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Using the Failure Mode and Effect Analysis (FMEA) methodology to reduce risks /A Case Study in the AL-Mahmoudiyah Residential Complex project in Baghdad Governorate

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Abstract

The research aims to reduce the risks of the AL-Mahmoudiyah residential complex project in Baghdad Governorate, using the Failure Mode and Effects Analysis (FMEA) methodology. It seeks to develop appropriate treatments and procedures to reduce these risks. FMEA is considered an effective tool for evaluating and reducing project risks, thereby improving project quality. A case study approach was used, and data were collected from the project-related department records for the years 2023-2024. The FMEA methodology was then used to analyse this data and reach conclusions. The results showed that the highest potential risk is financial risks (RPN=486), and the lowest risk is human resource risks (RPN=105).

1. Introduction

Product quality and process safety have become among the most important factors determining an organisation's success and sustainability in a rapidly competitive market. Among the effective tools developed to ensure quality and improve operations is the Failure Mode and Effects Analysis (FMEA) methodology. FMEA aims to identify potential defects in products or processes, assess their impact, and take appropriate measures to prevent or mitigate them.

FMEA is used in various fields, such as industry, healthcare, aviation, and engineering, as it provides a systematic approach to anticipating problems, analysing their causes, and prioritising their treatment based on their severity, likelihood, and detectability.

The research problem lies in a set of risks that could hinder project implementation. Therefore, FMEA (Failure Mode and Effects Analysis) can be used to identify potential risks and their impact on a project, including delays in project delivery due to coordination problems between different work teams, and to address these risks. The AL-Mahmoudiya Residential Complex project in Baghdad Governorate was selected because it has several failures that could lead to delays in implementation, risks to individuals' lives, and slow progress. The research also highlighted the availability of project-specific data to meet the research requirements.

The research concluded that using the FMEA methodology contributed to reducing the failure rate during the various project implementation phases and prioritising corrective actions, thus helping to direct resources towards the aspects most impactful on project success. The research recommended applying this methodology in future housing projects to improve project quality and to train engineers and supervisors on how to implement it.

2. Research Problem

The research problem was identified through the field visit to the project and interviews with project implementers; several risks were observed that could hinder the implementation of the AL-Mahmoudia Residential Complex project. The FMEA (Failure Mode and Effects Analysis) methodology is an effective tool for identifying failure modes and potential risks that affect the project, causing delays in project delivery due to coordination issues between work teams and other technical problems. Based on the above, the following research questions can be posed:

1. How can the FMEA methodology be used to diagnose project risks?
2. What are the priorities for project risks that should be addressed according to the RPN?
3. What are the necessary measures to reduce project risks?

3. Research Importance

The importance of the research lies in promoting a culture of quality in projects by emphasising continuous monitoring and accurate risk analysis. This raises awareness among all project workers about the importance of quality and the role of each individual in ensuring the project's success and achieving its standards. The application of FMEA also encourages a continuous improvement methodology in projects by identifying risks and ways to reduce them. This enhances the effectiveness of project management methodologies and leads to better results in future projects.

4. Research Objectives

1. Apply the FMEA methodology to diagnose project risks.
2. Identify the priority of project risks that should be addressed according to the RPN.
3. Develop appropriate treatments and procedures to reduce project risks using the FMEA tool, as a method used to assess risks associated with different failure modes. FMEA is used to evaluate project effectiveness, improve quality, and reduce risks.

5. Previous Studies

The study by Zidan & Al-Khatib (2021) [1] aims to identify the level of implementation of the environmental management system for each requirement of ISO 14001:2015 at the Middle Refineries Company/Dura Refinery, and to assess environmental risks using the FMEA tool. The research problem also lies in environmental pollution resulting from various industrial and operational activities, specifically the petroleum industry. The researcher selected the Dura Refinery/Light Derivatives Authority as a sample for the study during the FMEA application phase. He relied on the case study/checklist approach, the FMEA tool, and the most important results reached by the study: The service provided by the centre contributes to creating benefits for trainees, as it helps them add value to their knowledge and acquire new skills and capabilities. The centre also creates new training courses on modern topics that meet the needs of the community. Beneficiaries and diversity in delivery methods are used to successfully provide better service to trainees.

The study by Beiranvand (2024) [2] aims to develop a modified fuzzy regression and impact analysis method for environmental risk assessment of earth dams in the Ayvashan Dam. The research problem is that the construction of the dam and its associated facilities has significant physical, chemical, and environmental impacts on the ecosystem. The study adopted a descriptive-analytical approach/modified fuzzy inference system (MFIS-FMEA) method, along with the Shannon entropy method. The most important results of the research are that the proposed MFIS-RPN technique shows that the highest RPN was achieved with immediate action during the dam construction phase for soil erosion and soil pollution, and during the dam operation phase for water and aquatic pollution. Therefore, due to the increased degree of risk, immediate and more accurate monitoring is necessary during the construction and operation phases.

While the study of Szczyrba & Ingaldi(2023) [3] aims to evaluate the possibility of implementing the FMEA methodology to support the Hazard Analysis and Critical Control Points (HACCP) system for a Polish food company that manufactures canned meat, the case study method was used. The study concluded that there is synergy between the HACCP system and FMEA, which positively impacted the company by improving risk management, quality control, and safety in food production.

This study differed from previous studies by applying the FMEA methodology to a residential project in Iraq to identify the risks facing the project and the priority of the risks that should be addressed, thus reducing delays in project delivery.

6. Theoretical Aspect

6.1. Origin and Concept of the FMEA Methodology

The USA Army first developed FMEA in the 1940s. It was first used in the 1960s and entered full use when it was adopted by the National Aeronautics and Space Administration (NASA) for space missions [4]. FMEA was also used in the United States and Japan in the early 1950s to ensure the reliability of high-risk products or processes (such as aviation and space). It was also used in the Grumman Aircraft Corporation's naval flight control system in the 1960s [5]. In the 1970s, it was used in the military industry, and then in the automotive industry by Ford Motors, which faced research and development challenges. They published a manual for the method in 1984. It is currently widely used in various operations, not only in manufacturing but also in services and projects [6]. It has also been widely applied in the oil and gas sector, which may include examining failure modes in performing a function within specified limits, or inadequate or poor performance. For a function or an undesired function, the "impacts" analysis examines the consequences of such a failure on the system, individuals, or the environment. This is specifically for higher-level or multi-level impacts. There may be more than one impact for each failure mode, with the FMEA methodology team focusing on the most severe impact [7].

The abbreviation of the term FMEA can be explained as follows [8]:

1. Failure Mode (FM): The probability of a (process, product, system, project, service) failing to meet or deliver the desired function and associated requirements. This term combines two words. The Oxford Dictionary defines "failure" as the act of stopping work and/or a state of non-performance, while "mode" means the manner in which something occurs.
2. Effect (E): The result of a failure of a (process, product, system, project, service) or the end user. There are three levels of impacts (local impact, higher-level impact, and final impact). As for the process, the impact may be at the manufacturing or assembly level, and there may be more than one impact for each failure mode.
3. Analysis (A): This involves analysing the results, identifying the causes of failure, and possible solutions. This includes identifying the root causes of the problem, determining the difference between current and future performance, and identifying potential obstacles [9].

6.2. Benefits of Implementing FMEA

The main benefits of using FMEA are as follows [10]:

1. Assessing customer requirements and developing products and processes in a way that minimises the risk of potential failure modes.
2. Focusing on ensuring employee safety and health and system security.
3. Developing, evaluating, and enhancing design development and testing methodologies to eliminate failures and achieve world-class, competitive products.
4. Reducing costs and the time required from the project phase to market launch and improving product quality and reliability.
5. Increasing operational safety.
6. Increasing customer satisfaction, which ensures the organisation's competitiveness and enhances its market image.
7. Helping to increase safety and service reliability while simultaneously reducing warranty and service costs.

8.Helping to reduce the development process and increase compliance with planned conditions and process efficiency.

Identified the advantages of applying the FMEA methodology as follows[11]:

1. It allows for a structured, in-depth analysis that is adaptable for use across all industries.
2. It helps identify missing requirements and can help mitigate risks by identifying potential failure modes early in a process or product, thereby improving product and process quality and reliability.

The benefit of the FMEA methodology lies in its ability to predict problems before they occur, helping to reduce the costs associated with failure. It also contributes to improving quality and safety by prioritising risks and taking effective preventative actions. It also enhances the reliability and effectiveness of processes and systems, providing a means for continuous performance improvement.

6.3. FMEA Working Mechanism

The FMEA methodology uses the Risk Priority Number (RPN) as a product of three factors: Occurrence (O), Severity (S), and Detection (D), which is determined using the formula RPN = O x S x D, where a predetermined weight is assigned to each variable using a qualitative scale, as shown below [12]:

6.3.1. Severity

This refers to the severity of the potential impacts of failure. Failure is assessed based on its impacts. The severity of failure is rated on a scale from 1 to 10, with level (1) indicating the lowest level of risk (no risk and no impact), while level (10) indicates the highest level of risk (high risk and impact of failure) [13], as shown in Table (1).

Table (1) Failure severity classification [14].

Classification	Impact intensity	Impact
10	Very high severity rating: When a potential failure mode affects the project without warning.	Danger without warning
9	Very high severity rating: When a potential failure mode affects the project with warning.	Severe with warning
8	Project is inoperable with a devastating failure without compromising safety.	Very high
7	Project is inoperable with equipment damage.	High
6	Project is inoperable with minor damage.	Medium
5	Project is inoperable without damage.	Low
4	Project is inoperable with significant performance degradation.	Very low
3	Project is operable with some performance degradation.	Minor
2	Project is operable with minimal interference.	Very slight
1	No impact.	None

6.3.2. Occurrence

Occurrence is a value that indicates the frequency with which potential causes of failure occur. It describes the levels of failure probability, classified into (10) levels (1 being the best case for failure and 10 being the worst case for failure). [15] The table shows the classification of failure probability levels.

Table (2) Classification of failure occurrence (probability) [14]

Classification	probability of failure	Potential failure rates
10	Failure is inevitable	>1 in 2
9	Very high failure	1 in 3
8	Frequent failure	1 in 8
7	High failure	1 in 20
6	Moderately high failure	1 in 80
5	Moderate failure	1 in 400
4	Relatively low failure	1 in 2.000
3	Low failure	1 in 15,000
2	Remote failure	1 in 150,000
1	Remote failure is unlikely to occur	<1 in 1,500,000

6.3.3. Detection

This refers to the ability to detect a fault before it occurs. The degree of detection is evaluated against the ability to identify potential failure patterns, with detection based on the probability of failure using a scale of 1 to 10 [16]. Table (3) illustrates this.

Table (3) Detection criteria (D) for failure status[14]

Classification	Detection	Detection probability by design control
10	Absolute uncertainty	The probable cause cannot be discovered
9	Very remote	A very small chance of discovering the probable cause
8	Very low	A remote chance of discovering the probable cause
7	Low	A very small probability of discovering the probable cause
6	Medium	A small probability of discovering the probable cause
5	Moderately high	A moderate chance of discovering the probable cause
4	High	A fairly high probability of discovering the probable cause
3	Very high	A high probability of discovering the probable cause
2	Almost certain	A very high probability of discovering the probable cause
1	Absolute certainty	Will discover the probable cause

6.4. Risk Priority Number (RPN)

It is an important tool for assessing and analysing failure modes and their effects. It ranks failure modes according to their importance based on the Risk Priority Number (RPN) scores, which can be obtained using the following equation [17]: RPN = S*O*D.

7. Results and Discussions

The researchers applied this tool in the (AL-Mahmoudiyah Residential Complex Project) to assess risks that cause damage to the project, which negatively affects the progress of work and the resulting problems and risks in project management. This is done through implementing the following steps:

7.1. Step (1): Defining the scope of the FMEA tool

The AL-Mahmoudiyah Residential Complex Project was chosen. It is one of the governorate's projects. It is considered one of the largest projects that faced numerous risks during the stages (design, construction, implementation, and improvement), including risks (financial, legal, environmental, construction, political, infrastructure, human resources (labour), and others).

Figure (1) illustrates the flowchart of the AL-Mahmoudiyah Residential Complex Project.

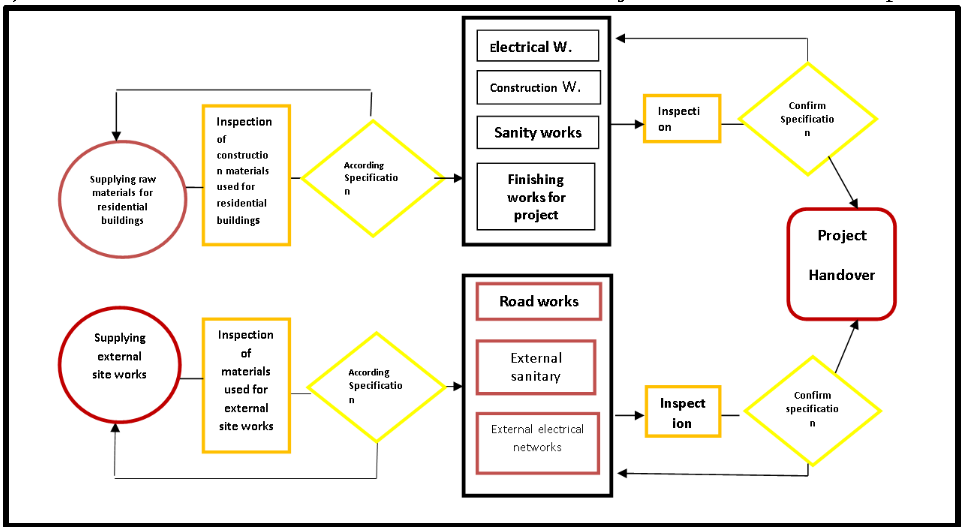

Figure (1) Flow chart of the project process for AL-Mahmoudiyah Residential Complex

7.2. Step (2): Assembling the FMEA Team

The FMEA team was formed from individuals with direct contact with the project's operational reality, from each department, division, or unit, and from various disciplines. This team comprised 13 individuals. They possessed sufficient functional expertise to help identify project risks and develop the necessary corrective actions to improve the project. The team consisted of the

Engineering Department, the Training and Development Department, the Performance and Quality Evaluation Department, and the Stalled Projects Department, as shown in Table (4):

Table (4) FMEA tool implementation team

Code	No.	Name	Office/Department/Division	Position	Specialization	Job Title
A	1	Haider Kareem	Engineering Department	Head of Engineering Department	Environmental Engineering	Senior Chief Engineer I
A	2	Uday Qasim	Engineering Department	Division Head	Civil Engineering	Chief Engineer
A	3	Yasser Hassan	Engineering Department	Director of Resident Engineer Dept.	Civil Engineering	Deputy Chief Engineer
A	4	Mohammed Taha	Engineering Department	Member of Resident Engineer Dept.	Mechanical Engineering	Deputy Chief Engineer
A1	1	Marwa Owaid	HR Dept. / Training & Development Division	Division Head	M.Sc. Public Administration	Deputy Director
A1	2	Mohammed Ismail	HR Dept. / Training & Development Division	Employee	M.Sc. Community Development & Security	Senior Translator
A1	3	Heba Mohammed	HR Dept. / Training & Development Division	Employee	B.Sc. Computer Science	Assistant Programmer
A2	1	Hussein Ali	Performance & Quality Evaluation Dept.	Deputy Head of Department	High Diploma in Quality Management	Chief Engineer
A2	2	Rabab Kareem	Performance & Quality Evaluation Dept.	Division Head	High Diploma in Strategic Planning	Deputy Director
A2	3	Mohammed Qasim	Performance & Quality Evaluation Dept.	Employee	M.Sc. Public Administration	Supervisor
A2	4	Hanadi Khudr	Performance & Quality Evaluation Dept.	Division Head	B.Sc. Political Science	Deputy Director
A3	1	Ahmed Jassim Mohammed	Technical Deputy Governor's Office / Delayed Projects Division	Employee	Civil Engineering	Assistant Engineer
A3	2	Baha Abdul Ameer	Technical Deputy Governor's Office / Delayed Projects Division	Employee	Civil Engineering	Assistant Engineer

7.3. Step (3): Understanding the system to be analysed

Define the processes related to project risks, which include (risk identification, assessment, treatment, and control). Potential project failures, their causes, and the potential impacts of these risks are identified.

7.4. Step (4): Brainstorming Sessions and Identifying Project Failures

After forming the teams shown in Table (4), interviews were conducted with them to explain the nature of the tool's operation and how to apply it to the project. They were also informed of the potential risks represented by project failures, their potential impacts, the necessary corrective actions, and the desired outcomes when completed as required. Work was carried out with the four departments involved in the project and their respective teams. Multiple meetings were also held with the relevant teams, each according to their assigned tasks in the project. The work was conducted in a step-by-step manner. The first step involved exchanging ideas and opinions through a brainstorming session to diagnose and identify project risks and their impacts.

7.5. Step (5): Determine the severity, occurrence, and detection (S, O, D) of the failures

A meeting was held for the task forces formed to clarify the FMEA tool's dimension tables, which range from 1 to 10. The tables illustrated the significance of each number, giving a true value for each of the identified project risks' severity (S), occurrence (O), and detection (D).

7.6. Step (6): Calculate RPN1 for each project failure case

After determining the values of the three dimensions (severity, occurrence, and detection), which were evaluated by experienced and specialised individuals who are in direct contact with the actual practical situation, multiplying these dimensions yields the initial RPN1 value as shown in Table (5).

Table (5) FMEA of AL-Mahmoudiyah Residential Complex Project

Potential Failure Mode (Project Risks)	Potential Effects of Failure	S	Potential Causes of Failure	O	Current Control Mechanisms	D	RPN1
1. Construction Risks: Construction Works	Failure in executing project phases and delay in project completion	9	Failure in production of construction materials	9	Replacement of used materials	5	405
			Delay in delivery of materials	9	Replacement of used materials	5	405
			Breakdown of transport vehicles	5	Temporary maintenance due to insufficient funds	4	180
	Rapid deterioration of buildings	9	Use of poor-quality materials	10	Use of medium-quality materials sometimes	5	450
2. Security Risks: Construction Works	Failure to provide security	9	High crime rates in surrounding area	9	Provide project security guards	4	324
	Theft/ vandalism at site	9	Lack of proper security systems	10	Provide project security guards	4	360
			Weak monitoring systems	10	Provide project security guards	4	360
3. Human Resource Risks: Construction Works	Failure in execution	9	Poor coordination among contractors, engineers, suppliers	8	Each team works separately	4	288
			Lack of motivation	6		4	216
			Scheduling conflicts/ poor execution	5		4	180
4. Financial Risks: Construction Works	Project delay	9	Rare/high-quality materials causing cost escalation	9	Use lower-quality materials	3	243
			Political/external circumstances	9	No actions taken; project suspended	6	486
			Lack of funding/unexpected cost increase	9	Bank loan withdrawal	3	243
5. Technical Risks: Finishing Works	Failure in organising lighting & tech works	7	Design vs actual site differences	7	Alternative labor	3	147
			Unskilled labour errors in technical works	8		3	168
6. Financial Risks: Sanitary Works	Error in sewer/ water networks	9	Insufficient funds	9	Bank loans	3	243
			Costs higher than expected	7		3	189
7. Infrastructure Risks: Electrical Works	Failure in pipeline installation	9	Incompetent engineers/ labor	9	Hire experienced engineers	2	162
						2	162
8. HR Risks: Sanitary Works	Sewer/ water network errors	9	Incompetent engineers/ labor	9	Hire experienced engineers	2	162
			Lack of worker motivation	7		2	126
			Individual work style	9		2	162
	Failure in inspection/ testing	5	Lack of incentives	7	Hire other workers	3	105
			Weak training	8		3	120
			Workers leaving unexpectedly	8		3	120
			Inaccurate dimension measurements	7		3	105
9. Security Risks: Finishing Works	Safety accidents	10	Lack of skilled labor	7	Provide equipment as needed	3	210
			Design errors	9		3	270
			Lack of safety measures	9		3	270

10. Infrastructure Risks: External Works/Roads	Road cracks/ failures	9	Poor soil	7	Current engineer plans	4	252
			Weak foundations	7		4	252
			Undocumented underground utilities	9		4	324
			Non-compliant materials shorten lifespan	9		4	324
11. Env. Risks: External Sanitary Works	Drainage blockage/ Failure	9	Weak stormwater drainage	7	Pumping	3	189
			Heavy rain/winds affect progress	7		3	189
12. HR Risks: External Sanitary Works	Sewer/ water network errors	9	Unskilled labor	7	Hire skilled workers	3	189
13. Security Risks: External Electrical Works	Internal safety accidents	10	Lack of safety measures	7	Provide equipment as needed	3	210
14. Raw Material Risks: External Electrical Works	Electrical network failures	10	Non-compliant equipment	8	Use alternatives	4	320
			Counterfeit/ poor-quality cables, breakers, transformers	9		4	360
15. HR Risks: External Fence Works	Worker accidents during excavation/ installation	10	Heavy lifting	9	Provide safety equipment	3	270
			Lack of safety training	9		3	270
			Inexperienced workers	9		3	270
16. Infrastructure Risks: External Fence Works	Damage to utilities during excavation	10	No underground service detection	9	Repairs after failure	4	360

We note from Table (5) that the highest RPN1 is (486), indicating financial risks, and represents political/external conditions; the lowest RPN1 is (105), indicating human resource risks, and represents a weak incentive system for workers. The degrees of risk will be clarified according to the levels in the matrix to help the company reduce the risk.

7.7. Steps (7, 8, 9): Work results

These steps were combined because they are included in the FMEA worksheet, and their details are shown in Table (5). Project risks were classified according to a risk prioritisation matrix, which includes three levels to help the team distinguish between risk levels and address them based on the degree of risk, as shown below:

1- Level One: This represents an unacceptable (significant) risk and is highlighted in red.
2- Level Two: This level represents a moderate (medium) risk and is highlighted in yellow.
3- Level Three: This represents a minor (small) risk and is highlighted in green. All of this is illustrated in Figure (2):

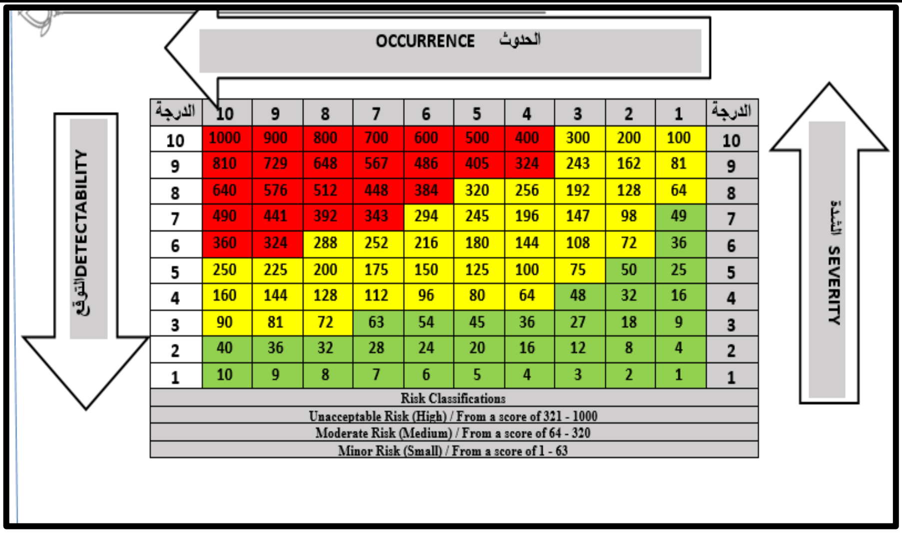

Figure (2) Risk Priority Rating Matrix (RPN) for the AL-Mahmoudiyah Residential Complex Project

Recommended procedures were presented to reduce the RPN value. It was not possible to implement all of the procedures in a short period of time, but additional actions were taken to reduce RPN1, resulting in a lower value, the revised RPN2. Table (6) shows the corrective measures and the adjusted values of RPN2, which were calculated using the same method as RPN1, taking into account the new values of D.

Table (6) FMEA of AL-Mahmoudiyah Residential Complex Project(PRN1-PRN2)

Potential Failure Mode (Project Risks)	Potential Effects of Failure	S	O	D	RPN1	Recommended Procedures	S	O	D	RPN2
1. Construction Risks : Construction Works	Failure in executing project phases and delay in project completion	9	9	5	405	Reorganise machinery for proper production	9	9	2	162
			9	5	405	Set a delivery schedule	9	9	1	81
						Impose financial penalties in case of delay	9	9	1	81
			5	4	180	Provide effective maintenance	9	5	2	90
	Rapid deterioration of buildings	9	10	5	450	Use high-quality materials	9	10	1	90
2. Security Risks: Construction Works	Failure to provide security	9	9	4	324	Provide adequate site security	9	9	1	81
	Theft/ vandalism at site	9	10	4	360	Strengthen security, provide sufficient guards	9	10	2	180
			10	4	360	Provide an effective surveillance system	9	10	2	180
3. Human Resource Risks: Construction Works	Failure in execution	9	8	4	288	Improve coordination, share info	9	8	1	72
			6	4	216	Management encouragement, scheduling	9	6	2	108
			5	4	180		9	5	2	90
4. Financial Risks: Construction Works	Project delay	9	9	3	243	Ensure supply contracts with factories	9	9	1	81
						Use alternatives of same quality at lower cost	9	9	1	81
			9	6	486	Develop contingency plan with funding	9	9	1	81
			9	3	243		9	9	1	81
5. Technical Risks: Finishing Works	Failure in organising lighting & tech works	7	7	3	147	Verify & adjust designs	7	7	1	49
			8	3	168	Employ skilled labor	7	8	1	56
6. Financial Risks: Sanitary Works	Error in sewer/	9	9	3	243	Contingency plan with financial allocation	9	9	1	81

	water networks		7	3	189	Contract with suppliers in advance	9	7	2	126
7. Infrastructure Risks: Electrical Works	Failure in pipeline installation	9	9	2	162	Employ skilled labor	9	9	1	81
				2	162	Proper design by skilled engineers	9	9	1	81
8. HR Risks: Sanitary Works	Sewer/ water network errors	9	9	2	162	Provide skilled engineers & continuous training	9	9	1	81
			7	2	126	Project management motivation	9	7	1	63
			9	2	162	Teamwork encouragement	9	9	1	81
	Failure in inspection/testing	5	7	3	105	Motivate staff	5	7	2	70
			8	3	120	Continuous training	5	8	1	40
			8	3	120	Backup workforce	5	8	1	40
			7	3	105		5	7	1	35
9. Security Risks: Finishing Works	Safety accidents	10	7	3	210	Ensure sufficient skilled workforce	10	7	2	140
			9	3	270	High-quality design	10	9	1	90
			9	3	270	Provide safety equipment	10	9	1	90
10. Infrastructure Risks: External Works/Roads	Road cracks/ failures	9	7	4	252	Soil improvement	9	7	1	63
			7	4	252	Work plan to avoid risk	9	7	1	63
			9	4	324		9	9	1	81
			9	4	324		9	9	1	81
11. Env. Risks: External Sanitary Works	Drainage blockage/ Failure	9	7	3	189	Contingency plan	9	**7**	1	63
			7	3	189					
12. HR Risks : External Sanitary Works	Sewer/ water network errors	9	7	3	189	Training	9	7	2	126
						Staff motivation by management	9	7	2	126
13. Security Risks: External Electrical Works	Internal safety accidents	10	7	3	210	Provide safety equipment before work	10	7	1	70
14. Raw Material Risks: External Electrical Works	Electrical network failures	10	8	4	320	Inspect materials before purchase	10	8	1	80
			9	4	360	Work with approved suppliers	10	9	1	90
15. HR Risks: External Fence Works	Worker accidents during excavation/ installation	10	9	3	270	Provide design maps & inspection	10	9	1	90
			9	3	270	Train workers	10	9	1	90
			9	3	270	Daily safety supervision	10	9	1	90
16. Infrastructure Risks: External Fence Works	Damage to utilities during excavation	10	9	4	360	Use detection devices before excavation	10	9	1	90
						Coordination with authorities for utility maps	10	9	2	180

To determine the reduction rate that shows the extent of the impact of the recommended procedures and actions in making a difference in reducing the Risk Priority Number (RPN) for each project aspect, this rate was calculated according to the following equation:

$$Reduction\ Rate = (RPN1 - RPN2) / RPN1 \times 100 \tag{1}$$

This is illustrated in Table (7), which summarises all types of risks in the AL-Mahmoudiya Residential Complex. The risks are categorised as high or moderate and are marked in red and yellow.

Table (7) Risk reduction rates in the AL-Mahmoudiyah Residential Complex Project

No.	Phase	Risks	RPN1	RPN2	Reduction Rate
1	Construction Works	Construction Risks	405	162	60%
2	Construction Works	Construction Risks	405	81	80%
3	Construction Works	Construction Risks	180	90	50%
4	Construction Works	Construction Risks	450	90	80%
5	Construction Works	Security Risks	324	81	75%
6	Construction Works	Security Risks	360	180	50%

7	Construction Works	Human Resource Risks (Labour)	288	72	75%
8	Construction Works	HR Risks (Labour)	216	108	50%
9	Construction Works	HR Risks (Labour)	180	90	50%
10	Construction Works	Financial Risks	243	81	66%
11	Construction Works	Financial Risks	486	81	83%
12	Construction Works	Financial Risks	243	81	66%
13	Finishing Works	Technical Risks	147	49	66%
14	Finishing Works	Technical Risks	168	56	66%
15	Sanitary Works	Financial Risks	243	81	66%
16	Sanitary Works	Financial Risks	189	126	33%
17	Electrical Works	Infrastructure Risks	162	81	50%
18	Sanitary Works	Human Resource Risks	126	63	50%
19	Sanitary Works	HR Risks	162	81	50%
20	Sanitary Works	HR Risks	105	70	33%
21	Sanitary Works	HR Risks	120	40	66%
22	Sanitary Works	HR Risks	105	35	66%
23	Finishing Works	Security Risks	210	140	33%
24	Finishing Works	Security Risks	270	90	66%
25	External Site Works / Roads	Infrastructure Risks	252	63	75%
26	External Site Works / Roads	Infrastructure Risks	324	81	75%
27	External Sanitary Networks	Environmental Risks	189	63	66%
28	External Sanitary Networks	Human Resource Risks	189	126	33%
29	External Electrical Networks	Security Risks	210	70	66%
30	External Electrical Networks	Raw Material Risks	320	80	75%
31	External Electrical Networks	Raw Material Risks	360	90	75%
32	External Fence works	Human Resource Risks	270	90	66%
33	External Fence works	Infrastructure Risks	360	90	75%
34	External Fence works	Infrastructure Risks	360	180	50%

By focusing on the causes of high-risk conditions that could lead to delays in residential projects, and addressing them through a set of measures that contribute to reducing these risks, we observe from Table (7) that the reduction rate ranged from 33% to 80%, depending on the type of risk:

Structural risks decreased significantly by 80% as a result of addressing failures in project implementation phases and implementing several procedures, including setting a delivery schedule, imposing financial penalties for delays in material delivery, providing maintenance to address damage caused by transportation, and using high-quality materials to address collapses in some parts of the building. This aligns with the findings of [5] regarding the importance of using high-quality materials to reduce risks. Furthermore, the use of several Total Quality Management (TQM) tools in environmental design, such as FMEA, contributes to product development and achieving environmental sustainability [18]. Security risks arising from construction work were significantly reduced (50-75%). This is attributed to providing the necessary site security through increased guarding and an effective monitoring system that prevents vandalism or theft of materials. Human resource risks related to construction work were also reduced by 50-75%. This is due to coordination among work teams and the sharing of information related to project implementation, as well as management's encouragement and motivation of employees, and the adoption of a schedule to organise the execution of project phases. This aligns with the findings of [5] regarding the activation of an incentive system.

Financial risks related to construction work decreased by 66%–83% due to the use of high-quality construction materials at a lower cost than before, achieved by contracting with factories that supply these materials to the site. A contingency plan was also established and funded in case of unforeseen circumstances. This aligns with the study by [2]. Technical risks related to finishing work decreased by 66% due to the availability of skilled labour to avoid errors in the technical aspects of building construction, and the execution of lighting finishing work in accordance with the design. Financial risks arising from sanitation projects decreased by 33% by implementing a contingency plan, securing a bank loan to address an error in the initial installation of the sewage and water network, and contracting with suppliers from the outset, specifying the required quantities and prices.

Human resource risks related to sanitation projects and errors in the installation of the water and sewage network decreased by between 33% and 66%. This reduction is attributed to employing skilled engineers with prior experience in this field, forming work teams, and providing training and development for employees. However, the risks to infrastructure caused by road works have decreased by 75% due to soil improvement (backfilling) to address road cracks and the implementation of a plan to mitigate risks stemming from weak foundations caused by the presence of water pipelines and electrical cables at road construction sites. This weakness resulted from the lack of accurate and up-to-date site plans.

Environmental risks arising from external sewage network works decreased by 66% through the implementation of an emergency plan to address blockages and malfunctions in stormwater drainage networks, which cause water to accumulate on roads and impede work progress. However, the risks associated with raw materials related to external electrical networks have decreased by 75% due to pre-purchase inspections to ensure compliance with standards, avoiding the use of substandard cables and transformers that could lead to serious malfunctions, and ensuring contracts are made with suppliers who meet the required specifications. Risks related to infrastructure, such as perimeter fencing, have also decreased by 75% due to coordination with relevant authorities to obtain utility maps and the use of underground utility detection equipment before excavation to prevent damage to electrical or water lines during digging.

7.8. Research Population and Sample

The governorate has numerous projects, and the AL-Mahmoudiyah Residential Complex project was chosen as the research sample for the following reasons:

1. The presence of some failures in general, and in the project in particular, which could lead to delays in project implementation and risks to individuals due to technical problems.
2. The availability of data specific to the project to fulfil the research requirements.

The research covers the period from 2023 to 2024. It used FMEA methodology, which relies on calculating the RPN equation.

8. Conclusions

1. The results of the practical application of the FMEA methodology in the AL-Mahmoudiyah Residential Complex project demonstrated its high ability to identify and analyse potential sources of risk before they occur, which contributed to reducing the rate of failures during the various implementation phases.
2. Improving project quality by focusing on critical criteria and ensuring that potential weaknesses are addressed in advance.
3. Accurately setting priorities, as the FMEA enabled the project team to rank risks based on the risk rating (RPN), which helped direct resources and efforts toward the aspects most impactful on the project's success.
4. Implementing the methodology contributed to improving communication between the technical and administrative teams, according to collaborative workshops and root cause analysis of failures.
5. The FMEA methodology showed that the highest potential risk was financial risks, and the lowest was human resource risks, which represented a weakness in the incentive system.

9. Recommendations

1. Implement the FMEA methodology in future housing projects to ensure improved quality and reduced risks.
2. Train engineers and supervisors on how to use this methodology effectively, ensuring accurate application and real benefits.

3. Review FMEA analysis results periodically during project implementation to adjust the risk assessment based on actual changes.
4. Integrate FMEA with quality management systems. Project efficiency can be enhanced by integrating FMEA results with systems such as ISO 9001 to ensure integration between risk analysis and the total quality system.
5. Document previous experiences. FMEA studies conducted in previous projects should be documented to serve as a reference for future projects, facilitating continuous improvement and reducing the recurrence of errors**.**

10. Supplementary material

(None).

11. Author's Contributions

Kabas Zuhir Alhasani: Designing, reviewing the research, and interpreting the results; Salam Abdul Sattar Abdul Jabbar: writing and conducting the analysis; Alla Hussein Ansaf: Reviewing the research.

12. Funding

(None).

13. Data availability statement

The authors collected their dataset from the AL-Mahmoudiyah Residential Complex Project, affiliated with Baghdad Governorate, Baghdad, Iraq.

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15. Conflict of interest

We declare that there is no conflict of interest.

16. Declaration of generative AI use

During the preparation of this work, the authors did not use AI or program translation for grammar checking and language polishing. The authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

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استعمال منهجية وضع الفشل وتحليل الأثر (FMEA) لتقليل المخاطر/ دراسة حالة في مشروع مجمع المحمودية السكني التابع لمحافظة بغداد

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المستخلص

يهدف البحث الى تقليل مخاطر مشروع مجمع المحمودية السكني التابع لمحافظة بغداد ،بأستعمال منهجية وضع الفشل وتحليل الأثر(FMEA)، ووضع معالجات و أجراءات مناسبة لتقليل هذه المخاطر. تعد منهجية (FMEA) أداة فاعلة لتقييم مخاطر المشروع و تقليلها و بالتالي تحسين جودة المشروع . تم استعمال منهج دراسة الحالة (Case Study) وجمعت البيانات من سجلات الأقسام ذات العلاقة بالمشروع لسنتي 2024-2023 ،فضلا عن استخدام منهجية (FMEA) لتحليل هذه البيانات و الوصول الى النتائج.وقد أظهرت النتائج ان اعلى خطر محتمل هو المخاطر المالية (RPN=486)، و الأقل خطرا هي مخاطر الموارد البشرية (RPN=105)

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