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

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***Abstract:** The aim of this research was 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 carried out to determine the impact, probability, and detection of the identified risk factors according to 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 reached results demonstrated that FMEA and risk management are quite similar in different aspects, but FMEA has an additional dimension to PMI's risk analysis, which is "detection". Such dimension affects how risks are managed and plays a major role in developing better strategies for controlling and detecting risks. This added depth provides more insights about the project and enables construction parties to make better preparations and decisions in their projects. The findings indicated that FMEA has a significant potential in the construction industry if it is properly applied. Findings of this research are envisaged to promote the application of FMEA as an upgrade to the currently applied PMI's risk management practice; thus, enhancing the efficiency, visualization, and eventually the 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 extra burden on projects to be completed on time, cost, and with proper quality [12]. Nevertheless, the general perception about the construction industry is lack of efficiency and not being able to complete the project on time, cost, and quality.

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It is well known that any construction project usually suffers from potential risks that directly and indirectly impacts the overall performance. The size and complexity of the project could lead to increasing the probabilities 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 the identification and management of potential failures and errors in any process, system, and project. FMEA can be used to identify and assess risks and ranked 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 significance of a risk based on its impact, occurrence, and detection [4]. Failure Mode and Effects Analysis was initially introduced in 1949 by the U.S Army and used improve their military operations [6]. FMEA was then used by Nasa at the beginning of 1963 in order to improve their reliability needs and optimize their safety analysis [4]. Since then, this technique 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 for the common technique that was used in design practices. In addition, risk FMEA was also used and presented in order to assess risks in the construction industry. Other different techniques such as risk priority number (RPN) was also presented, this technique is used to examine the impact of any risk using severity rates, occurrence rate, and detection. The critical FMEA is another form which concentrates only on the multiplication of the impact 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

There are multiple studies 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. The aim of that paper was to present a multi criteria of decision making using FMEA.

There are multiple benefits and advantages that 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 huge development in construction sector in developing countries, the percentage of occupational accidents is increasing every year. 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. Therefore, this study presented the use of fuzzy probabilistic FMEA in order to assess occupational hazards in construction projects. The presented fuzzy model provides multiple data analysis for accidents on site. The model was applied on 4 different construction projects. By applying 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 basic idea of the study was to enhance and improve the reliability of the design to reach an effective approach that can accomplish assigned goals and expectations. Estimating the cost impact of failures modes from the design phase can help in cutting costs [18][19][20]. 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 detect any risks that might impact the performance and flow of the project. 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][23]. discussed the possibility of using a composite FMEA for the risk assessment of construction projects. The researcher introduced the idea of integrating FMEA, 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. In order to conduct the present research, the research methods of this study are categorized in five stages; each stage revolves around the different steps needed to attain the research objectives.

[3] used fuzzy FMEA to evaluate safety risks in construction projects. The study combined the fuzzy logic and FMEA to improve the process of assessing hazards and risks in projects. Likewise, [10][21][22] analyzed the risks of elevated metro rail projects in India using fuzzy FMEA. The approach was valuable in detecting the possible risks in these types of construction projects and proved to be effective. Another way of implementing FMEA was to analyze construction delay, this was previously shown by [16]. Delay was evaluated based on the occurrence of risks, impact of risks on project's delay, and ability to handle and resolve the risk before it creates 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 with the efficiency of this approach for ranking and prioritizing 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 the in the 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 was a comprehensive literature review in order to identify all risks that are commonly faced in construction projects and discuss previous studies that used FMEA as a risk assessment tool. The literature included electronic resources, textbooks review, journals, publications, thesis papers, and other sources of data. A questionnaire survey was used to determine the current impact and probabilities of risks in the construction sector in Egypt. Then, interviews were conducted with experts in order to evaluate the collected risks and choose only the most significant ones that are applicable in the construction sector in Egypt. The main source of data in this research was a questionnaire survey. Due to the Covid-19 pandemic that took place at the beginning of 2020, this survey was structured to be answered online. Various professional parties from contracting, consulting, and contracting companies were invited to participate in the survey and 221 responses were gathered, but 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 is basically getting the impact and probability of each risk. Then, FMEA was the next approach used to prioritize risks using the risk priority number. The third approach was the fuzzy FMEA to involve some sort of simulation and accurate estimation of figures. Fuzzy logic offers the capability to generate a flexible and valuable reasoning while taking into consideration uncertainties and inaccuracies.

The following stage of the study was determining the level of alignment of participants responses. One of the most common problems in any research is the comparison of tendency within different values or groups. One of the most common statistical tools for examining such a comparison is known as t-test. The basic aim of this tool is to determine the mean, examine variations according to samples, and provide some evidence regarding the central tendency in mean values. In this research, the survey focused mainly on engineers and parties working in the construction sector in Egypt. Most of those who participated in this survey are contractors, consultants, and owners. The idea of applying a t-test is to estimate if there is any difference in terms of mean values between contractors, consultants, and owners. Hence, means for the impact, probability, and detection were compared to indicate if there are any differences between owners and contractors.

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The previous steps helped in analysing risks using different methods and approaches. However, it was essential to validate the accomplished results through determining the applicability of FMEA in the construction industry. Hence, it was important to consider the opinion of engineers who participated in the initial questionnaire survey to determine their opinion about the need of FMEA in the construction sector. The basic structure of this survey was mainly based on determining their own opinion about the efficiency, and simplicity of risk management process that is proposed by PMI and FMEA and indicated the possibility of using FMEA in future construction projects.

IV. RESULTS

A. Survey Results:

The number of participants in this survey was 221, but some responses were not validated and were completely eliminated from the results to reach 214 validated and accurate responses from experienced engineers working in various positions and companies in Egypt. The first part of the questionnaire survey collected some demographic information about respondents such as their age, company working with at the moment, and numbers of years of experience. Then, respondents were asked to evaluate the impact, occurrence, and detection of risks from 1 to 10 (1 represents the lowest impact, probability, and great ability to detect the risk, while 10 indicates the highest impact, probability, and complication in detecting the risk).

B. Level of Alignment:

This section shows the results of conducting the t-test through examining the variances in means between consultants, owners, and contractors for all risks in the project in terms of impact, probability, and detection. There were no significant variations between responses given by contactors and owners. It initially investigated the level of alignment between contractors and consultants using the t-test. However, the number of contractors that participated in the questionnaire survey were much higher than consultants, but yet the only variation was observed in the occurrence of variation order. Consultants thought that it has less occurrence 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 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 labours	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 labours	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 taken depending on the number of respondents (which is 214 in this case) to reach a specific average weight for both the impact and probability as demonstrated in the below table. The multiplication of both values can obtain the significance rate, which is then used to rank the most important risk factors according to this process. Table 2 shows the impact, probability, and significance values for all risks based on the results collected from 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 labors	6.9	5.9	40.8
Shortage of skilled labors	6.8	5.7	38.2
Delay in 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

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Delay in giving payments by 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 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 on construction projects. The top ranked factors that were ranked using their significance values were cash flow problems, delay in giving payments by 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 to 50. The reason for having a close range was basically because of having a quite high population in the questionnaire survey and the average was taken among 214 survey respondents.

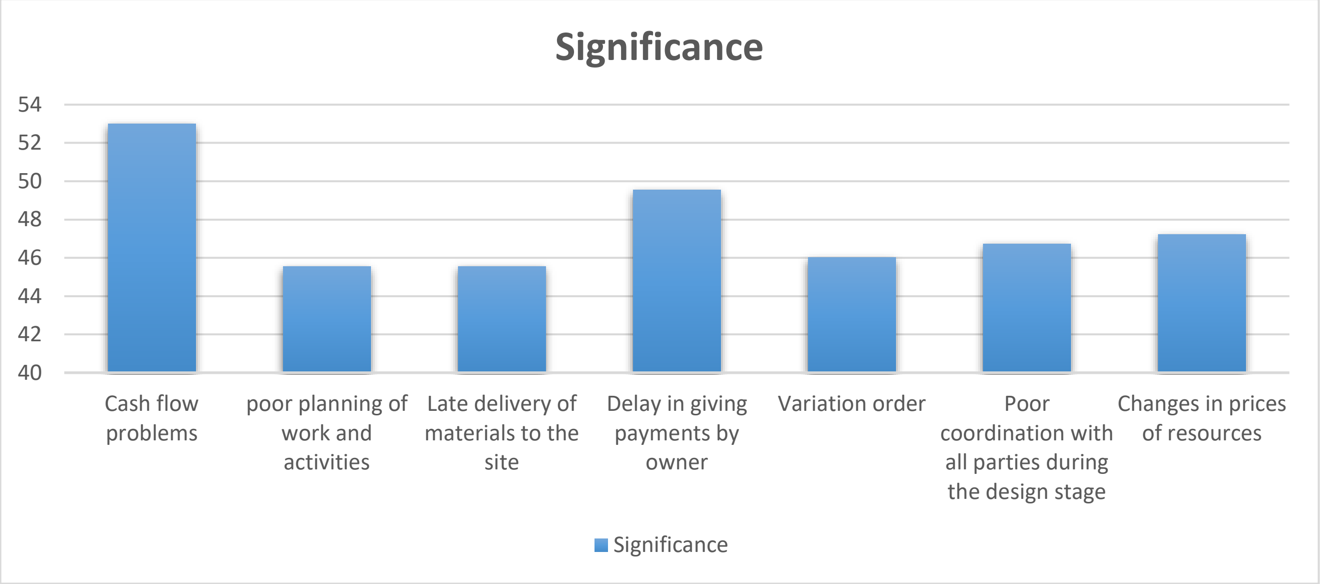

Fig.1. Risk Factors with a Significance Rate Higher than 40

D. Failure Mode Effect Analysis:

In order to apply the concept of FMEA, the most common tool that is normally used in this context is known as risk priority number. It is quite similar to PMI's risk assessment, but the additional factor in this case was estimating the detection of each risk. Hence, the probability and impact will remain the same, but the risk priority number will also include the detection rate. Hence, the Table 3 shows the results of applying the risk priority number tool. Hence, the ranking of risks for both techniques remained the same while taking into account that most survey respondents decided to consider the detection rate to be average due to the fact that detecting risks in any project depends on experience, qualification, and other important factors.

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 owner	7.5	6.6	5.7	282.2
Changes in 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 labors	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 labors	6.8	5.7	5.2	201.6
Delay in 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

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E. Fuzzy FMEA:

The use of fuzzy FMEA has been quite 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. O in this case represents the probability of occurrence, S is the severity, and D is basically not detection of risks in terms of a probability. The values of the O, S, and D are obtained from the conducted questionnaire survey with engineers in the construction field. The values assigned for each factor ranged from 1 to 10 as known in the traditional FMEA, but the only difference was that the detection became not detection and ranges from one to ten. Each factor was divided into several parameters, mainly, low, medium, and high. In order to overcome all these limitations, the researcher followed some guidelines provided by [14] including the following:

- Fuzzyfication: it is basically about re-defining the membership function in terms of occurrence, severity, and detection to get a fuzzy RPN.
- Indicate the most suitable fuzzy rules in order 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, severity is very high, and the detection is very high, hence the fuzzy RPN turns out to be very high.

For the conventional FMEA, risk assessment was done through multiplying the occurrence, severity, and detection to get 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 a fuzzy logic was the most suitable option using a 'mamdani' (min and max) progress. Mamadni is a common inference system in a fuzzy logic that is represented by minimum and maximum attributes. Table 4 shows the criteria used for severity, occurrence, and detection including 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 indictors were then used as an input variable in the membership functions, it was divided into three inputs, severity, occurrence, and detection as shown in Figure 2.

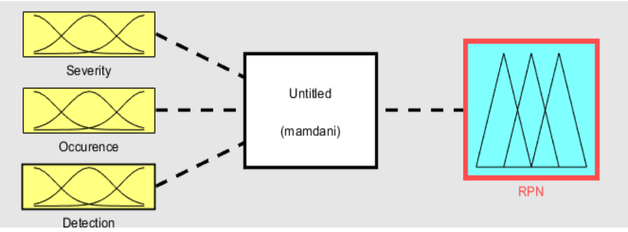

Fig. 2. Setting up the Input and Output for Fuzzy RPN

Table 5 shows the criteria of each category, type of curves used, and range of parameters. Each parameter had to include a certain 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 analysis.

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 quite similar but this time it focused mainly on the RPN values, which is the multiplication of severity, occurrence and detection. Therefore, the output was divided into several categories starting from zero, which is the lowest value, and 1000 as 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 originally obtained from the questionnaire survey results. The analysis of the survey was done with the help of Microsoft Excel but applying Fuzzy RPN was achieved using MATLAB software program as it contains a fuzzy logic toolbox that can aid in providing the needed analysis.

Table 7 shows the results of risk factors after applying the fuzzy logic. The initial step was to insert the severity, occurrence, and detection values, and then indicate the fuzzy RPN value in addition to the category at which this risk lies within starting from very low to very high risk.

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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 owner	7.5	6.6	5.7	282.2	442	M-H
Changes in 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 labors	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 completely different RPN values and changed dramatically the ranking of most significant risk factors. This was done because of reducing the influence of detection rates on the overall RPN value and providing more significance for both the severity and occurrence.

F. Comparison between the Adopted Methods:

The ranked risks are completely different using both PMI assessment and 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
Delay in giving payments by owner	Delay in giving payments by owner	Poor cost estimation
Changes in prices of resources	Changes in 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 prices of resources

Risk assessment using the impact and probability and conventional RPN method resulted in the exact ranking of risks and the only difference was in the variation order and poor coordination between parties, yet both of these risks are not 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 could be similar methods due to the fact that both of them analyse risks depending 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 having any effect on the project.

V. RESULTS VALIDATION

To validate the reached results and some of the concluding remarks regarding the efficiency of FMEA and the possibility of using it in the construction sector, another questionnaire survey was redistributed among engineers that were part of the initial one. A brief overview over the risk management process that is proposed by PMI and FMEA was initially presented before indicating some questions regarding the efficiency, and simplicity of each technique. It was essential to estimate if engineers working in the construction sector in Egypt heard about FMEA before. The results demonstrated that less than 10 percent of all survey respondents heard about FMEA, and this shows the ability to test the effectiveness of this method in real projects. Hence, this new method is not yet known or introduced to the construction industry in depth and only few studies discussed its usage theoretically. There are different techniques that are used in the construction sector to analyse potential risks, and hence respondents were asked if they think that other methods are needed to enhance the overall performance of construction works. More than 46% agreed to the need of new techniques for analysing 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 is in need for alternative and new methods that could be used to analyse risks in construction projects. The following question focused on analysing the concept and the usage of FMEA in terms of efficiency, simplicity, range of rank, and visualization of risks after providing a comprehensive introduction and definitions to survey respondents. Regarding the efficiency, the highest percentage was moderate and good due to the fact that there is no clear evidence regarding its efficiency in the field as mentioned by some respondents. For simplicity, 46% thought that this technique could be complicated during its early stage but more than 30% thought that it could be good and excellent in terms of simplicity. The following point was about the high range of ranking and more than 75% agreed about the excellent range of rating for the FMEA. Finally, the last section focused on the visualization of risks and most respondents were quite impressed with the good visualization of risks using FMEA, Table 9 provides a summary for all survey answers regarding the use of FMEA in the construction industry.

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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%, while the simplicity of risk management was much better than FMEA according to respondent's opinion. However, there is a quite low range of ranking in risk management, and this was the major and most critical disadvantage, in addition to having a poor visualization of risks. This means that there is no unique way of showing the results of risk management similar to the one common by FMEA. Table 10 shows the factors related to risk management and their evaluation.

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 beneficial, around 29% thought that both could be similar, and the rest indicated that having only the common risk management process is better. Finally, the basic aim of the questionnaire survey was to estimate the possibility of using FMEA in the construction sector in Egypt. The study investigated the opinion of respondents about the possible 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 extremely high and shows the potential of this method to be used as an alternative risk assessment process.

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 Project Management Institution (PMI). It has been used for decades in the construction sector, but recent studies discussed the current limitations of risk assessment and the need for further studies in this subject. Therefore, this paper proposed the adoption of FMEA as a risk assessment tool in the construction sector. Risk assessment using the proposed approach by PMI and RPN could be similar methods due to the fact that both of them analyse risks depending 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 its occurrence in the project. This variable is extremely important in construction projects because it allows dealing with risks before influencing the performance of the project. FMEA can be useful in visualizing and demonstrating all risks in the project in a very creative way which makes it easier to control and deal with risks in the project. Researchers claimed that FMEA has some limitations and one of them is being subjective. This is the same case with the risk management process as both of them 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 quite beneficial to the construction sector in analysing potential risks.

LIMITATIONS

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

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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 duly acknowledged in this thesis whenever I have referred to the work of other individuals. I confirm that no financial funding was received for the completion of this study and free from any conflicts of interest. The specific contributions of both myself and other authors to this work are explicitly outlined below. Author[1] was responsible mainly for writing the paper, and collecting and analysing the results, the remaining authors were responsible of data and critical analysis.

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