Stochastic Failure Mode Effect And Critical Analysis (SFMCEA) on Repair and Retrofitting Projects

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Abstract—FMEA is a known method in risk management that de-fines the failure that might happen and identifies its hazards on the system; this procedure can be done using the risk priority number "RPN" analysis system. This method is applied on a real repair project "Sheraton Hotel" located in Cairo city near the Nile River where they had to make urgent repairs to avoid failure and collapse of the building. This study concentrated on developing the results and most common failures that might happen in any emergency project by determining the severity, occurrences, and detection to get the overall RPN of each failure. Two methods were used to rank the risks, the first one is the traditional approach which is based on getting one value for the severity, occurrence, and detection. On the other hand, the other method is getting a range of values (3 values) for the severity occurrence, and detection. The results showed that using the traditional form of RPN resulted in three major risks such as ineffective work penalties, complex contractor's policies, and risks related to contract agreement. On the other hand, the use of a probabilistic analysis showed that the top risks are ineffective work penalties, problems with contract agreement, and unfavorable contract.

Keywords: Risk Analysis, Construction Sector in Egypt, Risks in Construction Projects, Failure Mode Effect Analysis, Risk Priority Number, Repair and Retrofitting Projects.

1.   Introduction

Failure mode effect analysis is considered a risk management practice that can help in determining and ranking potential failure modes and extreme errors in any process, system, and project while ensuring the availability of several solutions to any mistake. Determining the potential failure is normally done through the use of an expert's opinions and brainstorming techniques especially for experts working in the field. Each failure mode is then ranked through the use of risk priority number which is measured for each potential failure mode in the project. The risk priority number is measured using severity, occurrence, and detection that are given by experts in the field [2].

Failure Mode Effect Analysis was initially applied in 1949 by the U.S Army in order to improve their military operations [4]. The same technique was then used by Nasa at the beginning of 1963 in order to improve their reliability needs and optimize their safety analysis [2]. Since then, this technique kept on developing until being used in various industries such as aerospace sector, mechanical sector, and construction sector [4]. In addition, other different techniques were done to modify various domains to ensure estimation of risks as [3] 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 construction industry. Other different techniques such as risk priority number (RPN) was also presented which is used to examine the impact of any risk using severity rates, occurrence rate, and detection where the combination of all these factors yields the risk priority number value. All these changes were made in order to adequately present the exact condition and real scenario of each risk. Risk FMEA also presented another factor known as risk score which is calculated through multiplying the impact and occurrence rate [4]. Fuzzy FMEA was also recommended to be used to assess any schedule chain and ensure completion of projects on the assigned duration [8]. Risk assessment value was introduced to FMEA where this factor can help in assessing the reliability of any element while assessing failure possibility in any proposed element [9].

[6] conducted research about Improving the Quality Procedure Performance for Steel Structures Components Assembly using failure mode effect analysis. They say that FMEA is an effective procedure to reach the weaknesses of most technical systems by investigating the potential failure of a process. In this research, by conducting much different failure mode effects on possible failures that cause some defects and examining some improvements in maintenance program, obedience welding, as well as a scarfing machine. All these improvements were done to avoid costly improvements and modifications and to reduce time and health wastage. This paper discussed the potential use of FMEA in the construction sector and especially for repair and retrofitting projects.

2.   Method

The methodology of this paper is based on a quantitative analysis through the use of risk priority number as a tool of risk analysis. The initial step was going through a literature review to collect some of the common risks and issues that are faced in repair and retrofitting construction projects, then these risks were then evaluated by an expert through a personal interview. This expert was the project manager of Sheraton in Cairo and provided all required details and circumstances that were faced in the project. The concept of risk priority number and its use is well introduced below.

Risk priority number is a calculated approach to determine and evaluate the percentage of risk on a specific method, steps, or any type of processes. It is calculated by determining the severity, occurrence, and detection of a process and mutilating all givens to reach a risk priority number whether this step is in risk or not. However, this method can be applied on one process per time and then comparing the results with the other processes, but not the complete project with only one RPN step. The only reason for calculating RPN is to manage to decrease the total percentage and take into consideration the failure that might happen before it actually happens. RPN consist of three major components multiplied together to get the overall risk rate:

- Severity: it is an estimated value of how the next user or component will understand the effect of failure and such theory depends on the reactions that may be taken to overcome such failure.

- Occurrence: it is often called likelihood which represents the estimated number of how much the failure will occur during the process or production lifetime.

- Detection: it is often termed as effectiveness. It is the estimated value of how effective the detection of failure is before reaching the customer. The description of each factor is shown in table 1.

Table 1: Criteria of analysis using RPN

Rank	Severity	Occurrences	Detection
1	None	Almost never	Almost Certain
2	Very Minor	Remote	Very High
3	Minor	Very slight	High
4	very Low	Slight	moderately High
5	Low	Low	Moderate
6	Moderate	Medium	Low
7	High	Moderately High	Very Low
8	Very high	High	Remote
9	Serious	Very High	Very Remote
10	Hazardous	Almost Certain	Almost Impossible

Notice that each failure has 3 probabilities (Optimistic, most likely, pessimistic), probability for each failure and multiplying all these factors gives the RPN value and multiplying this RPN value with the probability gives the probabilistic RPN value. Furthermore, by applying 90% certainty rule of PERT which is as follows:

$$Mean = \frac{a + 4m + b}{2.6}$$

(1)

The project manager then provided the range of values for the severity, occurrence, and impact according to the performance of work in the project and major issues that were faced during its renovation.

3.   Case Study and Results

Sheraton Cairo is a five-star hotel in the heart of Cairo; in fact, it stands as one of Cairo's landmarks that has the commercial sign "Sheraton." Sheraton is Starwood's "leading" brand, providing luxury hotel and resort accommodation. The Sheraton hotel is located in the west of Al Giza city near al Jalaa square that is located in Aldoay district in front of the Nile river at the Center of the most beautiful sightsee-ing area in the city, only a few kilometres away from the national Museum, Oprah House, Cairo Tower, Tahrir Square, American University, and many traditional stores. The hotel was built at the end of 1970 and consists of two towers built next to each other called Nefertiti and Cleopatra. It consists of 650 rooms and wings. Sheraton Cairo provides guests with inspiring effortless experiences, sophisticated meeting rooms and restaurants. The hotel consists of 537 rooms and 113 suites most of them overlook the Nile River. Each room has all the requirements of any five-star hotel in addition to a gym, pool, renting cars office, clinic, Spa, shops, and many other facilities. It also consists of around eight restaurants and cafes that work around the clock all of them close by midnight except for one restaurant that works 24/7. Moreover, there are eight meeting and wedding halls and those are highly equipped with all materials and resources required. The process of repairing started during the late 2007 and almost ended in 2016 where it faced many problems and issues which delayed the final submission of the project. In this case study a comprehensive questionnaire has been developed with the owner to understand the basic structure of repair projects, and develop a failure criterion to avoid any certain problems in repair and retrofitting projects in the future. Table 2 shows the RPN results for all the potential failure modes in the case study.

Table 2: RPN Results

Potential Failure Mode	Severity	Occurrence	Detection	Probability (%)	RPN	PRPN	Mean (90%)
	8	2	1	0.15	16	2.4	
Decision making	9	3	2	0.15	54	8.1	45.69230769
	10	4	3	0.7	120	84	
	5	1	3	0.1	15	1.5	
Role of work	6	2	4	0.2	48	9.6	43.61538462
	7	3	5	0.7	105	73.5	
	6	8	3	0	144	0	
Agreement with contractor	7	9	4	0.01	252	2.52	156.1846154
	8	10	5	0.99	400	396	
	7	8	5	0	280	0	
Ineffective work penalties	8	9	6	0.01	432	4.32	246.5307692
	9	10	7	0.99	630	623.7	
	8	1	3	0.6	24	14.4	
Inexperienced consultant	9	2	4	0.2	72	14.4	39.23076923
	10	3	5	0.2	150	30	
	8	2	2	0.5	32	16	
Error in design documents	9	3	3	0.25	81	20.25	52.69230769
	10	4	4	0.25	160	40	
Bad project management	6	3	3	0.6	54	32.4	76.61538462
	7	4	4	0.35	112	39.2	

Failure							
	8	5	5	0.05	200	10	
	4	1	4	0.55	16	8.8	
Poor Financial control	5	2	5	0.15	50	7.5	27.38461538
	6	3	6	0.3	108	32.4	
	5	1	4	0.9	20	18	
Failure of Soil	6	2	5	0.05	60	3	13.96153846
	7	3	6	0.05	126	6.3	
	6	4	1	0.6	24	14.4	
Failure of Columns	7	5	2	0.3	70	21	54.46153846
	8	6	3	0.3	144	43.2	
	4	4	1	0.2	16	3.2	
Failure of Beams	5	5	2	0.2	50	10	41.53846154
	6	6	3	0.6	108	64.8	
	3	5	1	0.2	15	3	
Failure of Slabs	4	6	2	0.2	48	9.6	48.23076923
	5	7	3	0.8	105	84	
	7	3	6	0.6	126	75.6	
If contractor bankrupted	8	4	7	0.2	224	44.8	125.6923077
	9	5	8	0.2	360	72	

Ranking before Probabilistic Configurations:

Table 3 includes the ranking of potential failure where only including the highest RPN rank in each one of them before taking into account the probabilities of occurrence of each value.

Table 3: Ranking of risks before applying a probabilistic analysis

Failure	RPN	Rank
Ineffective work penalties	630	1
Contractor policies	490	2
Agreement with contractor	400	3
If contractor bankrupted	360	4
Unfavourable contract clauses	280	5
Bad project management	200	6
Error in design document	160	7
Unqualified workers	160	8
Inexperienced consultant	150	9
Failure of columns	144	10
Failure of soil	126	11
Decision making	120	12
Poor financial control	108	13
Failure of foundation	108	14
Failure of beams	108	15
Failure of slabs	105	16
Role of work	105	17
Poor internal communication	96	18
Weather conditions	96	19
Bad quality control	90	20

Ranking After Probabilistic Configurations:

Table 4 includes the ranking of potential failure including the effect of probabilities on the highest RPN value which resulted in a totally different ranking of problems.

Table 4: Ranking of risks after applying a probabilistic analysis

Failure	PRPN	Rank
Ineffective work penalties	623.7	1
Agreement with contractor	396	2
Unfavourable contract clauses	252	3

Contractor's policies	171.5	4
Failure of slabs	84	5
Decision making	84	6
Role of work	73.5	7
If contractor bankrupted	72	8
Poor internal communication	67.2	9
Failure of beams	64.8	10
Unqualified workers	64	11
Failure of columns	43.2	12
Error in design documents	40	13
Poor financial control	32.4	14
Inexperienced consultant	30	15
Conflicts between labours	28.8	16
Failure of stairs	27	17
Shortage of labours	21.6	18
Shortage of materials or equipment	12.15	19
Bad project management	10	20

The reason for having ineffective work penalties as the top ranked risk was basically the reason for delaying the whole renovation process as the contractor had multiple issues faced on site, and yet the owner could not assign any penalties due to rushing the process of preparing the contract documents. The use of a probabilistic configuration helps in having a range of values and somehow limits the possibility of errors due to any subjective analysis.

Table 5: Failure Mode and Effect Analysis Table

Potential failure mode	Potential effects of failure mode	S	Potential cause of failure	O	D	RPN	PRPN	Recommended actions	Responsibility "Actions"
Decision making	Delay in construction work	10	Unplanned situations	4	3	120	84	Determine side conditions	Project manager
Role of work	Conflicts on site	7	Poor plan of responsibilities	3	5	105	73.5	Find a solution by negotiations	Project manager & owner
Agreement with contractor	Delay in construction work	8	in agreed policies in the contract	10	5	400	396	Consultant can find best solution to reach an agreement	Consultant & owner
Ineffective work penalties	Conflicts between owner and contractor	9	Procedures of contract agreement	10	7	630	623.7	Provide liability rules	Owner & community
Inexperienced consultant	Poor quality control	10	Bad choice from PM and owner	3	5	150	90	Fire immediately	Owner & PM
Error in design documents	Delay and mistakes In construction	10	Not revising after design	4	4	160	40	stop construction and redesign immediately	PM
Poor financial control	waste in cost and overall budget	6	Wrong choice from owner & unqualified PM	3	6	108	32.4	Alarm and perform emergency plan	PM
Poor internal communication	Conflicts between parties	8	PM is not considering it	4	3	96	67.2	Consultant and owner must have a communication line	PM & Owner
Unqualified labors	Poor quality	8	Poor choice from contractor	5	4	160	64	Find a solution with contractor	Contractor
Conflicts between labors	Delay In construction	3	Conflict for any reason	4	4	48	28.8	If problem continued fire those labors	Contractor
Unfavorab	Conflicts	5	Gaining authorities	8	7	280	252	Reach an	Owner &

le contract clauses	between parties		between contract parties					agreement by negotiations	Contractor
Failure of soil	Problems in the structure of the building	4	Poor soil or due to GWT	3	3	36	32.4	Repairs & depends on situation	Contractor
Failure of columns	Problems in the structure of the building	8	Problems in the initial design	6	3	144	43.2	Repairs & depends on situation	Contractor
Failure of beams	Problems in the structure of the building	6	Problems in the initial design	6	3	108	64.8	Repairs & depends on situation	Contractor
Failure of Slabs	Problems in the structure of the building	5	Problems in the initial design	7	3	105	84	Repairs & depends on situation	Contractor
Failure of Stairs	Problems in the structure of the building	7	Problems in the initial design	3	3	63	37.8	Repairs & depends on situation	Contractor
If contractor bankrupted	Delay in construction work and further problems	9	Poor financial control	5	8	360	72	Agree with new contractor or complete work using contractor's crew	Owner & PM

4.   Conclusion

Project management is a set of principles, methods, and techniques that people use to effectively plan and control project work, this approach can be prepared by establishing a plan of resources, money, manpower, scheduling of missions and components, controlling the site, and leading the staff. One of the major components of project management is Risk management which is a very important factor in any future project since it estimates the project's success and determines if the constructed project will fail or not. One of the risk management types is failure mode effect and critical analysis FMEA which analyses the failure and how that component will affect the entire system. In the literature review, FMEA was investigated to define the process by different authors and then determine who used this method previously in engineering and other common majors and identified the results that each one of them reached. In order to define the failure and know exactly how it affects the system, it is best to use the most common failure analysis "RPN" to determine the severity, occurrence and detection of each failure. These failures were defined generally using previous studies and most common problems that might occur in each project and then extract these data results from the owner of the project, contractor, and consultant to determine the dangerous components and analyse them. After applying the RPN analysis on these results a probabilistic configuration is applied on each failure depending on the possibility of occurrence to give multiple results for each problem. After extracting the results, the RPN ranking can be applied to determine the most critical failures and then FMEA table to analyse and solve those problems.

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