.8	263.5	489	H
Poor coordination with all parties during the design stage	7.2	6.5	5.5	257.4	376	M
poor planning of work and activities	7.8	5.9	5.4	248.5	400	M-H
Inexperienced contractor	7.8	5.3	5.8	239.8	500	H
Poor production rate from the labourers	6.9	5.9	5.7	232.0	399	M-H
Poor cost estimation	7.8	5.4	5.4	227.4	500	H
Design errors	7.5	5.3	5.4	224.7	500	H

Applying fuzzy RPN resulted in significantly different RPN values and dramatically changed the ranking of the most significant risk factors. This was done to reduce the influence of detection rates on the overall RPN value and provide more significance for both severity and occurrence.

F. Comparison between the Adopted Methods:

The ranked risks differ significantly when using both the PMI assessment and the RPN. Hence, Table 8 provides a brief comparison between the ranked risks using the three different approaches.

Table. 8. Ranking of Risks using Risk Management (PMI), RPN, and Fuzzy RPN

Risk Management (PMI)	RPN	Fuzzy RPN
Cash flow problems	Cash flow problems	Inexperienced contractor
There is a delay in the owner's payment.	Delay in giving payments by the owner	Poor cost estimation
Changes in the prices of resources	Changes in the prices of resources	Design errors
Poor coordination with all parties during the design stage	Variation order	Late delivery of materials to the site
Variation order	Late delivery of materials to the site	Changes in the prices of resources

Risk assessment using the impact and probability, as well as the conventional RPN method, resulted in an exact ranking of risks, with the only difference being the variation in order and poor coordination between parties. However, neither of these risks was among the top three. On the other hand, the fuzzy RPN resulted in a completely different ranking of risks. This could be due to assigning various categories and using simulation to estimate the exact RPN value. Risk assessment and RPN are similar methods because both analyse risks based on their impact (severity) and probability (occurrence). However, RPN adds a third variable in the equation known as (detection) and counts for the capability of detecting risks before they have any effect on the project.

V. RESULTS VALIDATION

To validate the results and some of the concluding remarks regarding the efficiency of FMEA and its potential application in the construction sector, a follow-up questionnaire survey was distributed among engineers who participated in the initial study. A brief overview of the risk management process proposed by PMI and FMEA was initially presented, followed by some questions regarding the efficiency and simplicity of each technique. It was essential to determine whether engineers working in the construction sector in Egypt were familiar with the FMEA method. The results demonstrated that fewer than 10 per cent of all survey respondents were aware of FMEA, indicating the effectiveness of this method in real projects. Hence, this new method is not yet well-known or thoroughly introduced to the construction industry, and only a few studies have discussed its theoretical usage. There are various techniques used in the construction sector to analyse potential risks; hence, respondents were asked if they think other methods are needed to enhance the overall performance of construction works. More than 46% agreed to the need for new techniques to analyse potential risks in projects, 19.19% strongly agreed, 21.21% were moderate about this argument, and the rest, 13%, either disagreed or strongly disagreed. It is concluded that the construction sector needs alternative and new methods that could be used to analyse risks in construction projects. The following question focused on examining the concept and usage of FMEA in terms of efficiency, simplicity, range of ranking, and visualisation of risks, after providing a comprehensive introduction and definitions to survey respondents. Regarding efficiency, the highest percentage was moderate and reasonable, as there is no clear evidence regarding its effectiveness in the field, as mentioned by some respondents. For simplicity, 46% thought that this technique could be complicated during its early stages, but more than 30% believed it could be good and excellent in terms of simplicity. The following point concerned the high range of ranking, and more than 75% agreed that the rating for the FMEA was excellent. Finally, the last section focused on the visualisation of risks, and most respondents were quite impressed with the effective visualisation of risks using FMEA. Table 9 provides a summary of all survey answers regarding the use of FMEA in the construction industry.

Table. 9. Survey Answers Regarding Some Properties of FMEA

FMEA	Very poor	Poor	Moderate	Good	Excellent	N/A	Mean
Efficiency	2.02% 2	5.05% 5	27.27% 27	31.31% 31	16.16% 16	18.18% 18	3.67
Simplicity	6.06% 6	12.12% 12	46.46% 46	19.19% 19	12.12% 12	4.04% 4	3.20
A high range of ranking	4.04% 4	7.07% 7	17.17% 17	27.27% 27	42.42% 42	2.02% 2	3.99
Good visualization of risks	6.06% 6	5.05% 5	19.19% 19	32.32% 32	32.32% 32	5.05% 5	3.84

The same questions were asked about risk management, and most respondents agreed on the efficiency of this technique, with more than 50% in favour. According to respondents' opinions, the simplicity of risk management was perceived as being much better than FMEA. However, there is a relatively low range of ranking in risk management, which was the primary and most critical disadvantage, in addition to having a poor visualisation of risks. This means that there is no unique way of presenting the results of risk management, similar to the one common with FMEA. Table 10 presents the factors related to risk management and their corresponding evaluations.

Table 10. Survey Answers Regarding Some Properties of the Risk Management Process

RM	Very poor	Poor	Moderate	Good	Excellent	N/A	Mean
Efficiency	8.08% 8	9.09% 9	22.22% 22	42.42% 42	13.13% 13	5.05% 5	3.46
Simplicity	4.04% 4	5.05% 5	13.13% 13	30.30% 30	45.45% 45	2.02% 2	4.10
A high range of ranking	12.12% 12	31.31% 31	27.27% 27	16.16% 16	8.08% 8	5.05% 5	2.76
Good visualization of risks	13.13% 13	26.26% 26	25.25% 25	16.16% 16	10.10% 10	9.09% 9	2.82

After reviewing all the discussed properties of risk management and FMEA, respondents were then asked to evaluate which technique could be more beneficial to the construction industry in Egypt. Around 48% thought that FMEA could be more useful, around 29% believed that both could be similar, and the rest indicated that having only the standard risk management process is better. Ultimately, the primary objective of the questionnaire survey was to assess the feasibility of applying FMEA in the Egyptian construction sector. The study investigated the opinions of respondents regarding the potential implementation of FMEA in the construction sector. It is demonstrated that the average rate for the possibility of using FMEA is 3.6, which is exceptionally high and indicates the potential of this method as an alternative risk assessment process.

within the project. Researchers have claimed that FMEA has some limitations, one of which is its subjectivity. This is the same case with the risk management process, as both require values to be assumed based on personal experience. Therefore, using Fuzzy logic can help in simulating these values and ensure a higher degree of accuracy in estimating the severity, occurrence, and detection. The construction sector is a critical part of any economy, and proper considerations should be given to reduce all possible risks that could be faced. Having an effective technique to analyse risks can be beneficial in terms of understanding the influence of each risk, why it is caused in the project, the recommended action that should be taken, and the party responsible for taking these actions. Hence, FMEA can be pretty beneficial to the construction sector in analysing potential risks.

VI. CONCLUSION

Risk assessment is an integral part of the risk management process. One of the most common risk assessment methods is the process proposed by the Project Management Institute (PMI). It has been used for decades in the construction sector, but recent studies have discussed the current limitations of risk assessment and the need for further research in this area. Therefore, this paper proposes the adoption of FMEA as a risk assessment tool in the construction sector. Risk assessment using the proposed approach by PMI and RPN is similar because both analyse risks based on their impact (severity) and probability (occurrence). However, RPN adds a third variable in the equation known as (detection) and counts for the capability of detecting risks before or just after their occurrence in the project. This variable is significant in construction projects because it enables the management of risks before they impact the project's performance. FMEA can help visualise and demonstrate all risks in the project creatively, making it easier to control and manage risks

LIMITATIONS

Most survey respondents decided to evaluate “detection” in FMEA as an average value (5) because it depends on multiple factors, such as the type of project, its complexity, the contractor's experience, and the project’s owner. Therefore, to adequately understand the capabilities of FMEA and its comparison with risk management, both should be applied to a real construction project to test their effectiveness. Another limitation was that the number of respondents from each category (i.e., contractor, consultant, and owner) differed; hence, further investigation might be needed to involve a similar number of responses from all categories. However, this does not impact this paper, as it focuses on validating the application of FMEA rather than identifying risks in the construction sector and assessing them.

DECLARATION STATEMENT

I declare that we have independently written this paper, and it has not been presented for any other journal. Additionally, I confirm that due credit has been acknowledged in this thesis whenever I have referred to the work of different individuals. I confirm that no financial funding was received for the completion of this study, and I am free from any conflicts of interest. The specific contributions of both I and other authors to this work are explicitly outlined below. Author 1 was primarily responsible for writing the paper and collecting and analysing the results. The remaining authors were responsible for data collection and critical analysis.

Funding/ Grants/ Financial Support	No financial support or any kind of funds, grants, or financial assistance received.
Conflicts of Interest/ Competing Interests	There are no conflicts of interest to the best of my knowledge.
Ethical Approval and Consent to Participate	The article does not require ethical approval or consent to participate.
Availability of Data and Material/ Data Access Statement	Not relevant.
Authors Contributions	All authors have equal contributions.

REFERENCES

1. Amiri, M., Ardeshir, A., and Zarandi, M. Fuzzy Probabilistic Expert System for Occupational Hazard Assessment in Construction. Safety Science, Vol. 93, pp. 16–28. (2017). https://doi.org/10.1016/j.ssci.2016.11.008
2. Ahmed, M. (2014). Composite FMEA for Risk Assessment in the Construction Projects, Thesis Politecnico Di Milano. (2014).
3. Ardeshir, A., Mohajeri, M., and Amiri, M. Evaluation of safety risks in construction using Fuzzy Failure Mode and Effect Analysis (FFMEA). Scientia Iranica, Vol. 23 No. 6, pp. 2546-2556.2016)). https://doi.org/10.24200/sci.2016.2313
4. Bahrami, M., Bazzaz, D., and Saijadi, S. M. Innovation and Improvements In Project Implementation and Management; Using FMEA Technique. Procedia - Social and Behavioural Sciences, Vol. 41, pp. 418–425. (2012). https://doi.org/10.1016/j.sbspro.2012.04.050
5. Bongiorno, J. Use FMEAs to Improve Your Product Development Process. PM Network, pp. 47–51. (2004).
6. Carbone, T. A., and Tippett, D. D. Project Risk Management Using the Project Risk FMEA. Engineering Management Journal, Vol. 16 No. 4, pp. 28–35. (2004). https://doi.org/10.1080/10429247.2004.11415263
7. Karamoozian, A., and Wu, D. A Hybrid Risk Prioritization Approach in Construction Projects Using Failure Mode and Effective Analysis. Engineering, Construction and Architectural Management, Vol. 27 No. 9, pp. 2661–86. (2020). https://doi.org/10.1108/ECAM-10-2019-0535
8. Lo, H., and Liou, J. H. A Novel Multiple-Criteria Decision-Making-Based FMEA Model for Risk Assessment. Applied Soft Computing, Vol. 73, pp. 684–96. (2018). https://doi.org/10.1016/j.asoc.2018.09.020
9. Razaque, A., and Bach, C. (2012). Fostering Project Scheduling and Controlling Risk Management. International Journal of Business and Social Science, Vol. 3 No. 14, pp. 118–27. (2012).
10. Sarkar, D., and Manvinder, S. Risk Analysis by Integrated Fuzzy Expected Value Method and Fuzzy Failure Mode and Effect Analysis for an Elevated Metro Rail Project of Ahmedabad, India. International Journal of Construction Management, Vol. 22, No. 10, pp. 1818–29. (2022). https://doi.org/10.1080/15623599.2020.1742634
11. Sawhney, R., Subburaman, K., Sonntag, C., Rao, V., and Capizzi, C. A Modified FMEA Approach to Enhance Reliability of Lean Systems. International Journal of Quality & Reliability Management, Vol. 27 No. 7, pp. 832–55. (2010). https://doi.org/10.1108/02656711011062417
12. Shen, X, Jiang, S, Gong, L & Carr, C. Technology Progress in the Chinese Construction Industry under the Iron-Fist of Government, Technology Analysis and Strategic Management, vol. 25, no. 4, pp. 387. (2013). 402. https://doi.org/10.1080/09537325.2013.774343
13. Soebandrija, K. E. N., Suharjanto, G., Selvi, G. V., and Darmawan, R. Failure Modes and Effects Analysis (FMEA) in Indonesia's Construction Project through the Lens of Improvement and Decision-Making Strategy. Proceedings of the First Australian International Conference on Industrial Engineering and Operations Management, IEOM Society International. (2022).
14. Suryoputro, M. R., Khairizzahra, A. D. S., and Widiatmaka, N. W. Failure Mode and Effect Analysis (Fuzzy FMEA) Implementation for Forklift Risk Management in Manufacturing Company. IOP Conf. Ser.: Mater. Sci. Eng (2019). https://doi.org/10.1088/1757-899X/528/1/012027
15. Spencer, L., Ritchie, J., Lewis, J., and Dillon, L. Quality in Qualitative Evaluation: A Framework for Assessing Research Evidence. National Centre for Social Research. (2003).
16. Tafazzoli, M. Dynamic Risk Analysis of Construction Delays Using Fuzzy-Failure Mode Effects Analysis. University of Nevada. (2017).
17. Wang, R., Feng, Y., and Yang, H. Construction Project Risk Evaluation Based on FMEA. Earth and Environmental Science, Vol. 330 No. 2. (2019). https://doi.org/10.1088/1755-1315/330/2/022041
18. Wehbe, F. A., and Hamzeh, F. R. Failure Mode and Effect Analysis as a Tool for Risk Management in Construction Planning. Production System Design. (2013).

AUTHORS PROFILE

Wahbi Albasyouni is a PhD student at Newcastle University in the United Kingdom, currently researching the implementation of Failure Mode and Effects Analysis (FMEA) in the construction sector. Publications include Identifying the Causes of Delay in the Building Sector in Egypt: A Case Study of Small and Medium-Sized Companies. Science, Engineering and Technology. Volume 3, No 1; Investigating the Optimum Tilt Angle of PV Modules in Al-Sherouk City, Cairo. Journal of Architectural and Engineering Research, ISSN 2738-2656; Flexural Performance of Concrete Structures Reinforced with Fibre Reinforced Polymer (FRP). iRASD Journal of Energy & Environment. Volume 3, No 1; Value engineering in the construction sector in Egypt. Research Journal of Engineering Science, Volume 10, No. 1.

Ibrahim Abotaleb is an associate professor of construction engineering at The American University in Cairo (AUC). Abotaleb received his BSc and MSc degrees with honours from AUC and his PhD from the University of Tennessee, Knoxville, where he was a recipient of the Chancellor's Fellowship. Before joining AUC, he was a postdoctoral research fellow at the Missouri University of Science and Technology (Rolla). Abotaleb has taught courses in various areas, including construction methods and technology, risk management, value engineering, construction equipment, lean construction, engineering economics, resource management, numerical analysis, as well as simulation and optimisation. Abotaleb's research has resulted in the publication of over 65 refereed journal and conference papers in prestigious international journals and conferences.

Khaled Nassar received his Bachelor of Science and master's degrees with honours from Cairo University in 1992 and 1995, respectively, and his PhD from Virginia Tech, Blacksburg, Virginia, in 2000. Currently, he is a professor of construction and architectural engineering at The American University in Cairo (AUC). Before joining AUC, he was an assistant professor of construction engineering at Bradley University in Peoria, Illinois, and an associate professor at the University of Maryland Eastern Shore in the United States. He also served as the chair of the Department of Architectural Engineering at the University of Sharjah in the UAE. Nassar has taught and conducted research in several areas, including simulation applications, computing in design and construction, quantitative methods in construction management, and technology, as well as visualisation.