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A Proposal for the Use of Failure Mode and Effect Analysis as Risk Management Tool in Construction

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Dedication:

I dedicate this work to my dear family, and friends. I would also like to dedicate this study to my supervisors for their outstanding guidance and to all the students and instructors who guided me and helped me to reach this stage.

Abstract

The construction sector plays a significant role in developing and improving the economy of any country and aims to keep on evolving every year. The number and magnitude of projects are increasing annually, which requires more advancements in the methods of project management to ensure completion of projects on time and according to the agreed schedule. Risk management is one of the most important aspects in managing successful construction projects worldwide. Despite that, most construction projects still suffer from cost overruns, delays in schedule of work, and poor quality. The most common form of risk management that is used is the one proposed by the Project Management Institution (PMI) where the risks are quantified through estimating their impact and probabilities. On the other hand, one of the most common risk assessment methods in the manufacturing and process design industries is the Failure Mode Effect Analysis (FMEA) which has similarities to PMI's risk assessment with the addition of a third factor known as "detection" to help in ranking risks while considering the ability to identify them easily before they have any impact on the project. FMEA was initially used in the manufacturing industry and was considered an effective approach in the analysis of potential failure mode for machines and equipment. However, the number of studies that investigated the use of FMEA in the construction sector is limited even though that it envisaged to have substantial potential in construction projects.

The goal of this research is to improve the analysis of risks in construction projects through proposing the use of FMEA. Another secondary goal is to determine the level of alignment between consultants and contractors in terms of their perception of construction risks in Egypt. To achieve these goal, the following methodology was followed. 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 fuzzy logic. Finally, alignment and lack of alignment between project parties regarding the identified risks was identified through statistical tests.

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 we look at risks and results in changing risks ranking.

This added depth provides more insights about the project risks and enables project parties to make better preparations and decisions in their projects. The research also demonstrated that there are no significant differences between project parties in their view of the probability, impact, and detection of risks, except for few of them. In addition, the findings indicate 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: Construction Sector, Risk Assessment, Failure Mode Effect Analysis, Fuzzy Logic

List of Abbreviations

ANP	Analytic Network Process
D	Detection
DFMEA	Design Failure Mode Effect Analysis
FMEA	Failure Mode Effect Analysis
FMECA	Failure Mode Effect and Criticality Analysis
FRPN	Fuzzy Risk Priority Number
O	Occurrence
PMI	Project Management Institution
PPM	Portfolio Project Management
RM	Risk Management
RPN	Risk Priority Number
S	Severity
SFMEA	System Failure Mode Effect Analysis

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Chapter 1: Introduction

Chapter 1

Introduction

1.1. Background:

The construction sector plays a significant role in developing and improving the economy any country and aims to keep on evolving every year. The numbers of projects are increasing annually which requires more technologies and methods of project management to ensure completion of projects on time and according to the agreed schedule (Shen et al, 2008). This sector owns various features that must be understood properly to ensure that it will perform efficiently and effectively. However, during the past few years, the construction sector suffered from potential reduction in its efficiency and most projects aim to ensure completion of projects according to its original plan and cost. It is well known that any construction project usually suffers from potential risks in terms of cost and schedule. The size and complexity of the project could lead to increasing the rates of risk and uncertainty in the project. Therefore, risk management applications and practices are applied on projects to ensure the reduction of uncertainty and reach a final ending without any circumstances.

The theory of managing and analysing risks in construction sector was a major debate especially during the 1990’s. The initial development of this theory was mainly based on estimating the various conditions and risks that could be faced in the project, and preparing a certain procedure to follow the development of this risk in the project. However, this uncertainty is quite expected in any construction project due to the objectives of any project that could be challenging and difficult to be accomplished without proper management. There are different forms of uncertainty in any construction project that could be related to project’s cost, quality of work, schedule of activities, safety measures, and performance, all these factors must be adequately measured to ensure the reduction of uncertainty in the project. Planning of the project is an important procedure that can help in accomplishing the goals of any project and reach a successful management practice (Hamzeh et al, 2012). Nevertheless, any planning procedure must take into consideration all uncertainties that could be faced in the project during an early stage. Hence, risk management must be applied as an efficient tool to estimate any uncertainties in the project and reduce their influence.

Akintoye and Macleod (1997), stated that approximately 70 percent of contractors and project managers in the construction sector do not follow a formal risk management practice during their projects. In addition, most parties that are involved in construction projects are not familiar with the expected risks that could be faced, and this scenario is the main reason for project's failure (cost overrun, and delay) (Howell, 2012). Such huge percentages alarmed the construction sector about the importance of risk management in this industry and that it should be involved in the planning stage to prevent any failure from happening in the project. Actually, poor planning is considered a major factor that leads to failure of construction projects in the MENA area where managers and engineers normally neglect the importance of this step (Skaik, 2010). Risk management tools could be different from one industry to the other, but in the construction sector it could help in avoiding planning failures and other circumstances. There are different forms of risk management that could be applied in the construction sector such as the Risk Management approach proposed by the Project Management Institution, and Failure Mode and Effect Analysis.

Failure mode and 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 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 (Bahrami et al, 2012).

Failure Mode and Effect Analysis was initially applied in 1949 by the U.S Army in order to improve their military operations (Carbone and Tippett, 2004). 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 (Bahrami et al, 2012). Since then, this technique kept on developing until being used in various industries such as aerospace sector, mechanical sector, and construction sector (Carbone and Tippett, 2004). In addition, other different techniques were done to modify various domains to ensure estimation of risks as Bongiorno (2001) 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 which is used to examine the impact of any risk using severity rates, occurrence rates, 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 (Carbone and Tippett, 2004). Fuzzy FMEA was also recommended to be used to assess any schedule chain and ensure completion of projects on the assigned duration (Razaque et al, 2012). 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 (Sawhney et al, 2010).

On the other hand, risk management is considered as a significant part of project management. According to (Prichard, 2005), the idea of risk management is a basic methodology that is used to control events that could have a significant unwanted modification on the project. Nevertheless, not all risk factors could result in a negative impact on the project. Therefore, the basic definition of risk management is a systematic approach that helps in controlling risks in the project through eliminating and decreasing any uncertainties (Mulcahy, 2010). Risk management also helps in developing the idea of reducing negative impact of risks and increasing positive impact of other risks. Consequently, it is essential to properly understand the significance of risk management in construction projects due to the amount of risks and uncertainties that are involved in this sector.

The project management institution indicated that knowledge of project management involves ten major areas where risk management is considered one of the most important ones included. Not all projects or people can manage risks with the same matter, but in most cases common sense can be considered the most suitable way for managing risks (Cretu et al, 2011; Westland, 2019). However, it should be taken into account that not all projects could face the exact risks. If the complexity of the project is increased, it will directly result in more risks that could be faced and hence, the process of risk management cannot be the same in every project. Nevertheless, schedule of work and cost are considered the most important aspects for any organization. However, schedule risks, cost risks, and technical risks are usually based on uncertainties.

Applying intuitive reasons normally aids as an initial step of any decision practice, but in order to efficiently manage all major risks and reach the expected success point, it is important to apply a systematic and forward looking process that involves the use of risk management (Pritchard, 2005). Each activity in the project could suffer from potential risks. However, the main difference between each activity and the following one is the amount of risks involved in each one of them (Ehsan et al, 2010). Hence, this is the reason for defining risk management as an integral procedure that aims to determine and react to any significant risks faced in the project in order to increase positive impacts and decrease the negative impacts. There are different forms of risks that could be presented in projects and might require the management of people, quality management, time management, safety management, cost management, change and scope management, and contracts management.

1.2. Problem Statement:

Most construction projects are still suffering from different forms of risks and challenges. Even though risk management and assessment tools were developed many years ago, this sector is still suffering from delays, cost overruns, and other critical problems. This is well observed by many studies have been investigating these risks and proposing valuable and adequate solutions. The current PMI risk management practice is helpful and has several proven benefits. However, it has some limitations in how risks are analyzed (Pender 2001). Therefore, there is a need for improving risk assessment techniques that may enrich the concept and procedure of risk assessment in the construction sector. The number of studies and researches that investigated the use of FMEA in construction sector is extremely limited. Moreover, researchers did not look into the basic difference between risk management and FMEA in analyzing potential failure modes although that they follow a similar procedure.

1.3. Thesis Goals and Objectives:

The goal of this research is to improve the analysis of risks in construction projects through proposing the use of FMEA. Another secondary goal is to determine the level of alignment between owners and contractors in terms of their perception of construction risks in Egypt. The objectives to achieve the above-mentioned goals are:

- Estimate the most potential risks using risk assessment, FMEA, and fuzzy FMEA, with a focus on the Egyptian construction sector
- Compare comprehensively between the use of PMI’s risk management and FMEA to identify the differences on how the two methods view risks
- Highlight the differences and commonalities between the different construction parties on how they view risks, to evaluate the level of alignment.

- Explore the perception of construction participants on the benefits and possible use of FMEA as an upgrade to the current PMI risk assessment practice.

1.4. Thesis Methodology:

The methodology of this thesis can be summarized into the following:

- Explore the major risks that are faced in construction projects in Egypt through a literature review.
- Conduct a questionnaire survey to collect the impact, probability, and detection of each risk.
- Apply risk management process proposed by (PMI) to determine the ranking of risks using this approach.
- Apply failure mode effect and effect analysis and construct FMEA table for all possible risks in the project.
- Determine the level of alignment between contractors, consultants, and owners through the use of t-test.
- Validate the results reached in this thesis through the use of another questionnaire survey to determine the possibility of using FMEA in construction.

1.5. Significance of Thesis:

It well known that risk management is considered as one of the most important applications in any construction sector worldwide. However, most construction projects that are conducted in Egypt usually suffer from increase in their cost, delay in schedule of work, and poor quality especially during the last stages. Therefore, it is vital to propose the significance of risk management and its capability in managing risks to ensure completion of projects on time and specified budget. But, the significance of this thesis is mainly related to capability of using failure mode and effect analysis as a method for analysing risks in construction projects. It is commonly used in the manufacturing sector and provided outstanding results which indicates the need for applying it in construction. The numbers of studies that involved the use of FMEA in construction industry is quite limited. Therefore, all these factors indicate the need for applying this research to investigate the possibility of using FMEA as a tool for risk assessment in construction.

Several questions are answered through this thesis including the following:

What is the capability of using failure mode and effect analysis as a risk assessment tool in construction?

What is the basic difference between risk management (PMI) and FMEA in analysing risks in construction projects?

How aligned are the project parties when it comes to their view of risks?

1.6. Thesis Organization

This thesis is organized to include the following chapters:

Chapter 1 “Introduction”: the first chapter proposes the idea of this thesis in terms of a general background regarding risk management and failure mode and effect analysis. The problem statement that defines the importance of this thesis is included followed by research aims and objectives.

Chapter 2: “Risk Management in Construction”: the basic idea and definition of risk management in construction sector is proposed in this chapter. The initial part is about the risk management process starting from identification stage, risk assessment, risk response, and risk monitor or control.

Chapter 2 “Failure Mode and Effect Analysis”: this chapter goes through multiple studies that explored the failure mode and effect analysis to understand their basic theory. Moreover, the types of FMEA, process, and previous studies are also presented in this chapter.

Chapter 4: “Methodology”: this chapter presents the procedure of work and methods of data collection of this research. It provides general idea and definition of all methods that are used in this research and conclude with some significant remarks regarding the validity and reliability of results.

Chapter 5: “Data Analysis” this chapter is divided into several parts. The first part presents the results of a questionnaire survey with parties working in the construction sector in Egypt. The second part proposes the idea of t-test to indicate any variations in mean values given by participants. The next part is the risk management process. The fourth part is applying the common FMEA using risk priority number tool. Then, it presents the fuzzy FMEA which is basically applying fuzzy logic to RPN.

Chapter 6: “Conclusion and Recommendations”: the last chapter contains a brief conclusion about the reached results and the comparison between risk analysis approaches that were conducted. Moreover, it also contains some recommendations for the construction industry, development of FMEA in this sector, and recommendations for future studies.

Chapter 2: Background and Literature Review: Risk Management

Chapter 2

Background and Literature Review: Risk Management

2.1. Introduction:

The second chapter in this research goes through the general concept of risk management in the construction sector and the common process that is usually followed starting by risk assessment, risk response, and risk control. The chapter also includes some previous studies regarding the use of risk management on real construction projects.

2.2. Classification of Risks in Projects:

There are mainly two classification of risks in construction projects, the known risks, and unknown risks. A Known risk is defined as any event that is frequently presented in other construction projects which can have an investable effect on a project's resources (Smith et al, 2006). The possibility of occurrence is known, while the expected impact of this risk is also known which results in this classification of risks in projects (Winch, 2010). There are some risks that are partially known which means that their effect and occurrence rate can somehow be predicted (Smith et al, 2006). Unknown risks are those that involves degrees of uncertainty where the impact and occurrence rates are missing. A risk event is not known due to the fact that its sources are not determined (Winch, 2010). Therefore, these events can result in unforeseen circumstances and in order to deal with them, the impact and occurrence rates have to be determined. Risk management in projects involves categorizing impacts and occurrence of risks at which can be divided into several values as demonstrated in the following figure.

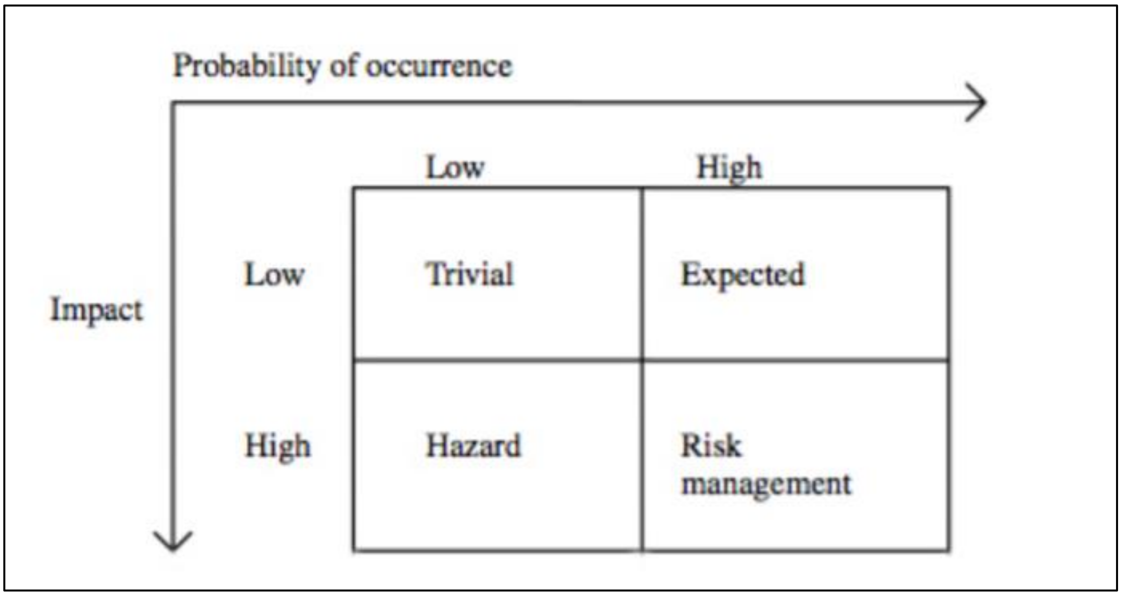

Figure 1: Classification of risks according to impacts and probabilities (Smith et al, 2006)

Figure 1 shows the comparison between probability of occurrence and its impact for any certain risk. Therefore, risk management tries to deal with high likelihood of occurrence and impacts for any risk.

2.3. Risk Management:

The initial theory of risk management was not properly dealt with and completely ignored in an arbitrary manner (Potts, 2008), but the current concept of risk management is an essential part of projects management (Serpella et al, 2014). Thevendran et al (2004) stated that the idea of an efficient risk management is to consistently monitor progress of work on site, define objectives clearly, determine any uncertainty that could be faced, examine each uncertainty through the use of risk management, and finally provide some risk responses that can reduce the impact and probability of each risk. It is basically reducing the impact and probability of negative events and maximizing the impact and probability of positive events especially those that could influence project’s objectives (PMI, 2000). Applying risk management can ultimately be used as an instrument for helping decision making process in construction companies and reduce or eliminate the possibility of risk occurrence.

2.4. Risk Management Process:

There are several models and methods that are used to manage risks in different projects, but the major method is risk management which involves four main stages in any construction project. The first stage is risk classification and identification, assessment of risks, develop risk response for each critical risk factor, and finally monitor and control each risk. Risk management process aids in observing and determining all possible risks that might be exposed in the project in order to make decision takers more involved with all possible problems and circumstances that can be faced in the project in terms of cost and resources, and develop some control plans that can reduce the impact and probability of occurrence for those undesirable events (Dehdasht et al, 2015). Therefore, transparency could be increased using risk management, and problems in construction works can be properly avoided during an early stage due to the fact that preventing risks before beginning of work can reduce the spent time and cost when dealing with them (Schieg, 2006). Moreover, Loosemore et al (2006) indicated that risk management is a proactive procedure which is opposite to any reactive methods. Most managers in construction sector think that they are applying risk management, but the real situation shows that most of them apply a reactive approach and a backward looking one which is completely different than the idea of risk management. In addition, Winch (2010) described that the model of risk management is a learning procedure with time as it is continuously evolving and becoming more critical during the past few years. According to literature, the main aspect of risk management can be exactly the same, but procedure of analysis can vary according to different industries and organizations that use it. But, the common systematic procedure is to apply it during the whole life cycle from the planning stage and until the final completion of any project, hence, the procedure must be iterative in order to ensure that the application of risk management is beneficial (Loosemore et al, 2006). Figure 2 indicates the most common risk management processes.

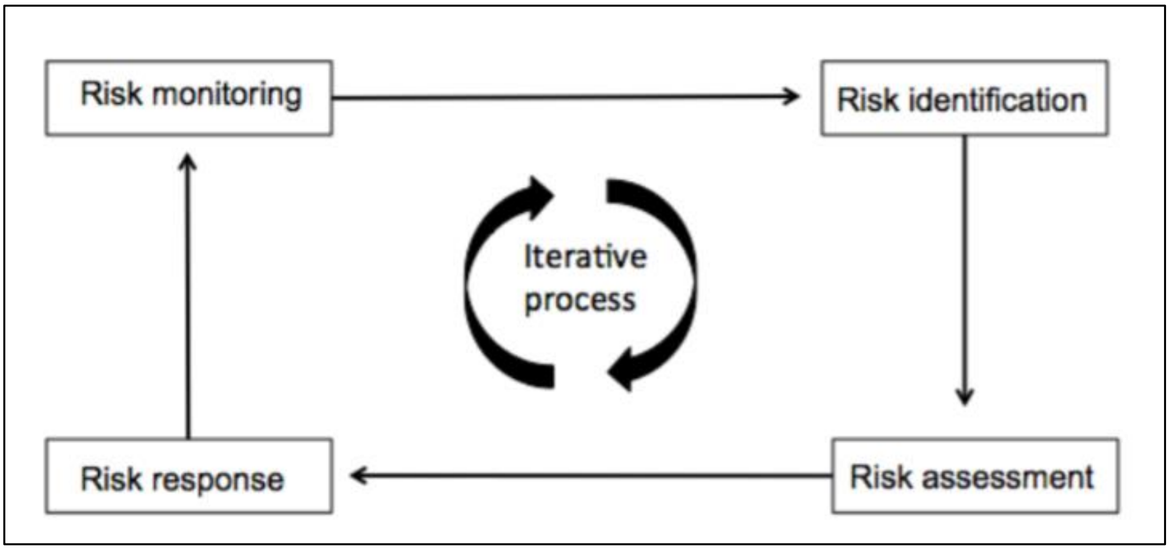

Figure 2: Procedure of risk management (Hillson, 2004)

Construction projects are becoming more familiar with risk exposure due to their nature of work (Schieg, 2006). Therefore, applying risk management during an early stage of the project is significant to take some critical actions before beginning of the construction stage to reach the optimum efficiency of following this method (Eskesen et al, 2004). Other motivations for identifying risk factors during an early stage of the project is that obtaining sufficient amount of data about all possible risks can aid in implementing a proper action and a strategic plan and apply it during an early stage. Therefore, it can aid in clarifying internal objectives and priorities from the project and enable the team to focus on preparing adequate schedule of work, budget, and safety considerations (Reilly and Brown, 2004). Through involving risk management during the planning stage, all possible risks can be determined to ensure the success of projects (Schieg, 2006). The risk management process depends on several stages that must be followed to achieve the desired outcomes, these steps are demonstrated in figure 3.

Figure 3: Risk management process Berg (2010)

2.4.1. Risk Identification:

One of the most critical steps in risk management process is risk identification (Banaitene and Banaitis, 2012). The major goal is not to perfectly predict all possible risk events, but it is done to identify potential risks that could have a great impact on project's objectives. However, the purpose should not be identifying all risks, but the goal is to estimate those with high impacts (Smith et al, 2006). Therefore, the intention of this stage is to determine and assess risks to make sure that they are managed and examined at an early stage and ensure the accomplishment of a project's goals and objectives. Risk management process has to be ongoing during the whole life cycle of the project due to the fact that risks are changing in their nature (Potts, 2008). Before managing risks in any project, they must be determined first, and this could be done by using previous experience and knowledge of other experts (Karimiazari et al, 2010). The basic description of risk management procedure indicated the need for determining all risks during an early stage.

Chapman and Ward (2003) discussed that the initial sources of any possible risks must be determined in addition to their secondary sources as well. The overall quality of risk identification stage in risk management process can be vital towards ensuring the success of the whole process (Chapman, 2001). The first step is taken during an early stage of any project which involves estimating the risks, strategies, uncertainties, and policies that must be followed by the management team (Potts, 2008). Nevertheless, given that most risks in projects are not entirely determined before beginning of work, and it is well expected to have other forms of risks that arise after beginning of project's work, then identification of risks stage must be applied in line with the procedure of work in the project in addition to following a forward looking concept (Schieg, 2006).

The project management body of knowledge described the significance of iterative technique during this step of risk management, and the generation and application of effective and simple risk response just after identifying any risk in the project. Yet, they also indicated that there is no need to apply iterative process to reduce the number of identified risks. There are several methods that are used to identify risks in construction projects such as project plans, checklist of risks, conducting interviews with experts, brainstorming, workshops, and other historical data of previous projects. Moreover, all risks that are known and others that are unknown for various reasons must be documented in order to save them for future projects (Klemetti, 2006). Conducting interviews with experienced managers and experts in the field can aid in solving most faced problems and avoid other problems that can be presented after the start of the project, and the rest of the members can be interviewed in order to determine the influence of each risk on the overall performance of work. Figure 4 shows multiple methods that are normally used to identify risks.

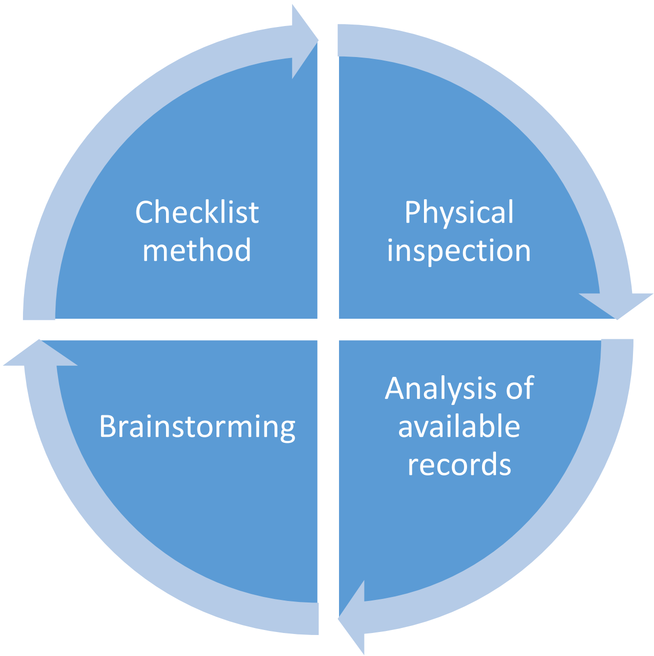

Figure 4: various methods used as risk identification Enshassi and Jaser (2008)

2.4.2. Risk Assessment:

The first phase of risk management is risk identification, but some of the determined risks might be significant and has to be examined and analysed properly. The following step is to estimate the quantitative significance of each risk before moving into management and response to risks. The main reason for this stage is to describe and analyse the situation of each risk as much as possible in order to rank them according to their significance (Schieg, 2006). Generally, according to literature, there are mainly two forms of risk assessment that can be followed, the first one is a quantitative approach, and the second is a qualitative approach. The qualitative approach might involve brainstorming, conducting interviews, and checklists. (Banaitene and Banaitis, 2012). Risk assessment using quantitative analysis methods aids in determining the probability of occurrence for each risk and its impact on the project. On the other hand, qualitative approach usually evaluates the impact and prepares a list of risks that should be highlighted and examined (Zou et al, 2007). Both methods can be used to complement each other where the main goal is to estimate the effect of risks on the project (Schieg, 2006).

It is important to analyse and quantify all risk factors that are predicted in any project. The impact of risks can be in several forms such as increasing cost of certain activities, increase duration of work, results in delay, and affects overall production rates. Some contractors that are managing more than one project tend to share and distribute resources according to progress of work in each project which might cause delays (Schatteman et al, 2008). Hence, one of the most known techniques for risk assessment according to Winch (2010) is known as impact and probability matrix. The classification of each risk depends mainly on their impact and probability of occurrence. It helps in providing a priority list for all risk factors in the project according to their magnitude. Figure 5 demonstrates the form of impact and probability matrix. Both the impact and probability can be either low, or high, but each category might involve certain actions to be taken according to the influence of each risk on the project. In most cases, if the impact and probability are high, then managers tend to reduce their effect by involving some risk responses which is the following step in risk management process.

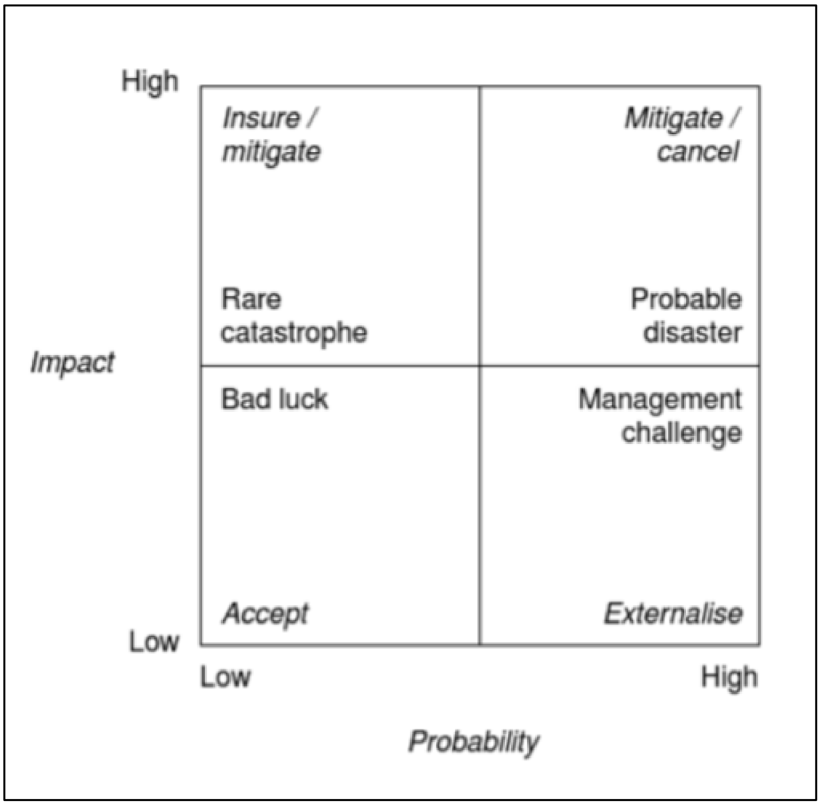

Figure 5: Probability and impact risk matrix (Winch, 2010)

If risks might have a negative effect and can be considered as a static risk, the use of risk matrix is quite common. It contains more information and depth analysis of risks than the use of the previous one. Decision makers tend to have a look on risk matrix in order to estimate their description before taking any action. Each colour presents a certain description either for the probability or impact, and decision makers tend to define a different name for each colour depending on the category of risks. Figure 6 shows the other form of risk matrix that involves greater details for probability and impact analysis (Flanagan et al, 2006).

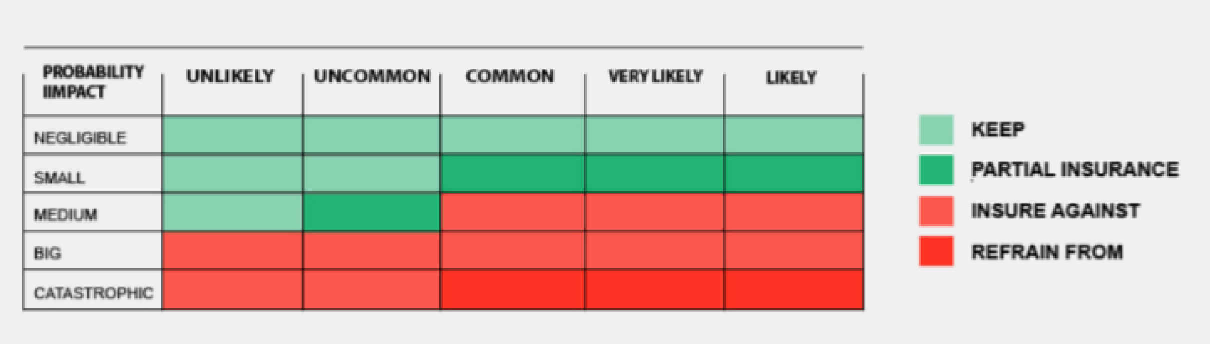

Figure 6: Risk matrix illustration (Flanagan et al, 2006)

There are multiple other quantitative methods that are used to analyse risks in projects. One of the most common one is known as sensitivity analysis, which is done to determine any uncertainty within the project especially those that might have high impact on a project's outcomes. The major aim is to investigate the sensitivity of multiple elements on a project's outcome through changing the number of a single variable every time to estimate its impact on the overall performance of work. Another technique is known by probabilities analysis, which is applied to estimate the significant impact of several uncertainties on the project. It helps in quantifying the influence of risks on budget and schedule of the project and applies the best scenario, worst scenario, and most likely scenario for each event. One of the most common methods that is used for this form of analysis is Monte Carlo Simulation. Another technique that is used in risk assessment is decision tree, which is quite useful in evaluating problems and estimating different options that could be taken. Using this technique involves illustrating the cause and effect of each problem which can help decision makers (Mhetre et al, 2016).

2.4.3. Risk Register:

Risk register is a fundamental approach used for controlling and monitoring risks in this process (Cooper et al, 2005). Risk register design relies on type of the project, people that are part of it, and the organization itself. It is important for each company to create their own form of risk register that can solve their own matters and to specify the form of work that is done by the company. Risk register should be in the structure of a database that can sort all data, act as a storage, facilitate registration process, and manage all information (Flanagan et al, 2007). Any risk factor that is already dealt with through risk avoidance or any other form of risk response, can be eliminated from the risk register with all action plans that were taken to provide some space for new risks, and to prevent any distraction. Moreover, the responsible team must consistently review all risks and their action plans to keep the register updated

(Cooper et al, 2005). Figure 7 shows some of the components that should be included in risk register.

	IDENTIFIED RISK	IDENTIFIED DATE	POSSIBLE IMPACT ON THE PROJECT		PROBABILITY		RESPONS	RESULT
			COST	TIME	HIGH	LOW		
1								
2								
3								
4								
5								

Figure 7: Risk register in risk management process (Flanagan et al, 2007)

2.4.4. Risk Response:

One of the major steps in risk management process is risk response, which is defined as the expected action plan that should be taken for different risk factors that were determined during identification stage (Mhetre et al, 2016). Risk response planning procedure was defined by project management book as the generation of multiple options and estimating certain actions that can enhance positive impacts and reduce any threats on objectives of the projects. The below is a brief explanation of each type of risk response.

2.4.4.1. Risk Avoidance

Risk avoidance is taken if any risk in the project is expected to result in a serious impact which might affect the overall success of the whole project (Potts, 2008). For instance, risk avoidance can be implemented through modifying the plans of the project in a proper way to reduce influence of risks (Klemetti, 2006). This technique promotes any modification to project plans through eliminating those risks that can affect project objectives with a negative impact. For example, avoiding an unfamiliar subcontractor can be part of risk avoidance in construction projects (PMI, 2000). Decreasing scope of work and increasing a project's schedule can be other examples of risk avoidance (Karimiazari et al, 2010).

2.4.4.2. Risk Transfer

This type of risk response is basically to transfer the risk and its consequences to another party that can accept the capability and responsibility of managing it, in addition to taking all liabilities of this risk (Mhetre et al, 2016). This technique is normally efficient in case of having risks that are related to financial management of the project. It involves the use of insurance companies or contracts with other parties in order to transfer all liabilities of certain risks to other parties that can manage it in a better way.

2.4.4.3. Risk Mitigation

This technique basically means to provide a mitigation plan for risks by modifying the scope of work in the project to reduce the possibility of occurrence for risks that could impact the project (Winch, 2010). Applying risk management during an early stage to decrease possibility of having risk event is more efficient than tending to repair the impact and damages after the risk has occurred in the project. Risk mitigation can be applied through involving less complicated procedures or modifying the project's conditions in order to reduce the impact and possibility of having risks, the other forms of mitigation can be adding additional time to project's schedule or adding more resources (PMI, 2000). Figure 8 shows several types of risk responses and their value of insurance.

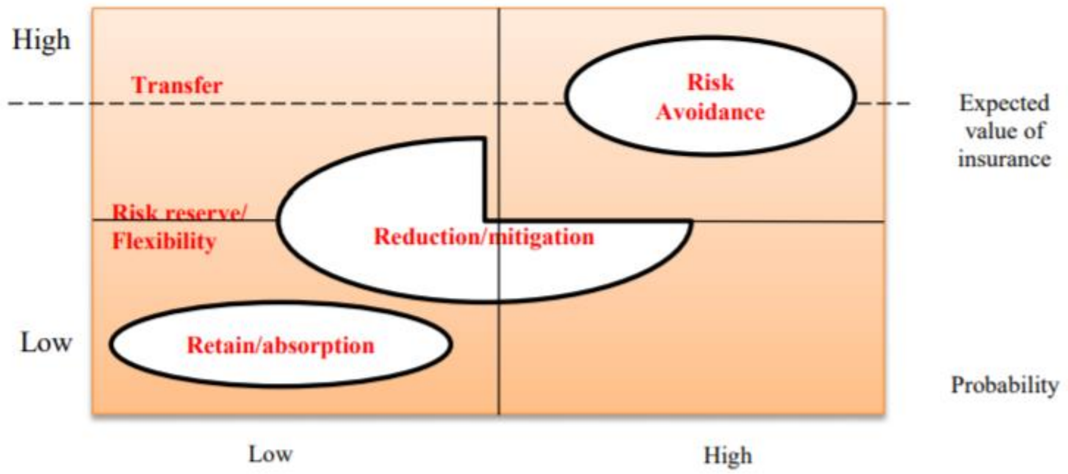

Figure 8: Form of risk response according to impact and probability rates (Vose,2008)

2.4.4.4. Risk Acceptance:

It is impossible to deal with all possible risks and eliminate any threat that could occur in the project, but it can be expected to deal with some threats by applying risk management process while neglecting other risk factors. Using this type of risk response is done when the response to certain risks cannot be possible, or it can be considered unreasonable to take any action (Mhetre et al, 2016). This approach of risk response usually means the expected impact of this risk can be dealt with without the need of applying any preventive actions. This basically means that project's plan and conditions may not be changed to deal with certain risks and apply a strategy as a risk response (Cooper et al, 2005). Providing an efficient control procedure might ensure the proper application of this stage (Klemetti, 2006).

2.4.4.5. Risk Monitor:

Consistent review and monitor for significant risks are quite crucial during the process of applying risk management. It makes sure that all new risks can be identified and well dealt with. The project manager must control the list of most significant risks that were determined in addition to expected action plan, and this list has to be the main tool used in most meetings with all project parties (Cooper et al, 2005). This is the last stage in the whole procedure and is considered one of the most significant ones.

2.5. Limitation of Risk Management Process (PMI):

Risk identification in the risk management process aims at determining all possible risks that may influence the project. Yet, it assumes that all risks can be determined and does not influence the fuzziness and lack of knowing all possible risks. Risk assessment or quantification is quite difficult without considering any simulation, and in some cases it is not clear. If simulation is added to the process, then the cost might be increased. The PMBOK did not mention any guidelines for providing a contingency plans and multi-level reversers (Pender, 2001).

An efficient risk management process has to determine all individual risk factors in the project and ensure the adequate deal with them, and there should be the right forms of responses. There should be a significant development in allowing the possibility of dealing with risks individually. However, any risk has a direct influence on the project, but yet risks are usually acting at the exact time which is not mentioned by risk management process and cannot deal with such condition. However, there are different papers that discussed the Egyptian market provided good insights about identifying the risks and their severity, yet, they did not attempt to solve the fundamental problems in PMI's risk management.

2.6. Knowledge and Risk Management

Knowledge is a significant element in risk management as the construction industry is a firm where knowledge is a core part, as the application of any activity in construction projects require problem solving personnel, experience, and experts with sufficient knowledge. Most ideas and knowledge in this sector are usually gathered from previous similar construction projects, and hence, it indicates the need of lessons learned from previous projects in order to avoid any risks that were exposed in the past and ensure the success of construction projects in the future (Maqsood, 2006). The management of data is a principle within risk management which is the procedure of managing knowledge of employees and understanding how such knowledge can be distributed among employees and making sure that they will use it properly in the future (Rodriquez and Edwards, 2008). The new data and information that is obtained from every old project is usually lost because the involved participants are assigned for new tasks or retire which results in losses of such knowledge and a major source of competitive advantage. It is only valid to properly reflect any real problem or action while being investigated in hindsight (Anumba et al, 2005). One of the major factors that can influence decision making criteria in construction project is the poor sharing of data, poor distribution of information, and lack of proper storage (Serpella et al, 2014). However, the procedure of managing data and knowledge in construction sector can be defined as extremely complicated due to nature of work and most of its activities and stages are fragmented (Tan et al, 2010).

2.7. Types of Risk in Construction

There are various forms of risks in construction industry and can be classified into the below categories: Enshassi and Jaser (2008)

- Construction risks
- Environmental risks
- Physical risks
- Contractual and legal risks
- Design risks
- Financial risks
- Political risks

2.7.1. Physical Risks:

The physical nature of work in the project is usually defined as physical risk in construction works. Most of risks that are located in this category are usually cannot be controlled. According to Enshassi and Jaser (2008), the below are some types of physical risks:

- Act of god risks such as landslip, weather conditions, and fire accidents
- Potential and deadly diseases spread on project’s site
- Unanticipated circumstances and events

2.7.2. Construction Risks:

Any risk that is presented during various stages within the life cycle of the project and especially the construction stage is included under this category. One of the major stages in any construction project is the construction one due to several changes that can be proposed at which might affect the quality, cost, and time. Therefore, it is quite important for all parties working on the project to understand the importance of dealing with risks located under this category. The below are some examples of this type of risk as stated by Enshassi and Jaser (2008):

- Late access to site by the contractor
- Any possibility of having damage or failure in used equipment which might affect production rates.
- Lack of equipment, supplies, and fuel to operate machines
- Poor production rate, poor quality of work, poor storing of materials during extreme weather conditions, late delivery of supplies, poor management of inventory, and improper use of equipment.
- Lack of sufficient number of labors and assigning labors with poor experience and capability to perform required works.
- Improper workmanship, poor site investigation, lack of sufficient details in project documents, and facing unexpected problems during the construction stage.
- Mistakes and errors with construction methods and working with project’s designs that contain some errors from the consultant or architect.

2.7.3. Design Risks:

Any significant risk in design progress or concept stage of the project is categorized under this form of risks. Early examination of project’s design will increase the possibility of removing all expected errors and risks that might have a potential failure on the project. This offers the capability to systematically examine the entire design and provide a reliable final design for the project. Any decision regarding a project’s design can be coordinated and discussed between all parties and members in the project while taking into account the overall cost, and ensuring the expected function from the owner.

Enshassi and Jaser (2008) provided several examples as below:

- Any design that is poorly defined and incomplete which resulted mainly from not including all the requirements and needs of user and owner.

- Lack of sufficient information, delay in giving all needed information by the contractor, use of new technology, and poor specifications of work.
- Errors in design, consistent variation order by owner, claims and disputes, complicated design of work, and improper inspection of work.
- Late approval and confirmation of the design.

2.7.4. Political Risks:

Having construction projects in an emerging market could result in several risks and challenges especially political risks. Therefore, it is quite important for all managers to investigate any possible risks from the political circumstances, the next are some examples for this type of risks Enshassi and Jaser (2008):

- Changes in governmental law and procedures.
- Risks of project stoppage, late in getting all permits, changes in building codes, and inconsistent regulations by the government.

2.7.5. Environmental Risks

One of the major growing problems and serious conditions in the construction sector is the environmental risk. Even though that most construction companies neglect the possibility of being exposed to environmental risks in various stages of the project, but in fact it is possible to face them during any stage. In order to ensure the success in current environmental conditions, contractors with forward looking can manage environmental situations during all stages of the project. Enshassi and Jaser (2008) mentioned several forms of environmental risks:

- Ecological problems, waste water, changes in ground conditions, pollution, and other public enquiry.
- Topographic limitation, limited working spaces, weather conditions, and other environmental constraints.

2.7.6. Legal Risks

The governing property has to accomplish a certain contractual framework and fit to the legal conditions needed. There are some obligations that must be fulfilled in order to ensure that the construction project is valid. Every project must obtain a legal advisor at the beginning of work in order to determine any expected sources of problems within the contract, and propose some solutions to prevent these circumstances. This legal advisor is responsible to work during the whole duration of the project to prevent and solve all legal problems that are faced. The below are some examples of legal risks:

- Facing problems with local codes and laws, liability to parties, and direct liability from the owner regarding any faced problem.
- Any legal conflicts between the owner, supplier, contractor, consultant, and subcontractor.
- Maintenance plans, presence of any liquidate damages, and circumstances related to contract conditions.

2.7.7. Financial Risks:

Any risk that is related to money or project's budget is categorized under financial risk. A financial risk can be defined as any possibility for having lower actual return in investment as it was expected from the concept stage. Most construction projects usually suffer from potential problems in their financial capabilities. Cash flow issues are also expected in construction projects which is having incapability to fund the needed expenses, labor, and supplies for the project. Therefore, ensuring the availability of funding can be considered vital for the success of construction works. The below are some examples of financial risks in construction:

- Lack of proper funding, cash flow problems, presence of disputes, slow payment by the owner, and other unsolved financial payment.
- Errors by the contractor which could lead to significant money losses.
- Change order by the owner
- Choosing lowest bid contractor in the project
- Changes in prices, inflation in economy of the country, fluctuation in exchange rate, and other financial crises.
- Poor insurance, disruption of business, and poor extension of bid.

2.8. Previous Studies:

Risk management in construction industry in Iraq according to the perspective of contractors was proposed by Abdulhussien and Shibaani (2016). During the past few years, the significance of risk management is becoming clearer for most companies especially in the Middle East. Nevertheless, there is a limited number of studies that were conducted regarding application of risk management in Iraq. Therefore, the idea of this research was to determine, examine, and understand the main risk factors that influence construction projects in Iraq according to contractors working in various projects. The study proposed a questionnaire survey that contains 36 risk factors. The results reached in this study indicated that most factors are mainly from terrorism attacks, military operations, and presence of wars in the country. The other forms of risks are lack of equipment and labor, unavailable supplies, and poor coordination between different parties in the project. The most effective way to manage risk and prevent their occurrence in Iraq is to use the experience of experts and their judgement.

Onengiyeofori (2016) conducted a study regarding the used system of risk management in the building sector in Nigeria. To accomplish the aim of this study, the researcher used a mixed methodology. It initially used a literature review to construct a comprehensive risk management framework that can be used for building construction works for developing countries. Then, a questionnaire survey was used to collect data and information from engineers working in construction sector in Nigeria to select from 79 different risk factors obtained from a literature review, and they are responsible on assessing them using impact, and occurrence rate on a scale from one to five. The number of engineers that actually participated was 343 participants including 38 clients working in private and public projects, and the rest were 305 contractors. A descriptive statistic was done on the collected responses in order to obtain the distribution and frequencies, in addition to using risk acceptability matrix. The results indicated the most significant factors that lead to failure of building projects in Nigeria are changes in prices of materials, safety and health problems, corruption and bribery, waste of materials on site, improper management of site, time overrun, and poor supervision, all these factors affected project’s cost. For the most critical factors that affected quality of work are supplying defective materials, extreme weather conditions, using the wrong construction method, poor allocation of time, poor communication with stakeholders, and using the wrong leadership style. Regarding the critical factors that affected the project’s time included site supervision and management, quality issues, low production rate, delay in giving payments by owners, poor communication, and choosing the wrong construction method.

Jayasudha et al (2014) indicated that applying risk management in infrastructure projects is quite complicated and involves a huge uncertainty. Hence, the methodology used depended mainly on a questionnaire survey from contractors working on bridge projects with different sizes. The idea of this research was to determine all risk factors that affected the performance of bridge projects to develop a framework for risk management. The number of companies that participated in this survey was 25, and reached results were examined using ANOVA, and t-test. Survey results outlined most factors such as not having a certain guideline to follow in managing resources on site, a huge amount of materials were stolen on site, and a long distance between the project and its resources.

In another study, Alhassan (2016) estimated the need for determining major issues that are faced in the construction sector in Ghana using risk management. The used risks were determined using a literature review and combined them into a questionnaire survey, and the used method for data analysis was the relative importance index. The number of contractors that provided their opinion were 41 contractors that are working in Ghanaian construction industry. The ranking of most critical factors are using defective designs, poor safety measures, inflation, variation in quantities used, delay in providing payments, and other significant factors. The findings of this study showed that contractors tend to use current and previous alike projects to apply preventive methods for risk management programs. However, it also demonstrated that contractors tend to use only this method for analysing risks and neglect the following of risk management process. The current payment procedure for contractors must be streamlined to provide better stability for contractors. Moreover, contractors must be part of the design stage in order to prevent having defective designs and reduce possibility of changes. Finally, contractors have to provide more training programs for their workers in order to properly ensure the completion of their activities.

Rahman (2018) used risk management to analyse complex construction projects. The basic aim of this study was to understand the insight of risk management in case of having complex projects to indicate the significance of measuring potential risks. The initial part of this thesis focused on a literature review and performance indicators that are related to risk management. It is then examined and validated through applying it on two real projects. Then, the research conducted a qualitative analysis in order to provide some insight regarding the performance of risk management in projects. There are several obstacles that are faced by complex projects in order to involve risk management in their process including alliance contracts and their proper understanding, complexity of projects, evaluation of RM performance, and mitigation of management strategies.

Sohrabinejad and Rahimi (2015) conducted a case study for using risk management in commercial and complex projects. Construction projects are considered a vital part of any infrastructure project especially for developing countries. There are multiple factors that influences the significance of each risk in various projects including their complexity, size, and type, and each risk can directly influence the objectives of projects. Even though that several projects were conducted to investigate the use of risk management in construction sector, but most of them were not practical and did not involve a case study. Hence, the general aim of this research was to determine and rank risks in projects. The model was investigated on a real case study to determine risk factors from a practical point of view. The authors ranked factors under each category under the performance of work in the project.

Another study was done on the golf region by Altoryman (2014) to identify the main risk factors that affects construction projects in this region. There are several construction works that suffer from poor management even though that the current risk management approaches are continuously improving. Another issue is neglecting the use of risk management methods which results in disputes between parties, poor performance of work, and delay. To understand the basic risk management criterion, there should be a deep analysis for the construction environment and its capabilities. The aim of this study was to determine and examine risk factors that are presented during the construction stage in projects located in the Gulf region including Bahrain and Kuwait. In order to collect the required data and information, a questionnaire survey was conducted with 78 clients, 71 consultants, and 99 contractors working in Bahrain, while in Kuwait they were 140 consultants, 139 clients, and 128 contractors. The most critical risk factors that were reached in this study are delay in revising and approving drawings, delay in accepting most changes in plans and drawings, and assigning contractors with poor experience.

Al-Harthi (2015) proposed a study about risk management in fast track projects and applied it on a real construction project in the United Arab of Emirates. The goal was to determine major risks that are faced in construction projects in UAE, understand various procedures followed, and finally present a framework for applying risk management in fast track projects. A questionnaire survey was used and distributed among 65 professionals working in the industry such as consultants, contractors, project managers, and subcontractors. This feedback was analysed using statistical methods, and some discussions were made with experts in the field. The results demonstrated that most risks that are faced in construction projects in UAE are external or internal risks, and the most significant ones were mainly risks related to the owner, and risks related to project’s design. On the other hand, Elijah (2017) provided some strategies to be followed in order to apply risk management in construction works in Kenya. The general concept was to determine how strategies of risk management affected performance of companies working in Kenya. There are multiple strategies that were involved with risk management such as performance risk management, control of risks, resources risk management, insurance risk management, and other forms of strategies. The other concern was to examine the current regulations and policies assigned by the government regarding the relationship between performance of work by companies and risk management strategies. The performance was measured according to quality control, time variance, and cost variance. The questionnaire focused on certain public projects and the sample was distributed randomly to these companies (97 respondents). Inferential statistics and descriptive statistics were used to analyse all collected data. According to achieved results, the most significant risk factors that affected the performance of organizations are control risks in the project, resources risks, and personnel risks. The study recommended most companies and projects conducted in Kenya to involve more risk management in their various practices to indicate the real influence of these approaches on the performance of this sector. This chapter proposed the common risk management process that is usually followed and conducted in real construction projects.

Table 1 is the collection of risks that are normally faced in the construction industry.

Table 1: Different categories and forms of risks in construction projects worldwide according to literature

Risk Category	Risks	Abdulhussien and Shibaani (2016)	Onengiyeofori (2016)	Alhassan (2016)	Sohrabinejad and Rahimi (2015)
Contractor	Unavailability of resources	●			
	Poor planning of work	●			●
	Safety accidents on site	●		●	
	Cash flow problems			●	
	Inexperienced contractor				●
	Error in the construction process				●
	Poor quality of work	●		●	
Labor	Poor production rate from labor	●		●	
	Shortage of skilled labor		●		
Equipment	Poor production rate by equipment	●	●	●	
	Failure in machines				●
	Delay in the delivery of equipment		●		
Materials	Supplying defective materials		●	●	
	Shortage of materials		●		
Owner	late access to site due to owner's decisions	●	●	●	
	Poor feasibility study	●			
	Poor cost estimation				
	Delay in giving payments to contractor	●	●	●	●
	Choosing lowest bid contractor			●	
	Variation order				●
	Poor specifications of work	●			
Consultant	Design changes	●		●	●
	Defective design	●	●	●	
	Wrong estimation of quantities		●	●	●
	Rush design			●	
	Consultant delay				
	Poor coordination with all parties during the design stage	●	●		
External	Presence of disputes between parties	●	●	●	●
	Inflation			●	●
	Changes in regulations	●	●		●
	Changes in prices of materials	●	●		
	Changes in exchange rates	●	●	●	●
	Extreme weather conditions	●			
	Corruption		●		
	Natural disasters		●		

Several efforts have been made to study the risks in the Egyptian construction sector. To list a few examples, Abdelalim (2019) explored the most potential risks that are affecting the delivery of construction projects in Egypt. There are a consistent and significant changes in the construction sector in Egypt, analysing all internal and external risks became a significant step. To achieve the desired objective of this study, a questionnaire survey and personal interviews were conducted. The reached results demonstrated that the top risks that are critical in the construction sector in Egypt are lack of sufficient experience, lack of commitment by owners, economic crises in Egypt, poor scope of work, and poor site management.

Ezeldin and Orabi (2006) explored the methods used for risk identification and response for large scale contractors working in developing countries as a case study on Egypt. A questionnaire survey was used to determine the major risks that are faced in the construction sector in Egypt. The top risks that were determined in this study are financial limitations faced by clients, poor management of projects, inflation, shortage of cash, and changes in exchange rates. Another study focused on the analysis of risks in mega commercial projects in Egypt (Ezeldin and Ibrahim, 2015). The study focused on different perspectives such as contractors, designers, consultants, and owners. The findings of this study showed that the major risk category that it usually faced in mega shopping malls is financial risk.

Chapter 3: Background and Literature Review: Failure Mode and Effect Analysis (FMEA)

Chapter 3

Background and Literature: Failure Mode and Effect Analysis (FMEA)

3.1. Overview:

This chapter presents a literature review regarding the evolution of failure mode and effect analysis starting by its history, type of FMEA, its purpose and major limitations. Moreover, the chapter also contains some previous studies for the use of FMEA in various industries especially the manufacturing sector and few of them were conducted in the construction sector.

3.2. Background of FMEA:

Failure mode and effect analysis (FMEA) is a systematic technique used in investigating a possible failure mode and its likely effect on any system, and process. There are multiple sectors that took into account the significance of this method including the manufacturing industry, aerospace, automobile, and even healthcare. In all these circumstances, FMEA could be used in order to examine the possibility of failure in terms of its impact, rate of occurrence, and detection of this failure mode (Snee, 2007).

The original use of this method dates back to the1940's where US military thought of improving their tactical strategies by preventing any possible failures. Moreover, FMEA was also used by aerospace industry in the mid-1960's in order to enhance quality performance of their products. It was then applied on Apollo space programs to reduce and mitigate possible risks in samples with small sizes. This method gained its momentum after the1960's as the design of Apollo reached the first time to the moon which enhanced the capability to perform this technology in the future. Then, Ford Motor Company applied FMEA in the automotive sector to improve safety of their equipment and products. Moreover, Ford applied this method to enhance design and production of their products. Then, during the 1980's, the automotive industry started to apply FMEA by applying standardized structures and methods in automotive industry. Even though that this method was applied in the military industry, FMEA technique became then applied in multiple other industries such as automotive, processes, software, foodservices, and plastics (Snee, 2007).

3.3. Purpose of FMEA:

There are multiple reasons related to applying FMEA procedure on any process. In case it is applied properly, it can help in reducing life cycle costs and mitigate possibility of having risks and failures in any product and its development. The basic idea of applying FMEA is to reduce the cost of any risk by identifying it during an early stage and prevent their occurrence from the first place. Moreover, it can estimate safety problems and catastrophes before it occurs. The below are some critical objectives of applying FMEA: (Doshi and Desai, 2017)

- Determine and properly understand each expected failure, causes of failure, and effect of this failure on any process or product.
- Examine associated risks with determined potential failure modes and provide a priority ranking to estimate the required corrective actions and mitigation plan.
- Apply estimated corrective actions to prevent any failure from occurring once again.

FMEA can be considered as a quantitative and a qualitative approach. There should be a working team responsible for assessing failure modes for any process by obtaining historical data from control systems and estimating the causes, effects, and possible detection for each failure mode. Nevertheless, in most cases the obtained data can be invalid, and the team must apply some measuring techniques in order to estimate these potential failure modes on any new process or product. Then, FMEA is usually measured in the form of a risk priority number in order to estimate the effect, cause, and detection rate of each failure mode. All factors are estimated in a range from 1 to 10 where for the effect, 1 can be the least effect, and 10 is known as catastrophic. For occurrence rate, it ranges from 1 to 10 where the lowest value is the least possible occurrence, and 10 is highly likely. For the detection, it ranges between 1 to 10 where lowest value indicates the capability of detecting failures in an easy manner, while 10 is the unlikelihood of detection. Therefore, the multiplication of these three factors can result in getting the risk priority number (RPN) as demonstrated in the following equation (1) (Snee, 2007).

$$Risk\ Priority\ Number = Severity\ (S) * Occurence(O) * Detection(D)$$

3.4. Types of FMEA:

The most common types of FMEA are system FMEA, design FMEA, and process FMEA (Doshi and Desai, 2017).

- System FMEA: this system is usually applied in order to estimate failures in the whole system and any other subsystems. It concentrates on defects and problems in the system such as service problems, human errors, surrounding environment, problems between other systems, integration with people, and safety of the whole system, in addition to any possible failure mode that could be faced. In this form of FMEA, the major goal is on the function and relationship that are not common in the whole system. It includes possible failure modes of these interactions and interfaces and estimates a single point failure that could result in the total failure of the whole system.
- Design FMEA: this type of FMEA concentrates on the design of products usually within the level of subsystems and components. The concentration is to detect any defects that can be applied to enhance the design, its life cycle, and improve the safety of the whole operation. Moreover, this type assumes that the product will be manufactured according to required specifications.
- Process FMEA: this stage concentrates on the procedure of manufacturing and assembly indicating the possibility of improvement in the design stage to ensure safety of work, reduce wasted time, and prevent rework. The concept of process FMEA is applied during the whole steps of the process until reaching the nearly optimized procedure of work.

3.5. Shortcomings of FMEA:

FMEA is an effective tool in order to estimate failure modes and possible errors in services, and products. FMEA is significantly efficient in case it is used in analyzing elements that could result in the failure of the whole system. However, FMEA can be useless and difficult to be attained if the analyzed system is complex due to the fact that some systems might have more than one function, and different components that must be examined and analyzed to estimate the failure of the entire system (Rausand, 2004). This issue can be improved if work modes are increased, and maintenance problems are taken into consideration. FMEA indicates the need for understanding working performance and properties for various systems and their components.

FMEA cannot be used after presence of failure, but it is applied to act as a preventive measure in order to accomplish the desired standards and satisfy customers. This method can be done to develop any changes in the process and design of products or elements, but it would require sufficient amount of resources, and sufficient amount of time to accomplish such goals.

However, just after the failure and financial losses, the importance of FMEA can be estimated. The other major limitation is mainly related to only having one method that is applicable for analyzing possible failures in FMEA which is known as risk priority number (RPN). This tool is used to determine the form of risk in order to demonstrate the right sequence for some corrective actions to be taken. The equation that governs the RPN is quite simple and can be used directly without having any complications. However, each factor is independent from the other one, and evaluating the influence of each factor on the other is extremely complex. Such distortion is the result of non-linear nature for values faced in projects. Therefore, some variances could result in a small RPN than other combinations which could lead to mistaken results. If the severity is high, then great attention could be essential especially in the case of having high occurrence as well. Hence, researchers developed the concept of applying critical FMEA which involves only measuring the severity and occurrence rates.

Although FMEA is used in the manufacturing industry as a common strategy for preventing risks, the results reached from applying FMEA is neglected or only concerns the process of improving quality of work (Popovic et al, 2009). Thus, users usually fail to estimate any significant improvements for the function of FMEA and results reached. The purpose of all these principles is mainly related to protecting the user from any possibility of having failure occurrence (Popovic et al, 2008).

- FMEA is done as a quality initiative and compliance controlling technique for starting the process of improving quality of products. However, each time FMEA is applied it does mean that different outcomes will be reached, and the quality will usually remain the same.
- FMEA does not concentrate on improving value. Most companies indicate no integration between performing FMEA and their quality strategies.
- Usually, teams responsible for applying FMEA have limited funding and difficult objectives to be completed. Hence, there is a limited financial support for applying such a method to improve potential quality of work and involve additional outcomes and results.
- FMEA structure might be poorly designed in case of analyzing a system that involves multiple parameters such as people, performance tracking, new technologies, and complicated organizations. Hence, additional efforts could be needed in order to develop such form of FMEA.

- The main principle that involves this method is known as find, and then fix which is completely different than finding out and then preventing. Hence, FMEA could be applied just after its highest potential which is improving quality of work.

Even though multiple organizations consider that FMEA is a method for reducing the possibility of risks, reducing negative impacts, and softening the whole process, but some of them debate that it involves several limitations. These issues can limit the capability of FMEA and reduce its overall efficiency.

The below are some of the major shortcomings that were proposed by Kmenta (2000):

- Process of FMEA consumes a huge amount of time and efforts.
- There is a huge gap and overlap between the concepts of process and design FMEA.
- All failures are not completely presented in method of FMEA.
- RPN is considered an inconsistent method to measure risks.
- There are multiple limitations that could face application of FMEA by companies due to having multiple decision makers.
- FMEA cannot aid in detecting current failure modes that are presented in real time.

3.6. Applications of FMEA:

There are multiple applications that involve the use of failure mode and effect analysis, but the below are the major ones (Snee, 2007).

3.6.1. FMEA on Existing Process or Products:

One of the major applications that uses FMEA is the development of existing process and product. The analysis of work can be part of an improvement program for any process. For instance, applying FMEA on existing products can start by estimating possible failure modes that might occur, their effect, and provide sufficient corrective actions to prevent its occurrence. Therefore, in this case RPN is helpful in determining possibility of failure modes and prevents them from happening.

3.6.2. FMEA on New Process or Product:

FMEA might be used within the design phase for new processes and products to estimate possible failure modes, their influences, and capability of reducing the likelihood of failures. In this case FMEA is an analytical practice in addition to risk management and aims to enhance overall performance of process and product. In order to examine potential failure in the design of a new process or product, the designer applies FMEA to estimate the possibility of failure in the product and provide some suitable corrective actions that could be taken. This can examine and analyze failure of products when it reaches the customer. Hence, it could help in reaching preventive controls and detection mechanisms to prevent this failure. Therefore, (RPN) is used to estimate the severity, occurrence, and detection of failure modes without the need for many resources and elements to measure the expected failure modes.

3.7. Failure Mode Effect and Criticality Analysis:

FMEA is a bottom up method that provides inductive analysis for any function or parts level. FMECA is related to the common failure mode and effect analysis but this time the detection of potential failure is not included in the analysis criteria. This method helps in estimating failure modes and their ranking according to severity and its occurrences, which offers the capability to take some corrective actions (Gupta and Mishra, 2016).

3.8. Previous Studies (Uses of FMEA in Different Industries):

There are multiple studies that applied failure mode and effect analysis in the construction sector. Lo and Liou (2018) presented a study on demonstrating a decision-making criterion based on FMEA as a risk assessment method. The aim of that paper presented a multi criteria of decision making using FMEA. There are multiple benefits and advantages that are related to this approach but mainly related to obtaining the severity, occurrence, and detection of risks based on their cost and weight.

Liu and Tsai (2012) used FMEA as a risk assessment to indicate major occupational hazards in construction projects. The used methods in construction sector were improved because of significant development in used technologies and sciences. Nevertheless, hazards in construction sector are not reduced as anticipated. In order to decrease and avoid occupational hazards in any project, fuzzy FMEA risk analysis was presented in that study to enhance methods of preventing occupational hazards. The study used quality function deployment in order to estimate the integration between construction items and the reasons of hazards in the project. Moreover, Fuzzy analytic network process (ANP) was applied to estimate the forms of hazards and their causes. Then, in order to assess each risk, the study applied FMEA using fuzzy approach. This technique was conducted on a telecom engineering company that is located in Taiwan. The reached results demonstrated that FMEA is quite efficient in assessing risks and hazards to improve any process.

Cheng and Lu (2015) applied FMEA as a risk assessment technique for pipe jacking and complex performance in the construction industry. Pipe jacking in construction sector is a quite complicated and uncertain procedure which requires risk assessment process to ensure its success. The aim of that study was to propose an innovated risk assessment practice known as failure mode and effect analysis to enhance the methods for applying pipe jacking in construction. The assessment measures the occurrence, severity, and detection while applying fuzzy analysis. The case study of this paper was a water transmission project in China where the validation of that project was demonstrated. A questionnaire survey was used in order to estimate main risk factors that were 31. The most critical factors for pipe jacking were determined through the use of fuzzy FMEA. These factors were segment welding, shaft construction, operation of jacks, and other problems. The presented method overcomes the limitations of the common type of FMEA and offer a reliable risk analysis in the construction environment. The study also provided a comprehensive risk assessment and evaluation method for managers involved in pipe jacking construction projects.

Bahrami et al (2012) presented the use of FMEA in order to improve implementation and management of projects. Nowadays, the management of projects is becoming quite complex and risky due to the use of advanced technologies. That study presented the efficiency of using FMEA method in management of projects. This tool is a systematic approach that can aid in determining, preventing, and controlling any potential risks. The major goal of that study was to apply FMEA during various phases of project management in order to prevent any risks that can affect either the time or cost of work.

Amiri et al (2017) 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 procedure with proper vision can help in determining and ranking most possible risks and required preventive actions. Therefore, that study presented the use of a fuzzy probabilistic FMEA expert system 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 result in hazards.

Albasyouni (2017) applied a stochastic failure mode and effect analysis on repair and emergency projects. The main aim of that study was to estimate the potential failures and main risks that could be faced in repair and emergency projects. The case study investigated the Sheraton Hotel which is located in Cairo. This project had a maintenance plan that took around 10 years due to multiple reasons that were investigated in that study. The reached results indicated the major problems that can be faced in these forms of projects in addition to the need of applying FMEA in construction industry due to its capabilities in reaching accurate and acceptable results. Spencer et al (2003) proposed a cost based FMEA for analyzing life cycle cost and failure mode of equipment. The basic idea was to enhance and improve reliability of design to reach an effective result that can accomplish assigned goals and expectations. This design took into consideration the influence of its cost to ensure that the overall quality and cost can complement each other.

Ahsen (2008) presented the use of cost-oriented failure mode and effect analysis. The common form of FMEA can result in wrong decision making for any financial matter. Therefore, the main goal of that study was to present an improved technique for ranking of failure modes through the use of FMEA. Through applying this cost-oriented approach, quality management might be enhanced. To take any decision, there should be some cost facts that can lead to this decision according to the boundaries of the company and evaluation of expected failure modes. The reached results in that study demonstrated the major need for this approach and its efficiency for companies.

Abdelgawad and Fayek (2012) showed a comprehensive framework for analyzing risks in construction through the use of Fuzzy logic, Failure mode and effect analysis, fault tree, and effect analysis. The basic nature of work in construction involves a huge percentage of uncertainty and risks during all phases of the project. Thus, risk management is critical in any work to ensure its success and accomplishment of all objectives. In the traditional event tree, the possibility of risk events for various reduction methods, and the outcome of multiple paths have to be examined through the use of a quantitative event analysis. Nevertheless, using event tree in the construction industry might face multiple challenges especially in case of lacking sufficient amount and accuracy of data. In order to avoid such obstacles, that study presented a comprehensive framework for construction industry to use a linguistic concept other than numerical analysis to apply event tree analysis and estimate the expected monetary value for each risk value. That framework also contains fuzzy logic analysis, failure mode and effect analysis, and fault tree analysis combined. It can allow professionals to indicate linguistic analysis for any risk circumstance which is applicable for the construction industry. Moreover, this study presented a framework as a method for analyzing risks in construction by three common methods in reliability engineering to take into account subjective risks related to quality. On the other hand, the use of fuzzy logic offers an efficient method to handle construction matters subjectively. The presented framework is done on software tools such as fuzzy analysis, and risk criticality analysis. In order to provide validation of the framework, a case study was proposed and EMV was measured through the indicated approach. The reached results were then compared with other results done by Monte Carlo Simulation which showed that the presented framework provided exact results to the simulation analysis, but the only advantage is related to allowing professionals to express their opinion linguistically. Therefore, that framework is considered more practical and simpler to be used in the construction sector.

Hoseynabadi et al (2010) used failure mode and effect analysis in order to design wind turbines. The use failure mode and effect analysis was done in order to measure the reliability of various systems that are used to generate power. That study applied FMEA on wind turbine systems in addition to using tools for analyzing reliability. A brief comparison was proposed between the results of reliability software data, and results of FMEA towards assembling certain changes in the design of wind turbines. The results are then examined in order to estimate the possibility of any improvements in future designs of wind turbines. Moreover, the final conclusion of that study demonstrated that FMEA can be efficient in terms of analyzing possible failures in the design of wind turbines.

Nielsen (2002) used FMEA in order to analyse possible moisture problems in buildings in the constructions sector. Avoiding damp building can aid in improving indoor air and reduce the possibility of suffering from potential health problems. There are multiple industries that used FMEA in order to avoid and mitigate risks. However, that method is generally new to the construction sector. The study also contains the installation and analysis of the building. Failure mode table provides the expected failures in case of suffering from free water. The study estimated the effect of every failure mode indicated in the whole process and then aimed to provide prevention measures that could be taken. Some failure modes can be easily detected, but others cannot be identified until the occurrence of failure. However, if the analysed project is common, then calculating levels of risks can be easier and solutions could be compared. Hence, FMEA risk analysis can be extremely useful for design, plan, and building new houses, but it can also aid in avoiding risks in current buildings.

Kahrobaee et al (2011) proposed a quantitative analysis known as risk based FMEA which depends on estimating probability of failure and scale of its influence in terms of cost. To investigate its capability, a wind turbine was chosen to be the case study of this research. The reached results showed that defining failure modes according to their failure cost in wind turbines can be more effective and practical than using the other traditional FMEA. Through the use of excel sheets, the presented technique can be used for all types of wind turbines. Moreover, the use of sensitivity analysis was needed to determine the efficiency of cost factors regarding each potential failure especially in the case of wind turbines due to the fact that each failure is translated into cost.

Liu (2013) showed that fuel tank failures and disasters are critical parameters that can influence safety of aircrafts in case of having any extreme accidents. The authors used fault tree analysis and FMEA in order to detect the possible reasons for failure of fuel tank systems to prevent them from happening and avoid any unwanted disasters.

Other studies, for instance, the one presented by Sheng and Shin (1996) involved the use of FMEA in the case of controlling the process or designing any product. The reason for using that method is to make sure that all reliability requirements in the product are done including an airbag starter. Design FMEA was used in order to estimate the plan for controlling process, visual aid, and verifying list of process. Moreover, there has been an integration between process FMEA and design FMEA by predicting the reliability between PPM files and suppliers. PPM reports contain all data and information that can be used to update the occurrence rate of failure in the design of products. Arunajadai et al (2004) explored around 80 percent of design products that involved some problems and cost issues. Quality and cost are considered quite significant factors during the concept stage and design of products. The researcher presented a statistical practice to determine potential failure modes during the design and concept stages. The example that was illustrated was the methodology of hypothetical designs.

Pantazopoulos and Tsinopoulos (2005) estimated that FMEA is a significant tool that can be used in reliability engineering to examine electronic and electrical elements produced for automobile and aerospace industries and their complex assembly. The basic reason for that study is to estimate the weaknesses of the followed system and reduce the possibility of having failure modes. They applied FMEA method during the design phase through the use of different types of FMEA such as system or product. The method was done on significant practices and steps followed in metal forming factories.

Segismundo and Miguel (2008) conducted a study that indicated the use of FMEA as a risk management process towards the optimizations of decision-making criteria for new developed products. The case study in this research focused on an automaker located in Brazil which developed some new products. The reached results indicated a huge decrease in the loops within the plan of work in addition to reduction in numbers of models that were needed to accept any product. Wang et al (2011) presented the use of quality cost factors which is commonly applied to take the place of ambiguous parameters that are used in the calculation of traditional FMEA. Moreover, graphical user interface was also proposed in that study which generate the outcome of FMEA in addition to integration of cause and effect of potential failure rather than using the traditional table of FMEA.

Ling (2012) used design FMEA to examine possible failure modes in diesel engines and apply risk priority number to rank these risks. Moreover, a new way for measuring RPN was also included in this study, but in order to estimate the real results of using that method within design FMEA, the case study focused on a cylindrical head diesel engine.

Guo (2013) presented a study that examined the reliability of wings in planes as it is considered a significant part of the safety of the whole structure. There are multiple external loads that can result in failure of wing structures such as wearing, cracks, and other forms of failure. Hence, it is significant to apply FMEA on wing design in order to determine and prevent the occurrence of any failure. To offer a proper optimal advice regarding the design of wings in planes, it is quite important to understand the distribution of stresses for each element and apply finite element analysis to estimate the strength of whole structure. Thus, this study proposed FMEA and advised some significant aspects in the design of wind blades.

Battles et al (2006) demonstrated that organizations had to involve the sense of learning from any safety accidents in order to develop their basic understanding and working environment. The major idea is to provide proper understanding that can help in producing direct actions to reduce hazards and risks that might result in potential safety accidents. A sense making is used as a comprehensive framework in order to provide the assessment of hazards and risks at the process stage using failure mode, at system stage using probability assessment of risks, and at a single stage through the use of root cause analysis. The results of each method and their combination were quite efficient if the end use provided some information, in addition to experience of professional analysers that helped in estimating potential hazards before examining them.

Jegadheesan et al (2007) stated that one of the most common techniques in total quality management is failure mode analysis. The author recommended that applying FMEA can be effective in the service industry. The research helped in designing a new model known by modified services FMEA. Applying this method was done on a transportation company owned by the Indian state government. This approach can accomplish a modified FMEA service which can estimate all possible failure modes using cost lost and service lost analysis.

Wetterneck et al (2009) examined the perception of members that participate in FMEA in order to provide some suggestions to enhance the current practices used in FMEA process for health care facilities. A survey questionnaire and structured interviews were used on team members who worked in real hospitals in order to examine their opinion about applying FMEA and major factors that could affect the performance of the team. Twenty-four different team members participated in the questionnaire survey and interviews. The reached results indicated that several factors were determined which could affect the efficiency of the whole team especially in the outputs and processes that were followed in their practices.

This chapter presented a literature review regarding the concept of FMEA and some previous studies related to the use of this tool in various sectors. However, the numbers of studies that considered using FMEA as a tool for analysing risks in construction are extremely limited. Even thought that RPN which is the tool used for analysing risks is similar to risk assessment process, but yet it was yet unknown for this sector and researchers as well. Hence, the basic idea of this research is to propose the possibility of using RPN as a tool for analysing risks in construction projects.

Chapter 4: Research Methodology

Chapter 4: Research Methodology

4.1. Overview:

The fourth chapter in this research provides the methodology that was adopted in this thesis. This chapter provides the process that was followed in this research while providing some justification for the chosen methods. It states various research approaches that were used to collect data in order to accomplish the objectives and aims of this research. The adopted methods were mainly chosen in order to provide a comprehensive comparison between risk management and failure mode and effect analysis and their use in construction projects.

4.2. Research Approach:

The research approach initially includes the collection of research questions, developing the required procedure for analysing data, and finally finding most the suitable methods which can be either primary or secondary.

For any scientific research, there are mainly two common reasoning approaches that are used, the first is a deductive approach, while the second is an inductive approach. The deductive approach for scientific researches is defined as having a strategy that is developed and designed to examine a certain hypothesis (Saunders et al, 2007). One of the significant facts about the deductive approach is that each idea has to be accomplished in a method through the use of quantitative and general statistics around the social behaviour regulations while keeping in mind that there should be a proper sample for numerical sizes (Saunders et al, 2007). On the other hand, the inductive approach is when the researcher applies various collection of data and then generates a theory according to reached outcomes and findings from data analysis. Therefore, it enables the research to focus on little samples unlike the deductive approach that depends on large numbers (Saunders et al, 2007). Therefore, Burney (2008) stated that inductive approach is a bottom up method as demonstrated in figure 9.

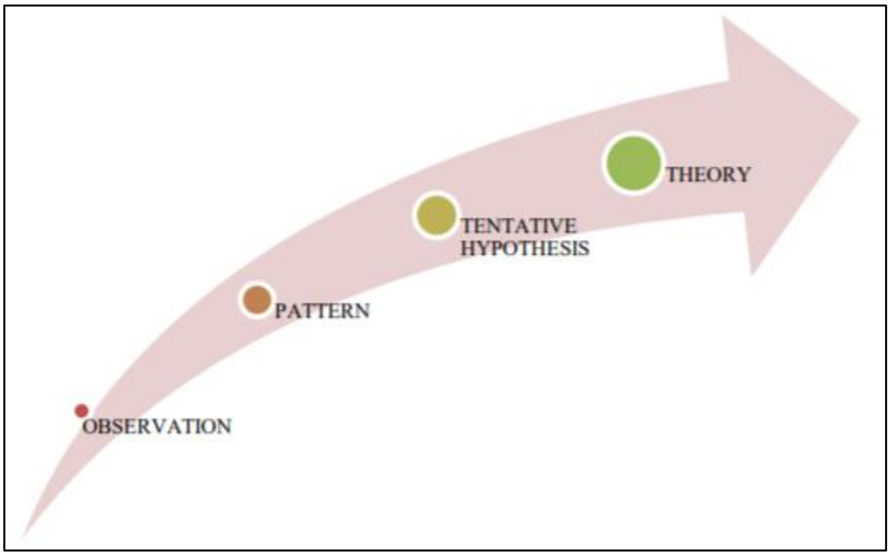

Figure 9: Inductive approach according to Burney (2008)

Therefore, this research basically involves mixed reasoning styles at the same time “deductive and inductive”. It investigates different risks in the construction sector in Egypt through applying failure mode and effect analysis and risk management to compare their results. This may also result in other observations that could be added to a current theory.

4.3. Research Method:

In order to conduct the present research, the research methods of this study are categorized in six stages, each stage revolves around the different steps needed to attain the research objectives. The steps constitute the risk identification, collection of responses, risk assessment, level of alignment, and validation of results.

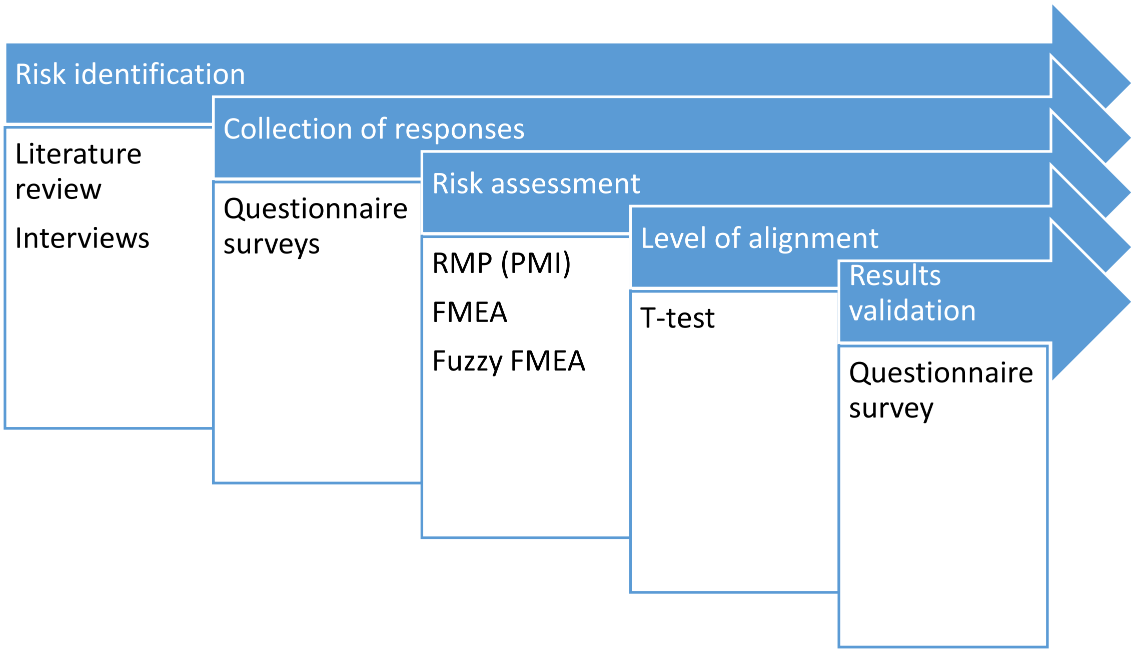

Figure 10: Research Methodology

The collection of data can be accomplished through the use of multiple methodologies. Blaxter et al (1996) stated that data in any research is classified into qualitative data which is in the form of descriptive data, and it can be quantitative data which is in the form of numerical data. Adequately selecting qualitative and quantitative methods relies generally on proper understanding of the context and application of research which is significant for ensuring the success of any research. Saunders et al (2007) proposed that choosing research methods depends on questions that would be answered and what is required to achieve this goal.

Research methods can be either in the form of primary or secondary sources of data. for primary sources of data, it can be in the form of questionnaires, observations, interviews, and measurements that are modified to answer questions of a research, but the secondary forms of data are the procedure of analysing information that were collected previously (Saunders et al, 2009). It can be some figures and factors provided by people through surveys, information provided by the government using population census, reports, journal reports, and academic researches. Nevertheless, the use of secondary forms of data cannot be essential according to research questions and objectives of research. The below are the steps taken for each component of the research methodology.

4.3.1. Step One: Risk Identification:

The initial phase of this research is a comprehensive literature review in order to identify all risks that are commonly faced in construction projects. Literature reviews aid in collecting all risks that are faced in construction to be used in the survey of this research, in addition to understanding the basic form of failure mode effect analysis and its applicability in the construction sector. The literature included electronic resources, textbooks review, journals, publications, thesis papers, and other sources of data. 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.

After collecting the major risks that are usually faced in the construction industry. The below were chosen to be investigated in the survey of this research.

Table 2: Major risks that will be used in the questionnaire survey

Risks in construction projects in Egypt
Cash flow problems
poor planning of work and activities
Late delivery of materials to the site
Safety accidents on site
Inexperienced contractor
Error in the construction stage
Poor quality of work
Poor production rate from labors
Shortage of skilled labors
Delay in delivery of equipment
Shortage of materials
Poor cost estimation
Delay in giving payments by owner
Variation order
Design errors
Wrong estimation of quantities

Poor coordination with all parties during the design stage
Changes in prices of resources
Poor supervision of work

4.3.2. Step Two: Collection of Responses:

The main source of data in this research is a questionnaire survey. Due to Covid-19 pandemic that took place at the beginning of 2020, this survey was structured to be answered online. The survey was established on Survey Monkey website that is accessible by all users and the survey was sent as a link for participants to provide their answers in the form of determining the impact, probability, and detection of each risk factor. Then, some experts were contacted to determine the risk response or the reaction to risks in order to reduce their impact and occurrence in construction projects. The number of responses collected were 221 and only 214 were valid.

4.3.3. Step Three: Risk Assessment:

Risks were assessed using multiple methods. The initial one followed the risk management process proposed by PIM which is basically getting the impact and probability of each risk. Then, risk priority number which is the main tool for applying FMEA was also applied through adding an additional factor "detection" to the PMI risk management. Each value ranged from one to ten depending on the opinion of every respondent. Then, it was essential to involve fuzzy logic to get different and simulated values.

Fuzzy logic is known as the extension of Boolean logic that was invented in 1965 through the use of a mathematical fuzzy seats to generate a set of a theory for a classical outcome. Through presenting a notion of degree in the process of verifying any conditions, it enabled the condition to be in a state of either true or false. Fuzzy logic offers the capability to generate a flexible and valuable reasoning while taking into consideration uncertainties and inaccuracies. One of the main benefits of applying fuzzy logic is that the rules are set in a natural language and involves human reasoning. In this study, the fuzzy logic is done to estimate the probability of occurrence through the use of this logic and provide an alternative way of analysing risks rather than having a subjective based model. The traditional FMEA using RPN was done in the first stage.

4.3.4. Step Four: Level of Alignment:

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 evidences regarding the central tendency in means. 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 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 will be compared to indicate if there are any differences between owners and contractors.

The t-test is mainly applied in this research to estimate the differences between means values for owners and contractors that participated in the questionnaire survey. The basic idea of the t-test depends on the below figure that shows the common graph used to demonstrate results, the reason for including this graph is to show any variations and indicate any outliers that could be eliminated from the obtained results.

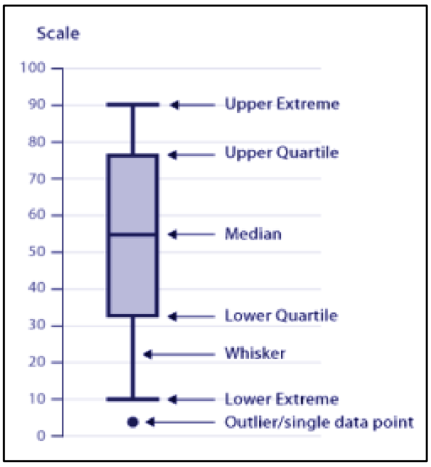

Figure 11: Common scale used for t-test (McLeod, 2019)

The idea of this test is summarized in figure 11 where the major goal is to estimate if there is any statistical difference between the two samples. This is done by going through several steps that depends mainly on the P-value.

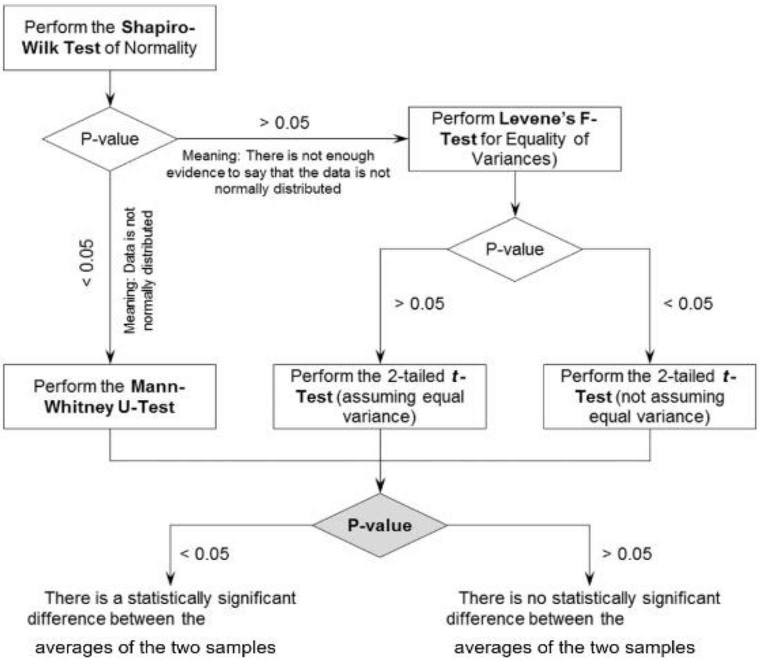

Figure 12: Framework for conducting the t-test (Abotaleb et al, 2019)

The entire steps are followed to reach the final p-value that indicates if there is any difference or not.

4.3.5. Step Five: Validation (Questionnaire Survey):

The previous steps helped in analysing risks using different methods and approaches. However, it is 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 is mainly based on determining their own opinion about the efficiency, and simplicity of risk management process that is proposed by PMI and FMEA, and indicate the possibility of using FMEA in future construction projects.

4.4. Ethical Considerations:

The research followed the ethical considerations established by the American University in Egypt, and the progress of this research was initially approved by the IRB to fulfil any ethical requirements. Ethics in this research are basically defined as the behaviour of the researcher and suitability of work in relation with the right of others who are related to the subject of this research or might be affected by its results. According to Cooper and Schindler (2008) the general idea of ethics is related to the standards of the researcher's choices and behaviour in relationship with other people. Therefore, ethical considerations were taken into account in this thesis to avoid any ethical problems, as people were part of the data analysis and interviews conducted in this research and the behaviour of the researcher is quite significant. Each participant was ensured that all data and information is completely confidential, and they have full rights to withdraw it from the whole research during any moment to save such right.

4.5. Summary of Findings:

This chapter presented the methodology that is undertaken in this research to answer all developed questions that were provided by this research. This research involved the use of a mixed methodology which contains some quantitative and qualitative methods of researching. It is much better to have more than one source of information and data in any research. Therefore, this research is designed to contain five major stages. The first one is to use a literature review to collect all risk factors that are faced in different types of construction projects. The following step is to use a personal interview with multiple experts and experienced engineers to provide their rate for each risk that is faced in the project. The third step is to apply risk management process that is proposed by PMI on collected data by estimating the impact and probability and following the four steps of risk management. The fourth stage is to analyse all obtained values using FMEA and fuzzy analysis to reach the final management of all possible risks. The last stage is to compare the reached results in each project between using risk management process that is proposed by PMI and FMEA to determine the possibility of using FMEA as a risk management that is proposed by PMI tool in construction projects. The chapter was concluded with some ethical considerations that should be taken into account.

Chapter 5: Results and Discussions

Chapter 5: Results and Discussions

5.1. Overview:

This chapter presents the data analysis of all results and numbers to indicate the basic comparison between risk management process that is proposed by PMI and failure mode effect analysis in construction projects. The first part of this chapter is the survey results that is divided into two sections, the first one is demographic information, and the second is some results of risk analysis. The second part of this chapter is demonstrating the results using risk management process that is proposed by PMI, and failure mode effect analysis. The last section of this chapter also presents the fuzzy FMEA and basic differences between risk management process that is proposed by PMI and FMEA in terms of demonstrating risk results.

5.2. Survey Results:

The number of participants in this survey is 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, or were part of any project in Egypt. The validation rate was observed to be around 96 percent.

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. The next section provides all this information.

5.2.1. Demographic Results:

Most of respondents were young in age and started their career during the past few years, but around 20 percent of respondents were older than 35 years. However, the results included a mixture of young and old engineers with a variety of specializations which was quite beneficial for the outcomes of this survey as shown in figure 13.

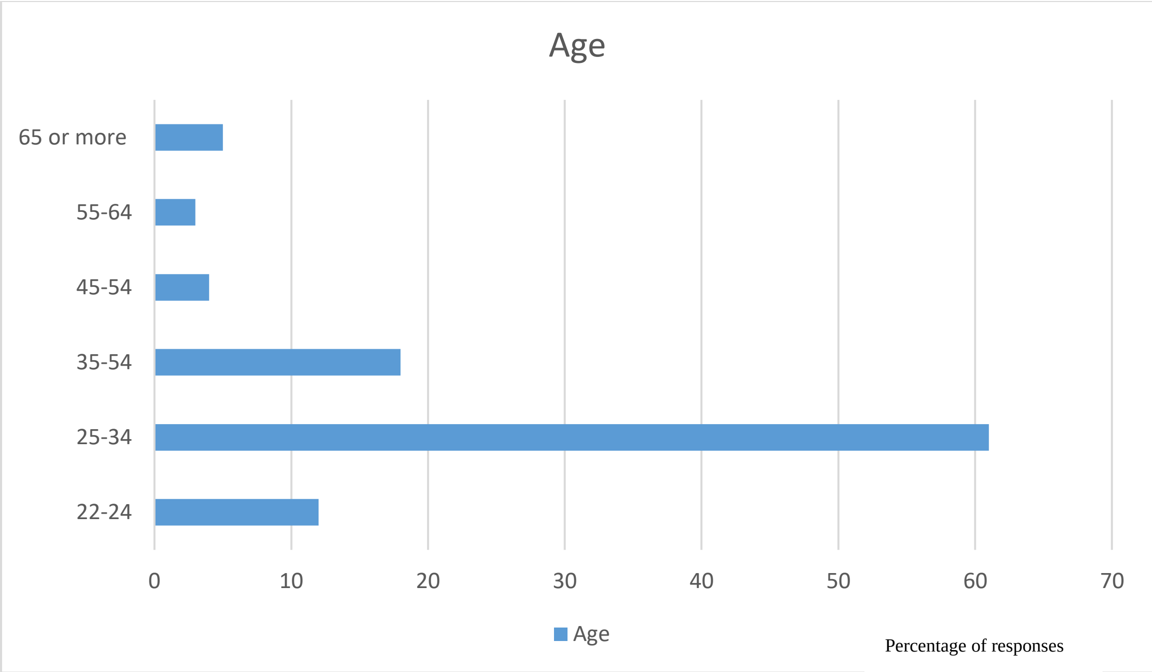

Figure 13: Ranges of age for survey respondents

The following question requested respondents to indicate the name of the company they are currently working with. The reason for this question is to make sure that all participants are working with construction companies to increase the validation of obtained results. Moreover, the specialization of each company is another important indicator included in survey results as shown in figure 14.

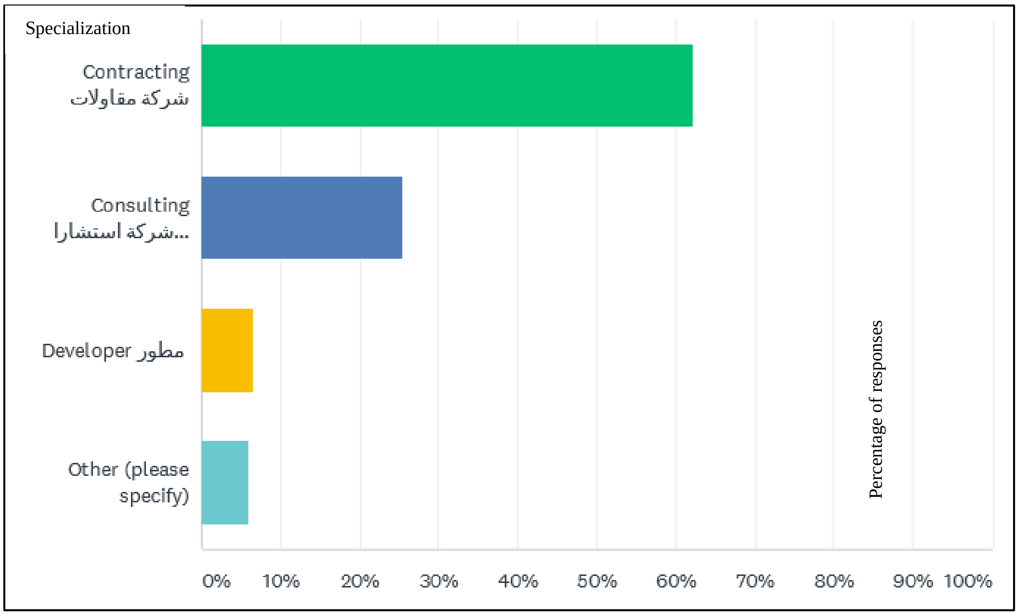

Figure 14: Specialization of companies that respondents work for

Most of respondents are currently working with contracting companies (62%), around 25% are working for consulting companies, around 6% work for developers, and the rest are specialised in other categories. On the other hand, the position of respondents is another information in the demographic data as it shows that different parties provided their opinion including managers, and other less experienced parties. Surprisingly, most of those who participated in this survey are office engineers and managers, and some CEO's and directors were also part of this survey as demonstrated in figure 15.

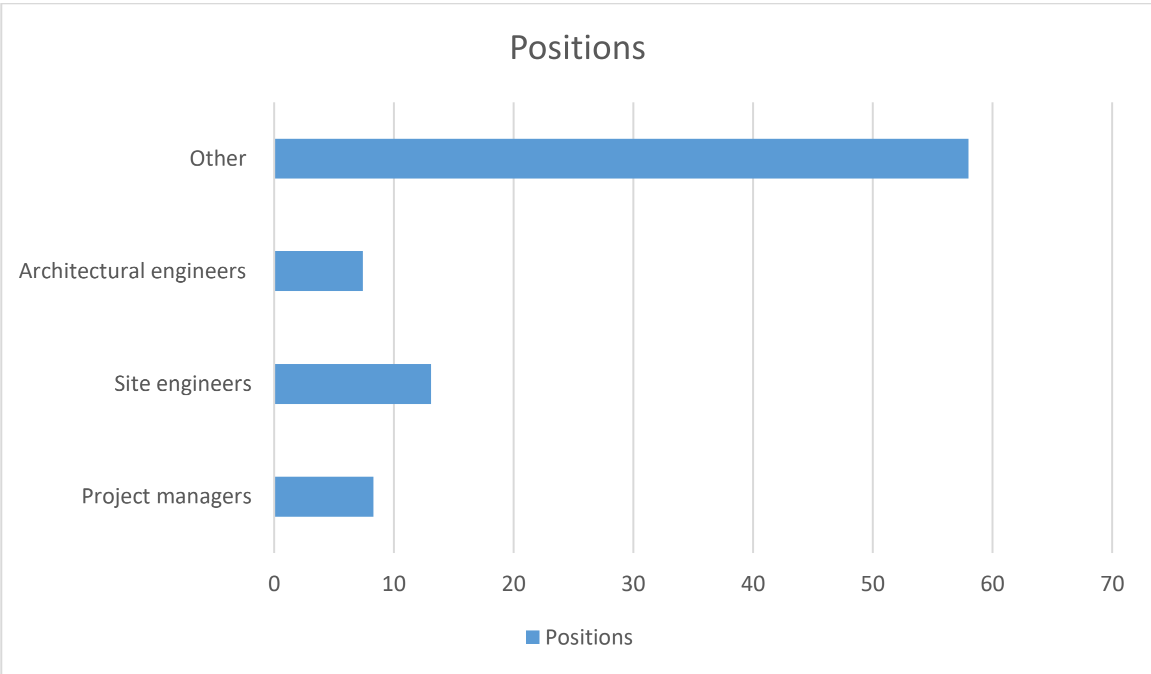

Figure 15: Various positions that are currently held by respondents

Table 3 shows the other 60% "others" of positions including the number of participants of each category.

Table 3: Other positions involved in the questionnaire survey

Position	No.	Position	No.	Position	No.
Cost control manager	10	Proposal engineer	1	Vice chairman	1
Planning engineer	44	Contract manager	1	Contract engineer	6
Cost engineer	17	Managing director	8	Quality control engineer	2
CEO	5	Office engineer	12	Quantity surveyor engineer	1
Planning Manager	8	BIM coordinator	1	Procurement engineer	2
Tender engineer	1	Project coordinator	1	Chairman	1
Owner	2	Quality control manager	1	Procurement specialist	1

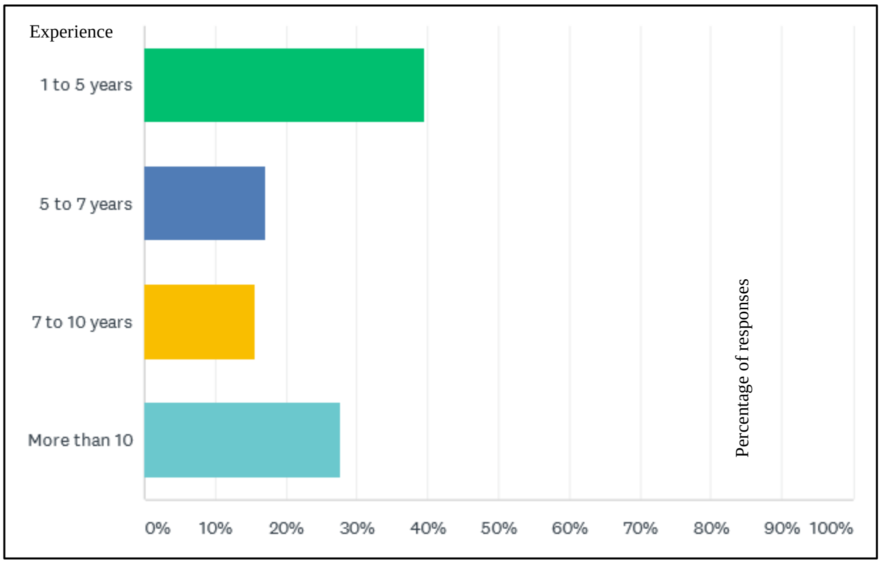

Figure 16: Years of experience for respondents in the field of construction

Years of experience in the field of construction also matters in this survey as having more years of experience results in a better understanding in the occurrence, and impact of risks on various forms of projects. Therefore, the major aim of the following question is to indicate the availability of some parties with great experience which will be beneficial to the outcomes of this research, and the results demonstrated that more than 20% of respondents have more than 10 years of experience in the field which is a great outcome.

5.3. 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. 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 where consultants thought that it is has less occurrence than contractors. Table 4 shows the p-values for contractors and consultants.

Table 4: 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 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 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

The only major difference between contractors and owners was basically the number of respondents from each category, as only few owners were part of this questionnaire survey. This is the main reason for having such differences in terms of P-value. However, the most critical variations could be observed in some risks such as delay in giving payments by owners, variation order, poor production rate from labours, delay of equipment delivery, and shortage of materials as shown in table 5.

Table 5: Results of P-values for contractors and owners

Risks	Impact			Occurrence			Detection		
	Mean		P-value	Mean		P-value	Mean		P-value
	Cont	Owner		Cont	Owner		Cont	Owner	
Cash flow problems	8.46	7.55	0.21	6.54	5	0.08	5.85	3.625	0.019
Delay in giving payments by owner	7.85	5.4	0.0285	6.78	5	0.1002	5.93	3.2	0.006
Changes in prices of resources	7.67	7.3	0.606	6.4	6	0.61	5.87	5.4	0.58
Poor coordination with all parties during the design stage	7.28	5.11	0.016	6.67	4.88	0.044	5.34	4.81	0.63
Variation order	7.04	6.66	0.64	7.37	4.88	0.002	6.3	4.22	0.031
poor planning of work and activities	7.79	7.33	0.46	5.94	4	0.014	5.45	3.77	0.066
Late delivery of materials to the site	7.84	7.11	0.306	5.93	4.44	0.07	5.99	4.66	0.112
Poor cost estimation	8.02	7.11	0.24	5.53	3.22	0.013	5.46	4	0.111
Inexperienced contractor	7.92	6.11	0.14	5.45	3.77	0.037	5.91	4.77	0.23
Poor production rate from labours	7	4.9	0.003	6.19	4	0.002	5.99	4.3	0.04
Design errors	7.86	6	0.02	5.38	3.67	0.04	5.44	4	0.08
Shortage of materials	7.58	5.55	0.13	5.67	3.11	0.001	5.95	3.67	0.01
Poor supervision of work	6.99	5.7	0.1	5.75	3.4	0.004	5.6	3.7	0.02
Shortage of skilled labours	6.62	5.3	0.03	6	4.6	0.16	5.48	4.1	0.12
Delay in delivery of equipment	7.15	4.8	0.003	5.48	2.4	0.0007	5.45	3.5	0.02
Poor quality of work	6.67	6.55	0.87	5.375	3.67	0.03	5.57	5	0.52
Wrong estimation of quantities	6.66	6.11	0.5	5.61	4.11	0.08	5.27	4.11	0.17
Error in the construction stage	7.3	5.77	0.07	4.75	2.88	0.02	5.86	3.11	0.01
Safety accidents on site	6.7	4.9	0.03	5.17	4.2	0.25	5.57	2.9	0.03

5.4. Risk Management Process (PMI) Results:

This section introduces the analysis of risks using a risk management process that is proposed by PMI at which begins with risk assessment, risk visualization, and finally risk response.

5.4.1. Risk Assessment:

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 table 6. The multiplication of both values can obtain the significance rate which is then used to rank the most significant risk factors according to this process.

Table 6: Results of applying risk assessment process

Risk	Impact	Probability	Significance
Cash flow problems	8.28	6.4	52.992
poor planning of work and activities	7.76	5.87	45.5512
Late delivery of materials to the site	7.72	5.9	45.548
Safety accidents on site	6.42	4.99	32.0358
Inexperienced contractor	7.78	5.33	41.4674
Error in the construction stage	6.97	4.64	32.3408
Poor quality of work	6.64	5.36	35.5904
Poor production rate from labors	6.88	5.93	40.7984
Shortage of skilled labors	6.75	5.66	38.205
Delay in delivery of equipment	7.05	5.19	36.5895
Shortage of materials	7.32	5.35	39.162
Poor cost estimation	7.8	5.36	41.808
Delay in giving payments by owner	7.54	6.57	49.5378
Variation order	6.67	6.9	46.023
Design errors	7.51	5.34	40.1034
Wrong estimation of quantities	6.41	5.47	35.0627
Poor coordination with all parties during the design stage	7.19	6.5	46.735
Changes in prices of resources	7.52	6.28	47.2256
Poor supervision of work	6.89	5.57	38.3773

5.4.2. Ranking of Risks:

Table 7 shows the ranking of top 5 risks according to the results obtained and using risk management process.

Table 7: Ranking of top 5 risks in construction projects in Egypt using risk management process (PMI)

Risk	Significance
Cash flow problems	53.0
Delay in giving payments by owner	49.5
Changes in prices of resources	47.2
Poor coordination with all parties during the design stage	46.7
Variation order	46.0

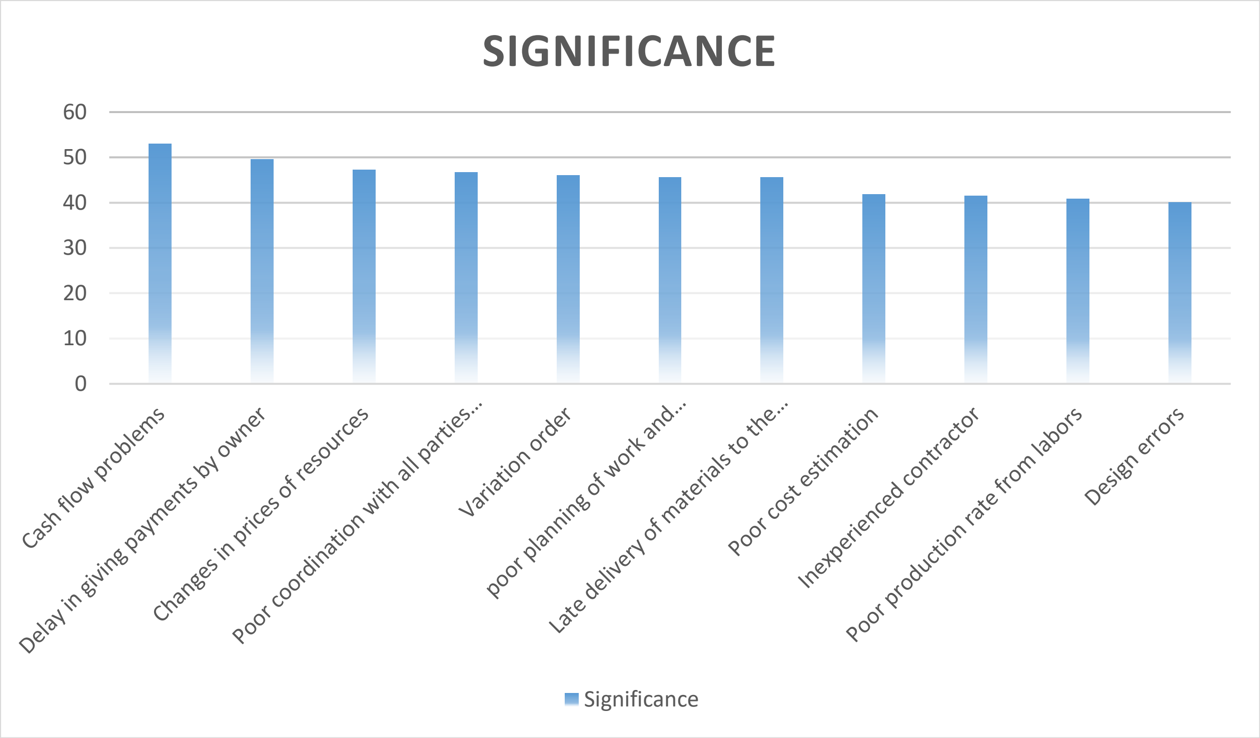

Figure 17: Risk factors with a significance rate higher than 40

5.4.3. Summary of Risk Management Process:

All analysed risks must be dealt with in order to prevent or reduce their impact on the project. This step is known as risk response, it can be avoidance which is preventing this risk from occurring in the project, mitigate which is dealing with the risk after its occurrence to reduce its impact, transfer to let other parties take the liabilities of this risk, share, and finally acceptance for risk factors that are expected to not harm the performance of work in the project. Moreover, table 8 provides a summary for all risks, their impact, probability value, significance, and finally risk responses.

Table 8: Table of risks in the project (summary)

Risk	Impact	Probability	Significance	Risk Response
Cash flow problems	8.28	6.4	53	Avoidance
Changes in prices of resources	7.52	6.28	47	Mitigate
Delay in delivery of equipment	7.05	5.19	37	Mitigate
Delay in giving payments by owner	7.54	6.57	50	Avoidance
Design errors	7.51	5.34	40	Avoidance
Error in the construction stage	6.97	4.64	32	Mitigate
Inexperienced contractor	7.78	5.33	41	Avoidance
Late delivery of materials to the site	7.72	5.9	46	Transfer
Poor coordination with all parties during the design stage	7.19	6.5	47	Share
Poor cost estimation	7.8	5.36	42	Avoidance
Poor planning of work and activities	7.76	5.87	46	Avoidance
Poor production rate from labors	6.88	5.93	41	Transfer
Poor quality of work	6.64	5.36	36	Acceptance
Poor supervision of work	6.89	5.57	38	Acceptance
Safety accidents on site	6.42	4.99	32	Acceptance
Shortage of materials	7.32	5.35	39	Transfer
Shortage of skilled labors	6.75	5.66	38	Acceptance
Variation order	6.67	6.9	46	Avoidance
Wrong estimation of quantities	6.41	5.47	35	Mitigation

5.5. Failure Mode Effect Analysis:

In order to apply the concept of failure mode effect analysis, the most common tool that is normally used in this context is known as risk priority number. It is quite similar to risk management, but the additional factor in this case is 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 which is from one to ten depending on the average weight of all results. Hence, table 9 shows the results of applying failure mode effect analysis on the same risks using risk priority number tool.

Table 9: Risk priority number results (FMEA)

Risk	Severity	Occurrence	Detection	RPN
Cash flow problems	8.28	6.4	5.69	301.524
Delay in giving payments by owner	7.54	6.57	5.73	283.852
Changes in prices of resources	7.52	6.28	5.85	276.27
Variation order	6.67	6.9	5.98	275.218
Late delivery of materials to the site	7.72	5.9	5.84	266
Poor coordination with all parties during the design stage	7.19	6.5	5.49	256.575
poor planning of work and activities	7.76	5.87	5.42	246.888
Inexperienced contractor	7.78	5.33	5.82	241.34
Poor production rate from labors	6.88	5.93	5.73	233.775
Poor cost estimation	7.8	5.36	5.38	224.927
Shortage of materials	7.32	5.35	5.67	222.049
Design errors	7.51	5.34	5.43	217.761
Poor supervision of work	6.89	5.57	5.32	204.167
Shortage of skilled labors	6.75	5.66	5.22	199.43
Delay in delivery of equipment	7.05	5.19	5.43	198.681
Poor quality of work	6.64	5.36	5.57	198.239
Wrong estimation of quantities	6.41	5.47	5.21	182.677
Error in the construction stage	6.97	4.64	5.47	176.904
Safety accidents on site	6.42	4.99	5.27	168.829

5.5.1. Ranking of Risks Using RPN:

The ranking of risk factors was quite similar to the one generated by risk management process that is proposed by PMI, and this could be mainly due to the opinion of respondents that most detection values should range between 4 and 5 as there are several parameters that affect the capability of detecting risks in any project. Hence, the ranking was not quite affected by including the detection rate, but only the variation order had the highest value because it is not easily detected in construction projects. Table 9 contains the ranking of risk variables after applying risk priority number analysis.

Table 10: Ranking of risk variables after applying risk priority number analysis

Risk	RPN
Cash flow problems	302
Delay in giving payments by owner	284
Changes in prices of resources	276
Variation order	275
Late delivery of materials to the site	266

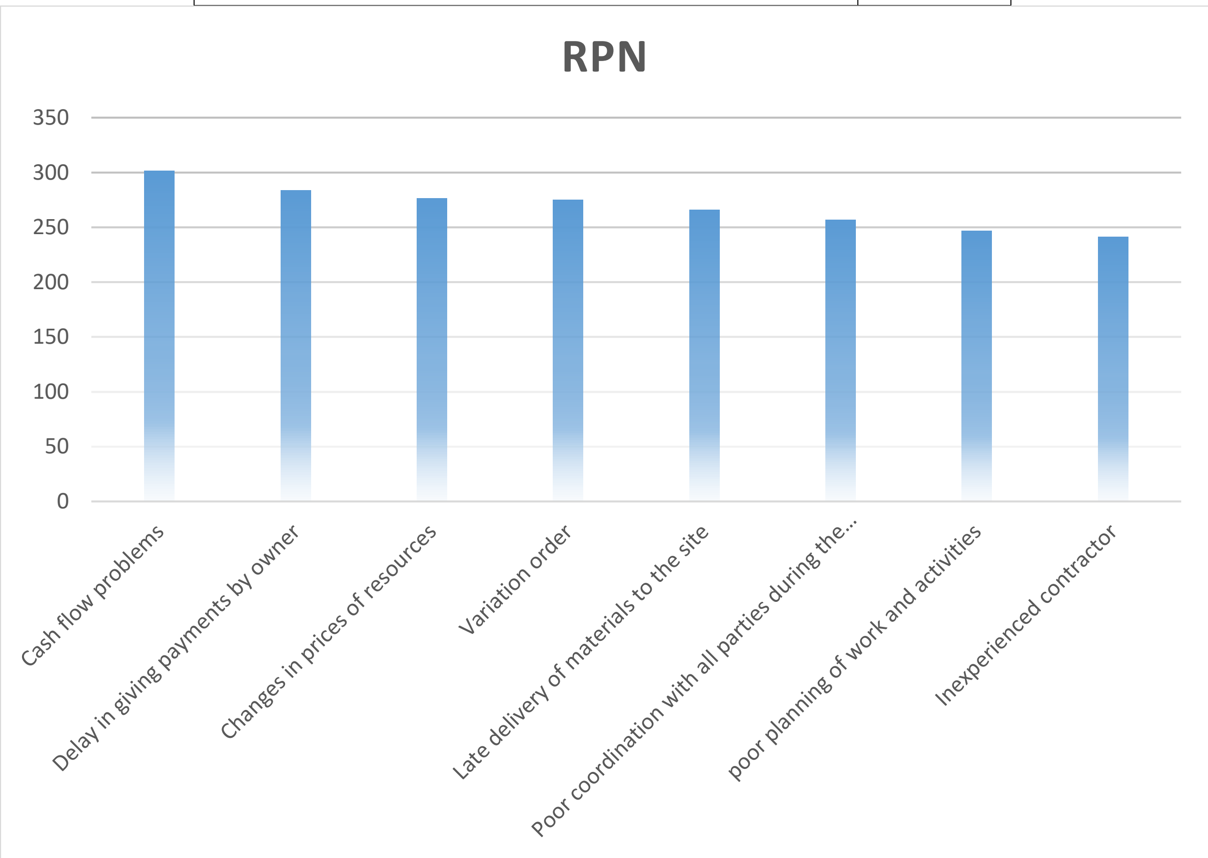

Figure 18: Highest ranked risks using risk priority number tool

5.6. Fuzzy FMEA:

A fuzzy logic was one of the most common analysing systems that could involve some degrees of uncertainties. The use of fuzzy logic can help in getting more accurate results than the use of the conventional FMEA only. There are several weaknesses in the conventional FMEA that indicates the importance of applying fuzzy logic as it is a subjective method explained in the natural language, it depends on three parameters that are alike in terms of values, but in reality each one of them is different and must be evaluated differently, and finally some risks might have the exact RPN value.

Fuzzy logic was another significant outcome of this research as the numbers of studies that conducted fuzzy FMEA is extremely limited. It is based on applying risk priority formula that is based on the occurrence, severity, and detection. 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 is that the detection became not detection and ranges from one to ten. Then, a failure mode and effect analysis was conducted to estimate the influence of failure or risks on construction projects. Each factor was divided into three parameters, the first is low, medium, and then high. It depends on the value of severity that is given where from zero to 1.5 is low, from 1.5 to 5 is high, and high is until 10.

In order to overcome all these limitations, the researcher followed some guidelines provided by Suryoputro (2019) 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 common FMEA, risk assessment was done through multiplying the occurrence, severity, and detection to get a risk priority number. Nevertheless, conventional FMEA neglected the significance of every input as each one of them had the exact importance. Moreover, 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 11 shows the criteria for severity, occurrence, and detection including the category of each input.

Table 11: 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 19.

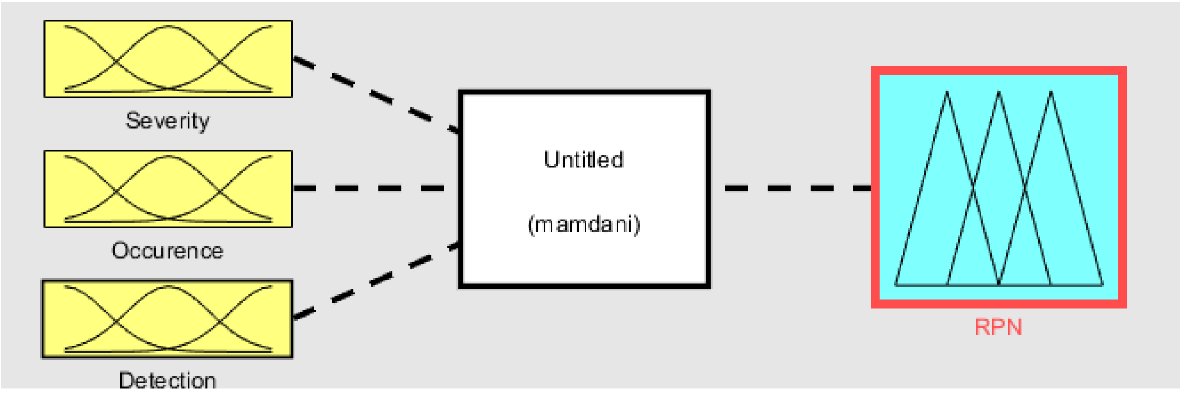

Figure 19: Setting up the input and output for fuzzy RPN

Table 12 shows the criteria of each category, type of curves used, and range of parameters. The reason for choosing these parameters is that previous studies obtained accurate results from fuzzy analysis in case of using this approach.

Table 12: Used parameters for the membership function of the input variable (Suryoputro et al 2019)

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 value.

Table 13: Used parameters for the membership function of the output variable (Suryoputro et al 2019)

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 questionnaire survey results. The analysis of the survey was done using Microsoft excel, but applying Fuzzy RPN was achieved using MATLAB software program as it contains a fuzzy logic toolbox that can help in providing the needed analysis.

Table 14 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.

Table 14: Results of fuzzy RPN and risk categories

Risk	Severity	Occurrence	Detection	RPN	Fuzzy RPN	Category
Cash flow problems	8.28	6.4	5.69	301.524	441	M-H
Delay in giving payments by owner	7.54	6.57	5.73	283.852	442	M-H
Changes in prices of resources	7.52	6.28	5.85	276.27	465	M-H
Variation order	6.67	6.9	5.98	275.218	426	M-H
Late delivery of materials to the site	7.72	5.9	5.84	266	489	H
Poor coordination with all parties during the design stage	7.19	6.5	5.49	256.575	376	M
poor planning of work and activities	7.76	5.87	5.42	246.888	400	M-H
Inexperienced contractor	7.78	5.33	5.82	241.34	500	H
Poor production rate from labors	6.88	5.93	5.73	233.775	399	M-H
Poor cost estimation	7.8	5.36	5.38	224.927	500	H
Shortage of materials	7.32	5.35	5.67	222.049	300	M
Design errors	7.51	5.34	5.43	217.761	500	H
Poor supervision of work	6.89	5.57	5.32	204.167	309	M
Shortage of skilled labors	6.75	5.66	5.22	199.43	317	M
Delay in delivery of equipment	7.05	5.19	5.43	198.681	300	M
Poor quality of work	6.64	5.36	5.57	198.239	300	M
Wrong estimation of quantities	6.41	5.47	5.21	182.677	300	M
Error in the construction stage	6.97	4.64	5.47	176.904	300	M
Safety accidents on site	6.42	4.99	5.27	168.829	300	M

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 to both severity and occurrence as they are considered the most potential parameters. Therefore, table 15 shows the top five risks after applying the fuzzy RPN.

Table 15: Ranking of risk variables after applying fuzzy risk priority number

Risk	RPN	Fuzzy RPN	Category
Inexperienced contractor	241.34	500	H
Poor cost estimation	224.927	500	H
Design errors	217.761	500	H
Late delivery of materials to the site	266	489	H
Changes in prices of resources	276.27	465	M-H

The ranked risks are completely different than the initial estimation using both risk management process that is proposed by PMI and risk priority number. Hence, table 16 provides a brief comparison between the ranked risks using the three different approaches.

Table 16: Ranking of risks using three followed approaches

Risk Ranking	Risk Management	RPN	Fuzzy RPN
1	Cash flow problems	Cash flow problems	Inexperienced contractor
2	Delay in giving payments by owner	Delay in giving payments by owner	Poor cost estimation
3	Changes in prices of resources	Changes in prices of resources	Design errors
4	Poor coordination with all parties during the design stage	Variation order	Late delivery of materials to the site
5	Variation order	Late delivery of materials to the site	Changes in prices of resources

Risk management process that is proposed by PMI 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, but 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 which indicates the accuracy that could be generated from applying the fuzzy logic. Table 17 is the famous FMEA table for all risks that were analyzed in this research.

Table 17: Failure mode effect analysis table for all risks in the project

Potential failure	Function	Potential Effect of Risk/failure	Severity	Potential cause/ sources	Occurrence	Detection	RPN	Recommended actions	Responsibility
Cash flow problems	Ensure flow of direct costs	Delay in completion of activities	8.28	Poor cost estimation, or poor management	6.4	5.69	302	Adequate cost estimation and management of resources	Owner
Delay in giving payments by owner	Ensure flow of direct costs	Conflicts and delay in completion of activities	7.54	Poor management of funding and cash flow	6.57	5.73	284	Contract can include a penalty for any delayed payments	Owner
Changes in prices of resources	Resources are essential for completing activities	Conflicts and progress of work might be stopped	7.52	Inflation and economic factors	6.28	5.85	276	Contract should include a clause that can satisfy both owners and contractors	Owner and contractor
Variation order	Satisfying the client or customer	Conflicts, delay in progress of work, and changes in project's documents	6.67	Neglecting communication and coordination during the design stage	6.9	5.98	275	Communication and coordination between all parties during an early stage	All parties
Late delivery of materials to the site	Resources are essential for completing activities	Delay in completion of activities	7.72	Poor management and not assigning a good supplier	5.9	5.84	266	Sign a contract with a known supplier	Owner or contractor
Poor coordination with all parties during the design stage	Determining all possible problems from the beginning	Could lead to changes and not understanding project's requirements	7.19	Lack of effective management plan	6.5	5.49	257	Owner must be aware of the importance of this step	Owner and all parties

poor planning of work and activities	Planning is essential for everyday activities	Delay in completion of activities	7.76	Inexperienced planner and lack of effective management	5.87	5.42	247	Assign a good management team	Owner
Inexperienced contractor	Contractor is responsible for taking many important decisions everyday	Delay, conflicts, and different problems depending on project's type	7.78	Poor bid selection and analysis	5.33	5.82	241	Conduct a proper bidding analysis that is not only based on the cost	Owner
Poor production rate from labor	There should be a certain production rate to complete plan of work	Delay in completion of activities	6.88	Poor supervision of work and shortage of skilled labor	5.93	5.73	234	Proper management and supervision	Contractor
Poor cost estimation	Cash flow depends on the correct estimation of budget	Cost overrun, and conflicts	7.8	Inexperienced parties and lack of efficiency	5.36	5.38	225	Assign a good management team	Owner
Shortage of materials	Resources are essential for completing activities	Delay in completion of activities	7.32	Poor management and lack of a good supplier	5.35	5.67	222	Sign a contract with a known supplier	Owner
Design errors	It is important to prevent having errors in the design to avoid any delay	Changes in design, and delay. There might be additional cost	7.51	Not revising drawings and inexperienced designer	5.34	5.43	218	Only assign experienced designers with consistent coordination	Owner
Poor supervision of work	Supervision of work is making sure that everything is according specifications	Poor quality, and errors	6.89	Lack of an effective management plan	5.57	5.32	204	Assign experienced supervisors on site	Contractor and owner

Shortage of skilled labor	Skilled labor can complete activities faster and with good quality	Poor quality, and errors	6.75	Lack of a criterion for choosing labor	5.66	5.22	199	Contractor must use a criteria for choosing labor	Contractor
Delay in delivery of equipment	Equipment are essential for most activities	Delay in completion of activities	7.05	Lack of an effective management plan	5.19	5.43	199	Contractor is responsible for planning the availability of equipment	Contractor
Poor quality of work	Quality means satisfied client and user	Delay and cost overrun in case the owner rejects the work	6.64	Inexperienced contractor and labor, unclear specifications	5.36	5.57	198	Assign experienced supervisors on site	Contractor and consultant
Wrong estimation of quantities	Resources are essential for completing activities	Cost overrun, and conflicts	6.41	Lack of an effective management plan	5.47	5.21	183	Assign a good management team	Owner
Error in the construction stage	/	Delay and cost overrun	6.97	Inexperienced contractor and labor, unclear specifications	4.64	5.47	177	Only experienced contractor must be chosen with proper supervision on site activities	Contractor and consultant
Safety accidents on site	Safety is done to prevent any accidents	Delay and poor motivation	6.42	Lack of a proper safety plan	4.99	5.27	169	Establish safety rules and regulations	Owner and contractor

5.7. 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, a questionnaire survey was redistributed among engineers that were part of the initial questionnaire survey. 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. To compare the results and mean values between contractors and owners, the first question investigated the specialization of each respondent. Most of survey respondents were either contractors or owners by more than 70 percent and only 17.17% of survey respondents were consultants as shown in figure 20.

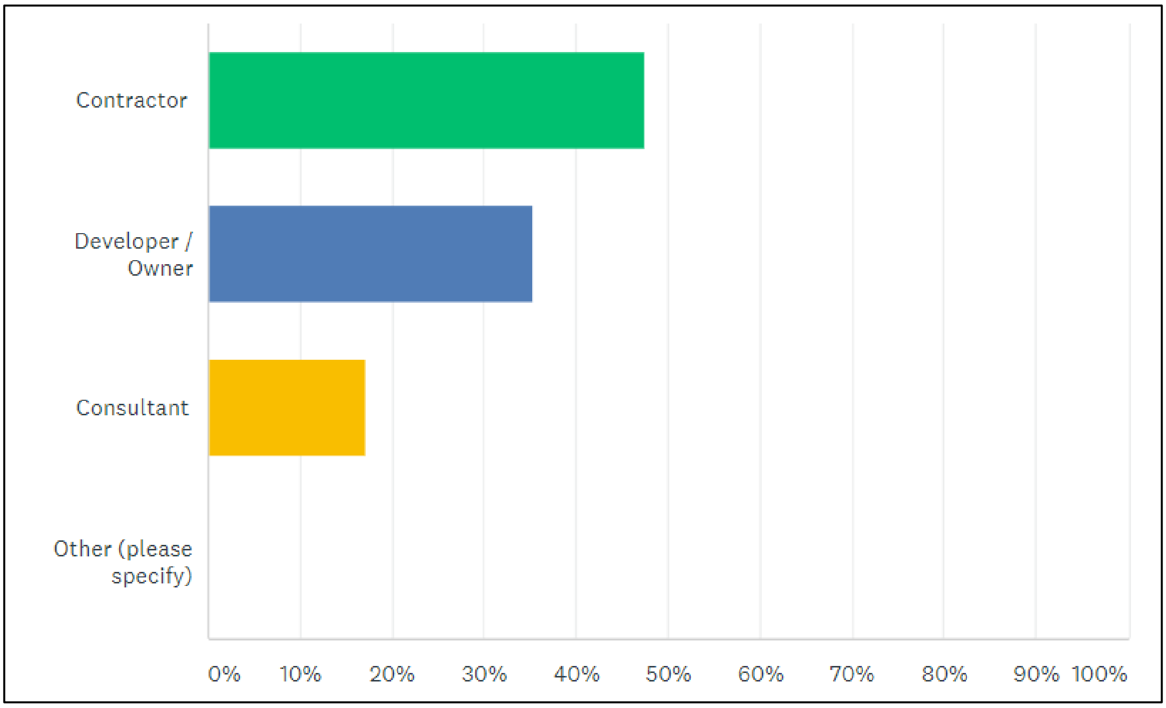

Figure 20: Specialization of survey respondents

It was essential to estimate if engineers working in the construction sector in Egypt heard about failure mode and effect analysis before. The results demonstrated that less than 10 percent of all survey respondents heard about this new technique and shows the expected benefits from proposing it to the construction industry as shown in figure 21.

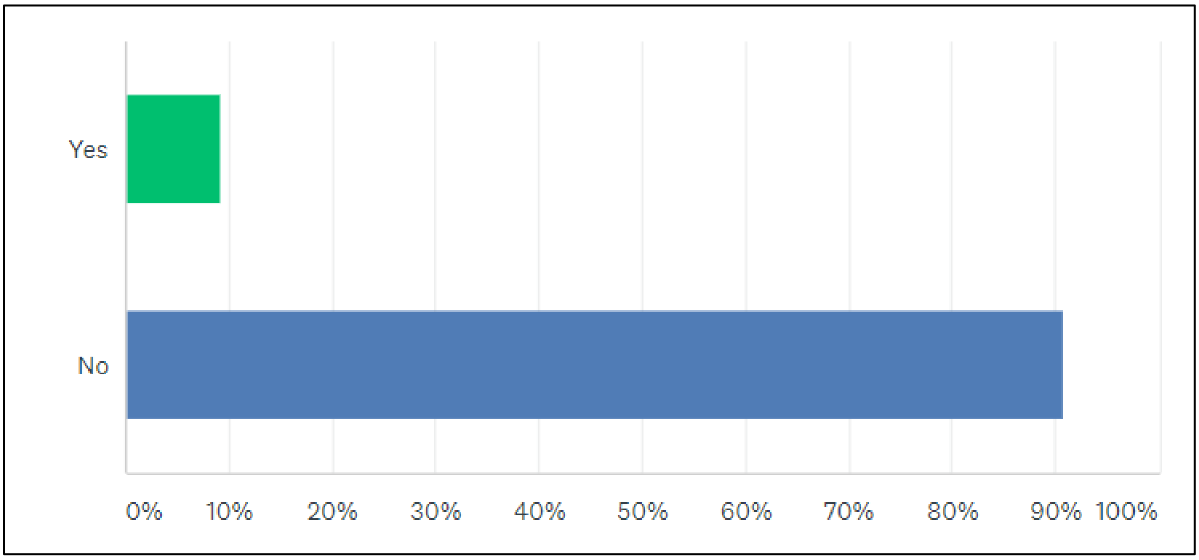

Figure 21: Respondents were asked if they heard about FMEA before

Hence, this new method is not yet known or introduced to the construction industry. 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. As shown in figure 22, 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.

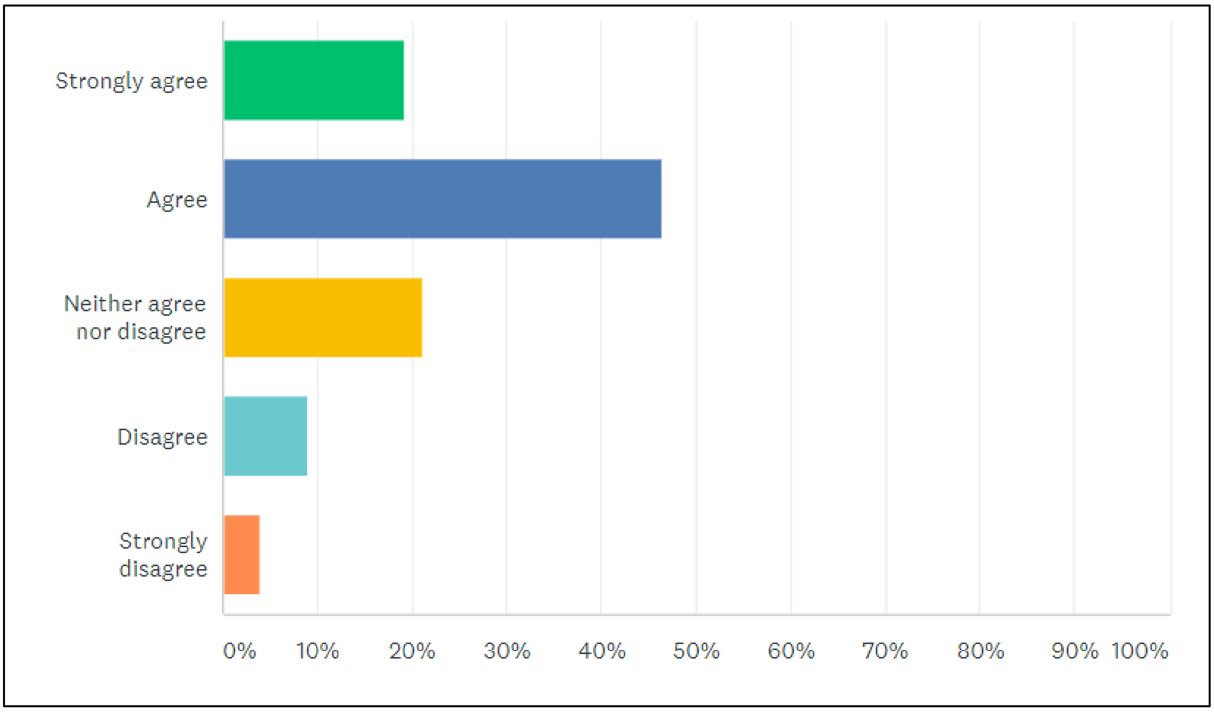

Figure 22: The need for new techniques to analyse risks in construction projects

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 use 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 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 18 provides a summary for all survey answers regarding the use of FMEA in the construction industry.

Table 18: 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.

Table 19: Survey answers regarding some properties of 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 and use of risk management process and FMEA, respondents were then asked to evaluate which technique could be more beneficial to the construction industry. 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 could be beneficial.

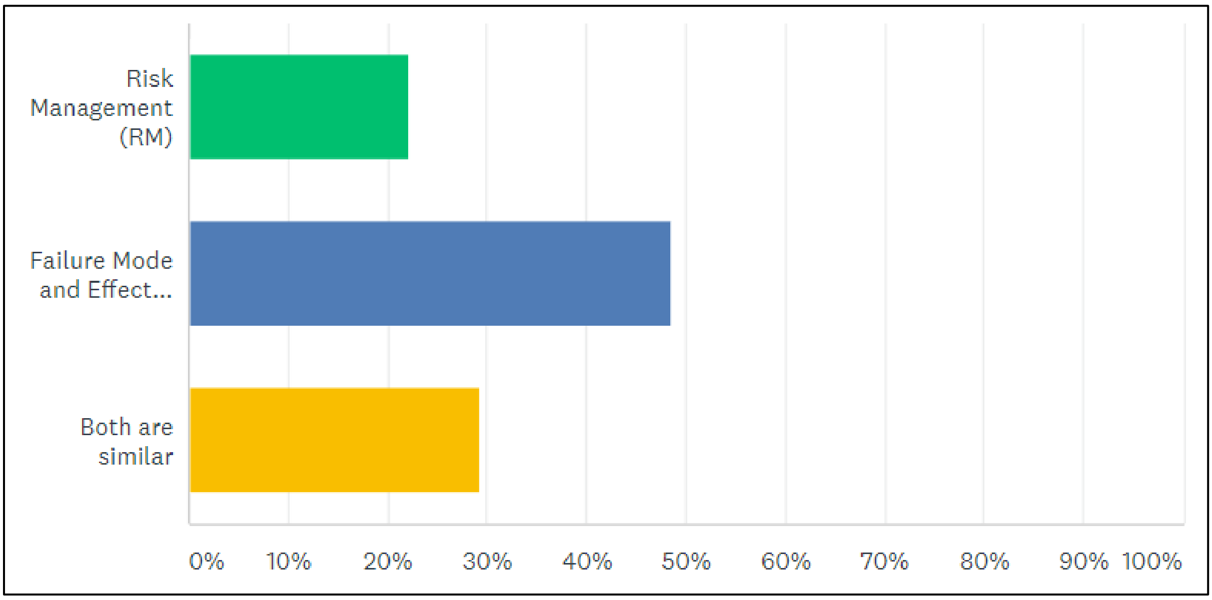

Figure 23: Which technique is the most beneficial to the construction sector

Finally, the basic aim of the questionnaire survey was to estimate the possibility of using FMEA in the construction sector, and the last question helped in ranking this concern from one to five, where one means no possibility, and 5 indicates very high possibility. It is demonstrated that the average rate for the possibility of using FMEA is 3.6 which is extremely high.

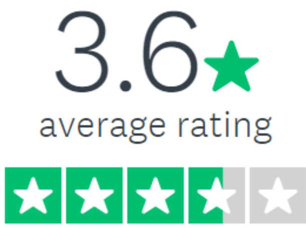

Figure 24: Average rate of using FMEA in the construction sector

Table 20 provides a summary for the collected responses regarding the possibility of using FMEA in the construction industry.

Table 20: Survey answers regarding the possibility of using FMEA in the construction sector

Rate	Not applicable	Could be possible	Moderate	Possible	Very possible	Mean
Percentage and number of responses	5.05% 5	13.13% 13	21.21% 21	37.37% 37	23.23% 23	3.61

5.8. Discussion:

Failure mode effect analysis is one of the most common approaches used to analyse the potential failure in the manufacturing and production industry. It was introduced to this sector during the 20th century and now became a common and effective tool by integrating it with risk priority number tool to estimate the severity, occurrence, and detection of each failure. Thus, there are numerous studies and researches that focused on the use of FMEA in analysing potential failure in the manufacturing industry. Most of these studies showed the great influence of such tools and the outcomes that are achieved every time they are used in the analysis of failure for equipment, and components. However, the number of studies that indicated the possibility of using FMEA in the construction sector is extremely limited. Most of these studies focused on applying FMEA without involving the risk priority number or applying real results and indicators on any project. Therefore, the aim of this study was to investigate the capability of using FMEA and RPN tool in the analysis of risks in construction projects.

Risk assessment and risk priority number 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 in order to deal with risks before exposing the project in a severe manner. FMEA can be useful in visualizing and demonstrating all risks in the project in a very creating way using the famous FMEA table (table 17) which makes it easier to control and deal with risks in the project. Involving the idea of fuzzy logic can also help in getting more accurate results through simulating various outputs until reaching the desired RPN value according to some inputs that are added (shapes and values).

Chapter 6: Conclusion & Recommendations

Chapter 6

Conclusion and Recommendations

6.1. Summary and Conclusion:

Risk assessment and analysis is considered one of the essential steps in any construction project. It was established several years ago and kept on developing until it became part of any project. Hence, most construction works depend on risk assessment to prevent any possible failure, delay, cost overrun, and other forms of failure in their project. There are multiple techniques and approaches that are used to analyze risks in construction projects, but the most common one is known as risk management process that is proposed by PMI. It is used until this recent day, but yet construction projects are still suffering from potential delay, cost overrun, poor quality of work, and lack of efficiency. Another major limitation of risk management that is proposed by PMI is that usually depends on two factors only, impact and probability which could result in having more than just one single risk with the exact significance rate. Visualization of risks and their analysis is another important limitation in risk management that is proposed by PMI unlike other techniques that help in understanding the real influence of these risks on the project.

The first part of this research is a literature review for previous studies that investigated the use of FMEA in the analysis of potential failure in various industries. Exploring the literature helped in estimating that FMEA is not quite known and applied in the construction industry. Hence, the aim of the study focused mainly on showing the real influence of using FMEA and RPN on analysing risks in construction projects, and if it will be with any variations with the commonly used approaches. In order to achieve this objective, the study is divided into four sections, the first section is about conducting a questionnaire survey with engineers and experts working in the construction field to rank risks depending on their impact, probability, and not detection. Each respondent was requested to propose a value that ranged from one to ten depending on their own opinion. The number of responses collected in the survey were 221 and only 214 were validated. Most of these respondents were contractors, consultants, and developers. The reason for conducting the survey was achieved and the second stage of this research was about applying the risk management process that is proposed by PMI. The impact and probability of each risk helped in estimating the significance rate for each risk and develop a ranking of most potential risks in construction projects in Egypt. Another essential part of this study was conducting a t-test to estimate the differences between average values for both owners and contractors. This test helps in understanding if the opinion of owners is different from the opinion of contractors through conducting some statistical analysis. The reached results showed that there was no huge difference between owners and contractors in the impact and probability results, but the only differences were observed in the values given for detection. This could be related to opinion of contractors and owners regarding the detection of risks as it depends on multiple factors.

FMEA was then used to analyse all potential risks using risk priority number that depends on the severity, occurrence, and detection of risks. It used the same impacts and probabilities of risk process, but the only new factor in this case is the detection. The reached results in both approaches indicated the same risks with minor changes only, and this could be mainly due to the opinion of engineers that the detection is normally 5 as it depends on multiple factors (experience, project manager, and organization). The most ranked risk factors are cash flow problems, delay in giving payments by owner, changes in prices of resources, variation order, and late delivery of materials to the site. Both of them had the exact ranking but the variation order was the only variation. Hence, in order to obtain more accurate results, a fuzzy FMEA was then applied to generate some RPN values that could differ the obtained results. To validate the reached results and determine the opinion of experts about the use of FMEA in the construction sector, another questionnaire survey was conducted with 99 respondents. The collected responses demonstrated the efficiency and the need for using FMEA in the construction sector as a risk assessment tool.

It is quite significant to understand the importance of analysing risks in construction projects to ensure their success. This requires great attention towards small and complicated details of any project starting from an early stage, and during the whole life cycle of the project. Risk management that is proposed by PMI and FMEA could be similar, but the procedure of analysing risks and their visualization was proved to be more effective in the second approach. Hence, the following are some general recommendations for applying FMEA in the construction industry:

- FMEA is much more efficient in terms of visualizing risks, but in order to conduct this approach, experts could be involved to reach more accurate results.
- Fuzzy FMEA is more effective as it provides more accurate examination of risks according to a specific criterion that researchers choose. It can provide a specific weight

for risks at which would eventually lead to a different ranking and analysis of risks. Therefore, projects can depend on fuzzy logic in case of requiring comprehensive results.

6.2. Thesis 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. 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.

It should be taken into account that these risks are investigated before the COVID-19 pandemic. If the analysis involved the current state, new risks would be added, and the overall rating and ranking would change drastically. But this does not impact this thesis, since the thesis focuses on validating the application of FMEA rather than identifying risks in the construction sector.

6.3. Proposed Direction for Future Research:

This research was focused on the concept of proposing a new tool for risk assessment, and according to the reached results, there is a great potential for the use of FMEA in the construction industry. Future studies should consider the use of FMEA and PMI’s risk assessment process on a real project to demonstrate the differences between them in a more efficient way. Moreover, it is well advised to develop a user friendly tool that can be used in construction projects, but this tool must be connected FMEA table and respondents can fill this whole table to reduce the complexity of using FMEA in future projects.

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Appendix A (Fuzzy RPN Results)

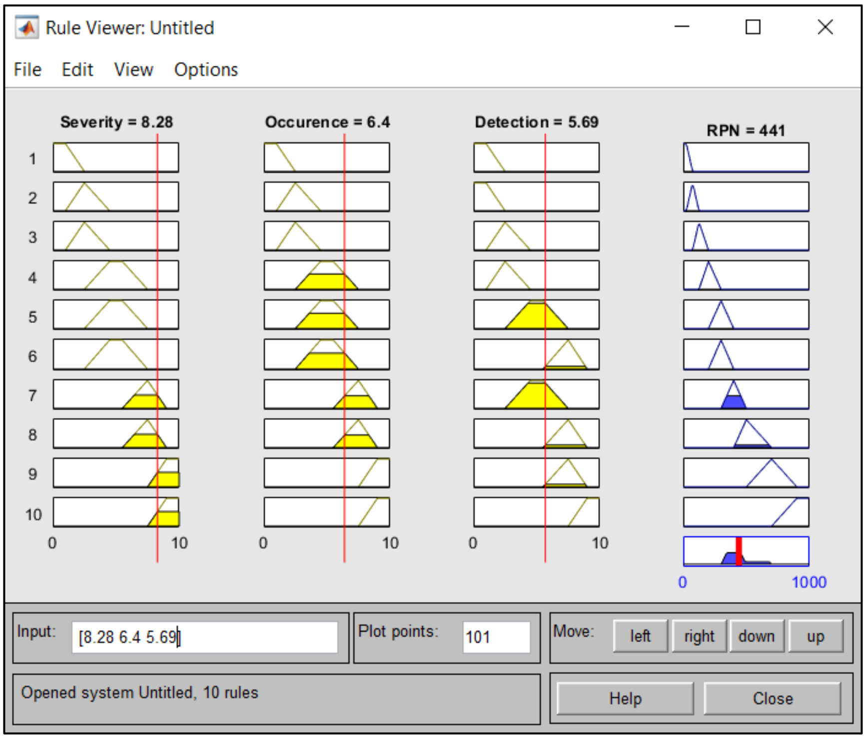

Figure 25: result of cash flow problems using fuzzy RPN

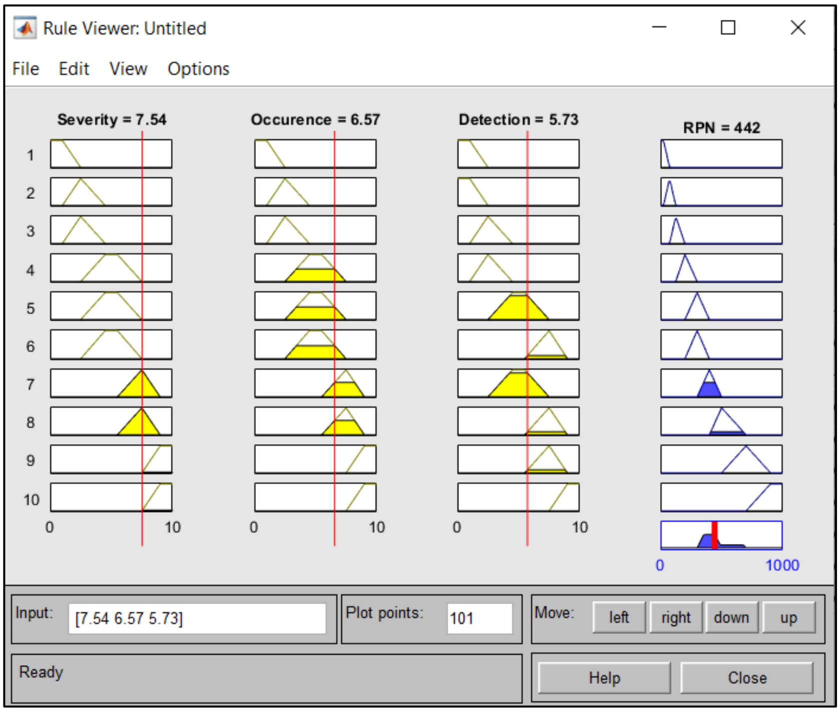

Figure 26: Result of delay in giving payments by owner using fuzzy RPN

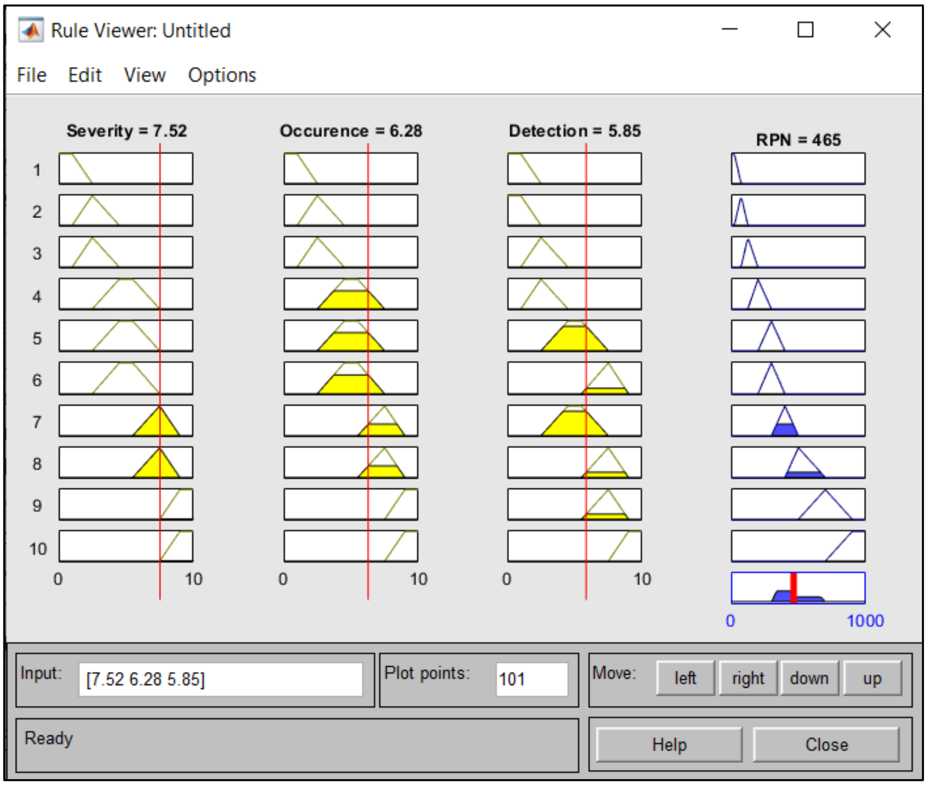

Figure 27: Result of changes in prices of resources using fuzzy RPN

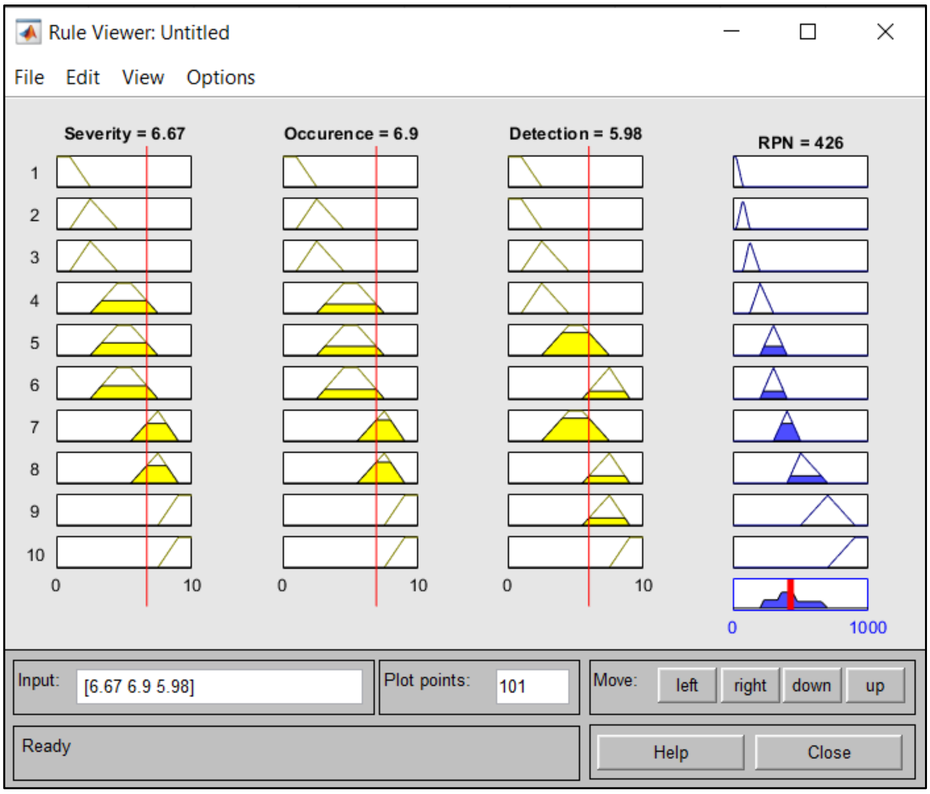

Figure 28: Result of variation order using fuzzy RPN

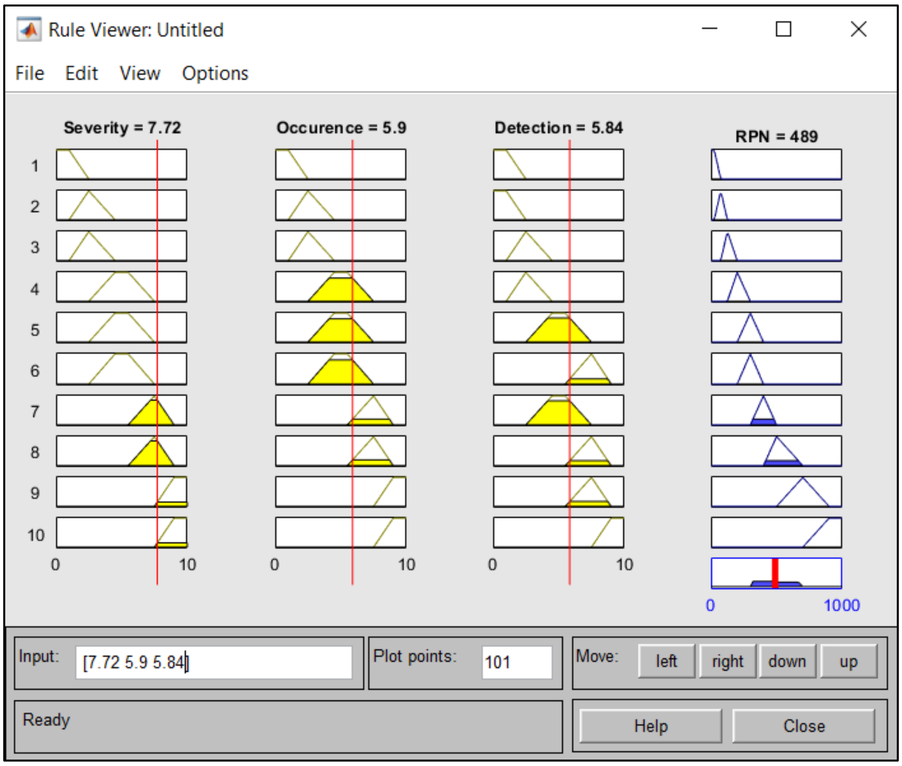

Figure 29: Result of late delivery of materials to the site using fuzzy RPN

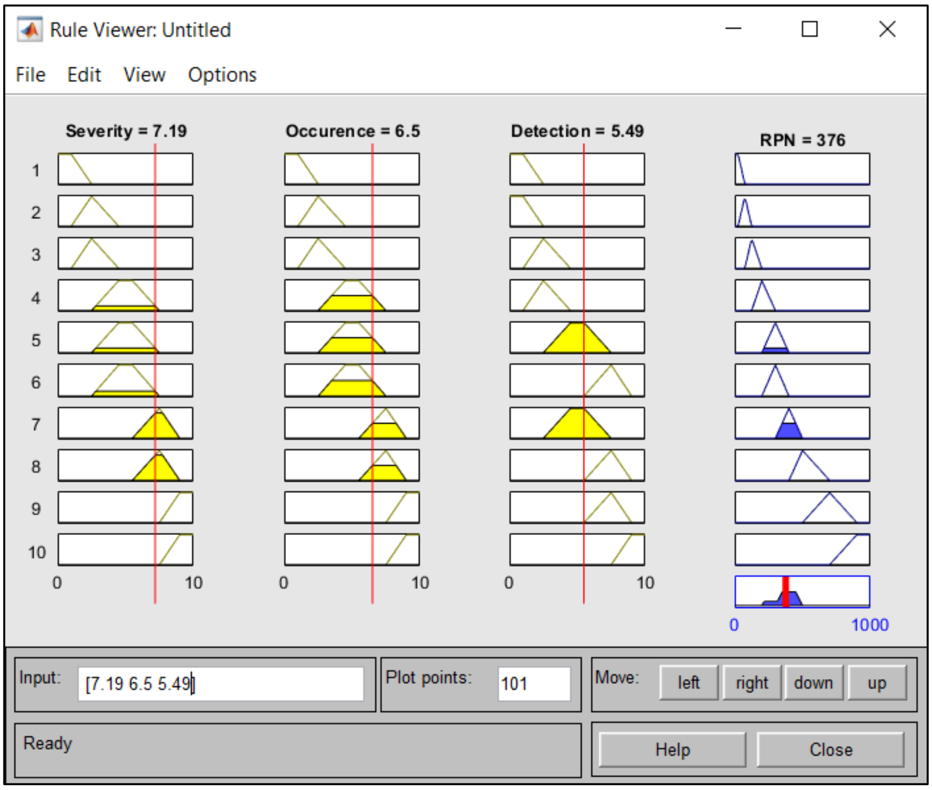

Figure 30: Results of poor coordination with all parties during the design stage using fuzzy RPN

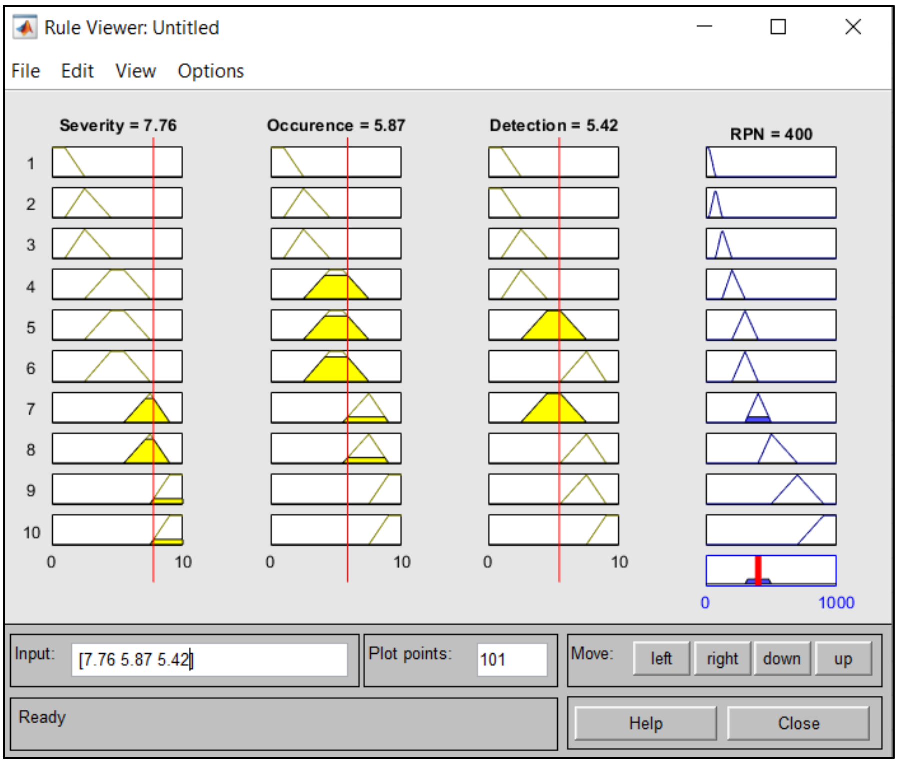

Figure 31: Results of poor planning of work and activities using fuzzy RPN

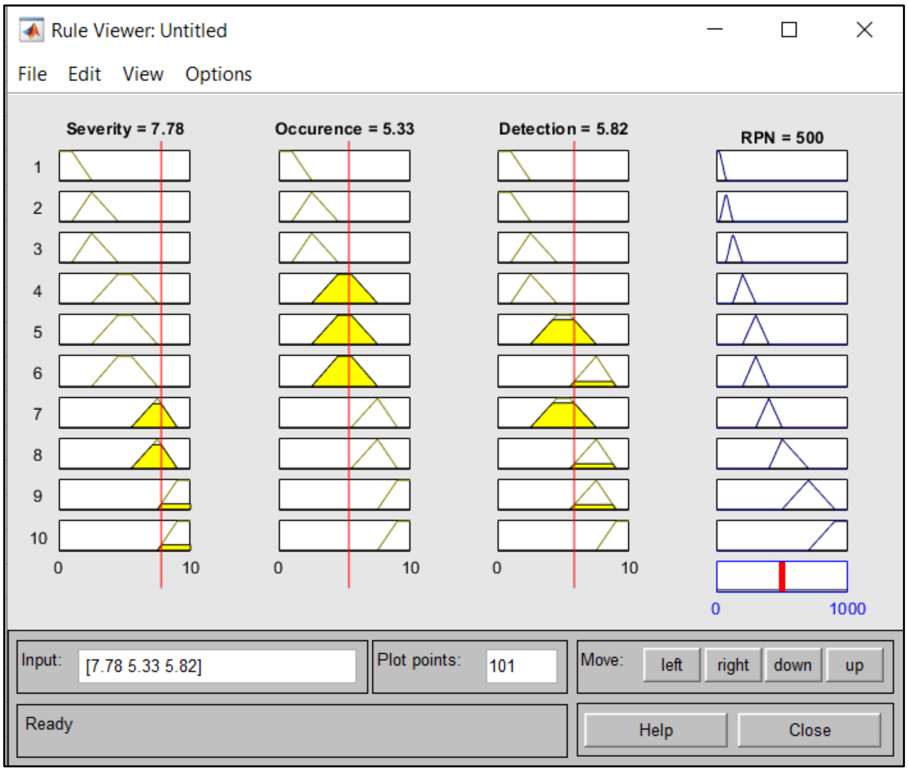

Figure 32: Results of inexperienced contractor using fuzzy RPN

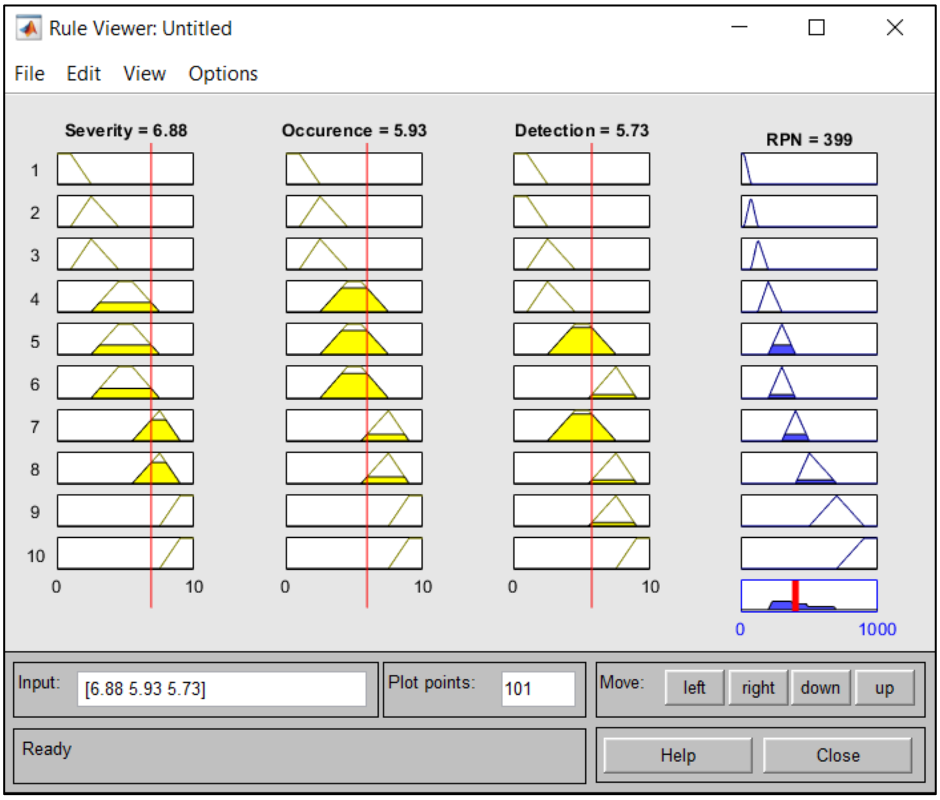

Figure 33: Results of poor production rate from labors using fuzzy RPN

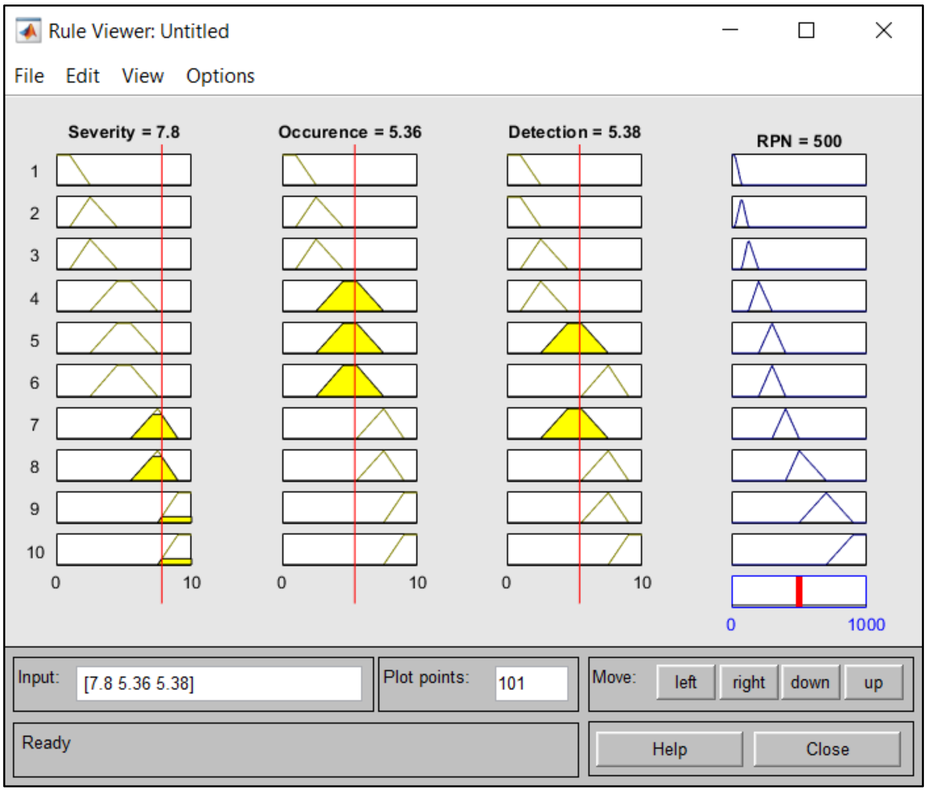

Figure 34: Results of poor cost estimation using fuzzy RPN

Figure 35: Results of shortage of materials using fuzzy RPN

Figure 36: Results of design errors using fuzzy RPN

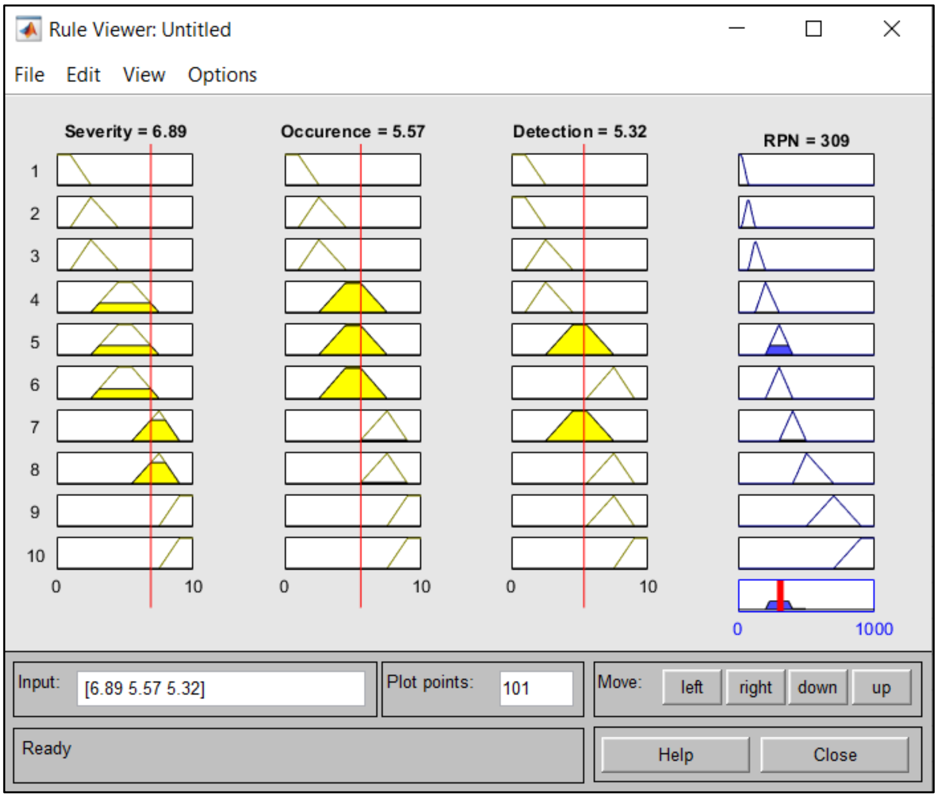

Figure 37: Results of poor supervision of work using fuzzy RPN

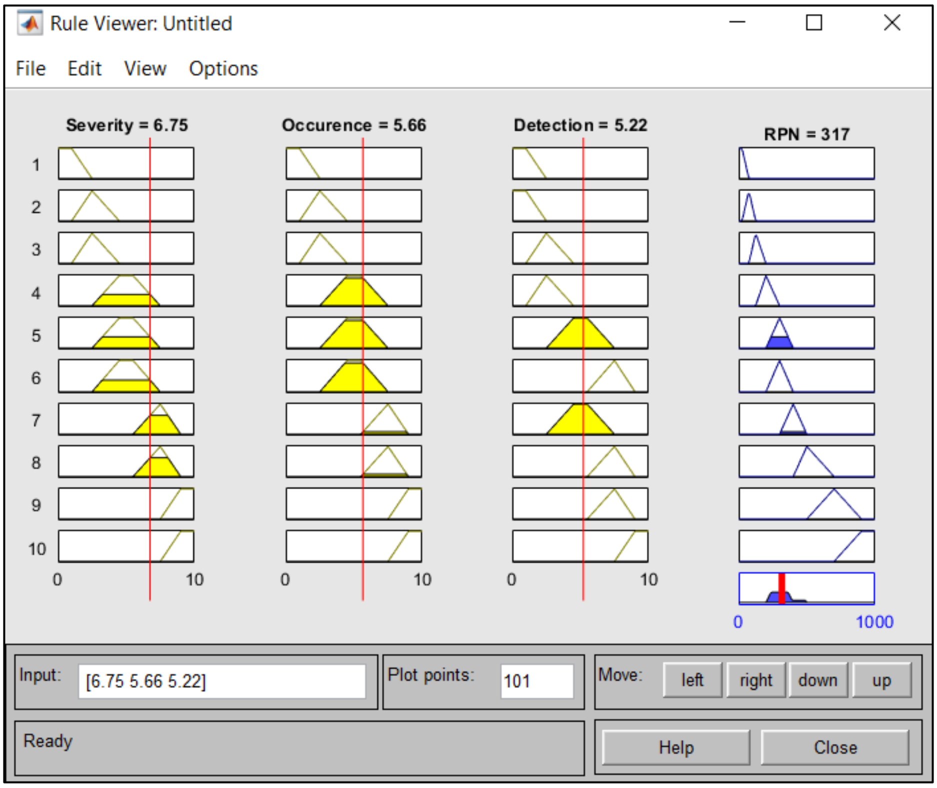

Figure 38: Results of shortage of skilled labors using fuzzy RPN

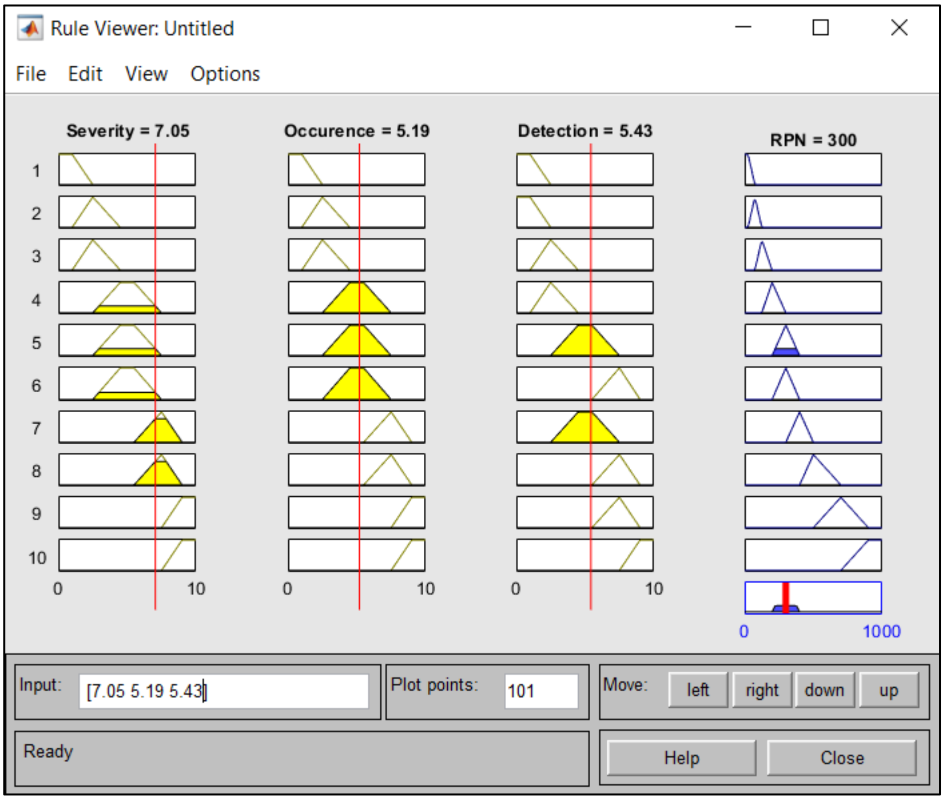

Figure 39: Results of delay in delivery of equipment using fuzzy RPN

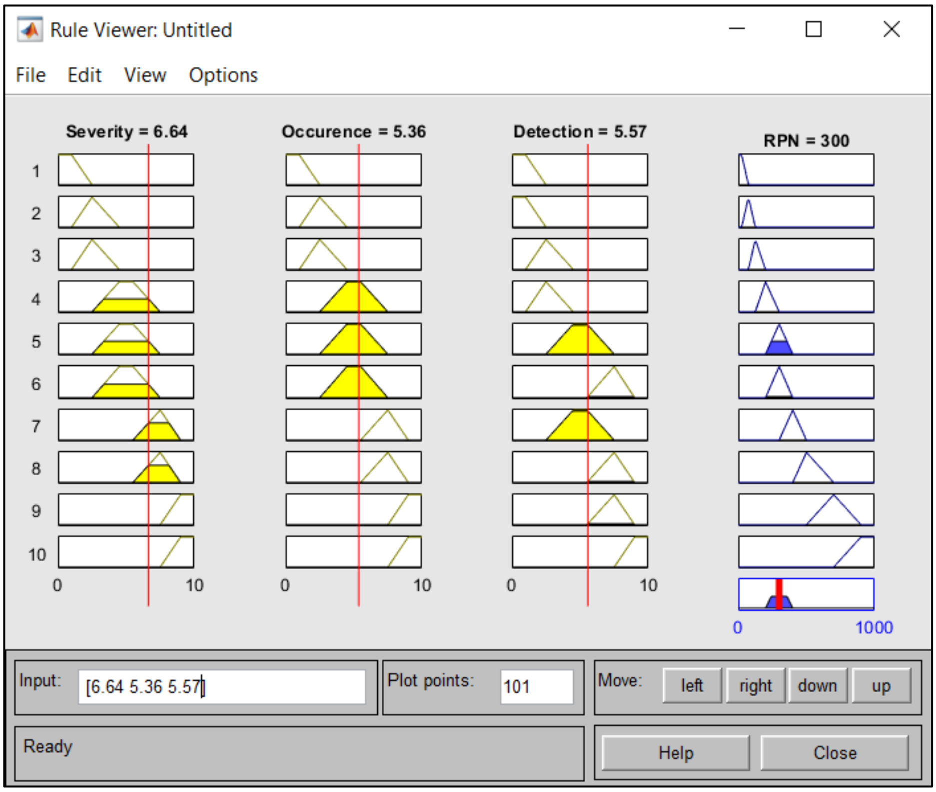

Figure 40: Results of poor quality of work using fuzzy RPN

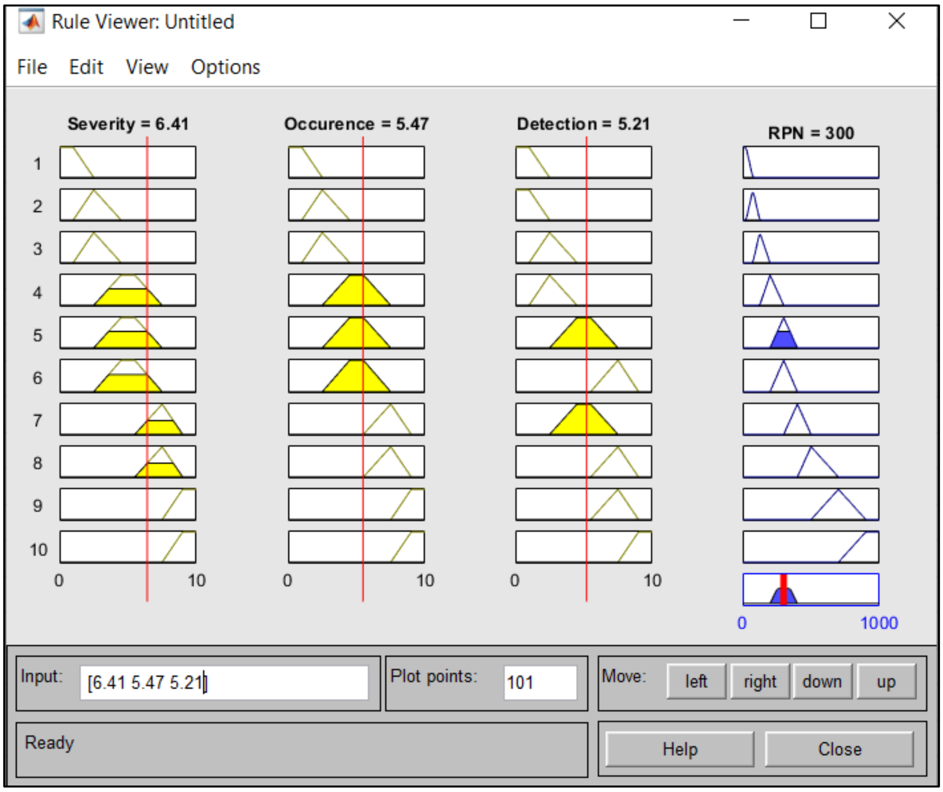

Figure 41: Results of wrong estimation of quantities using fuzzy RPN

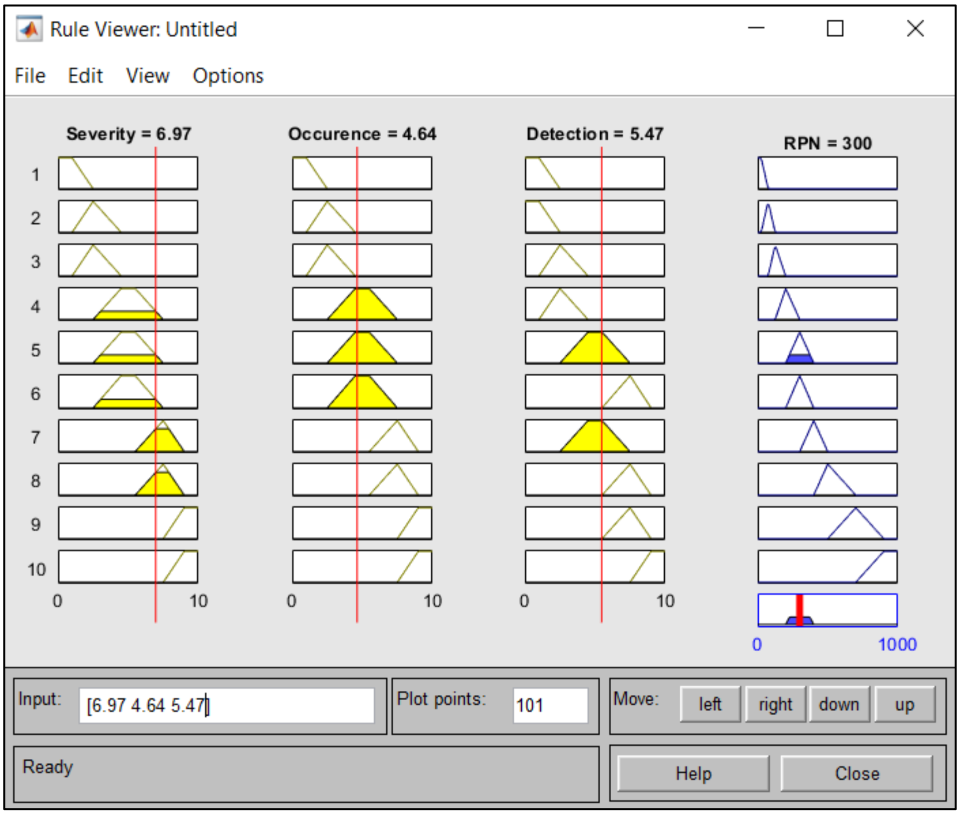

Figure 42: Results of error in the construction stage using fuzzy RPN

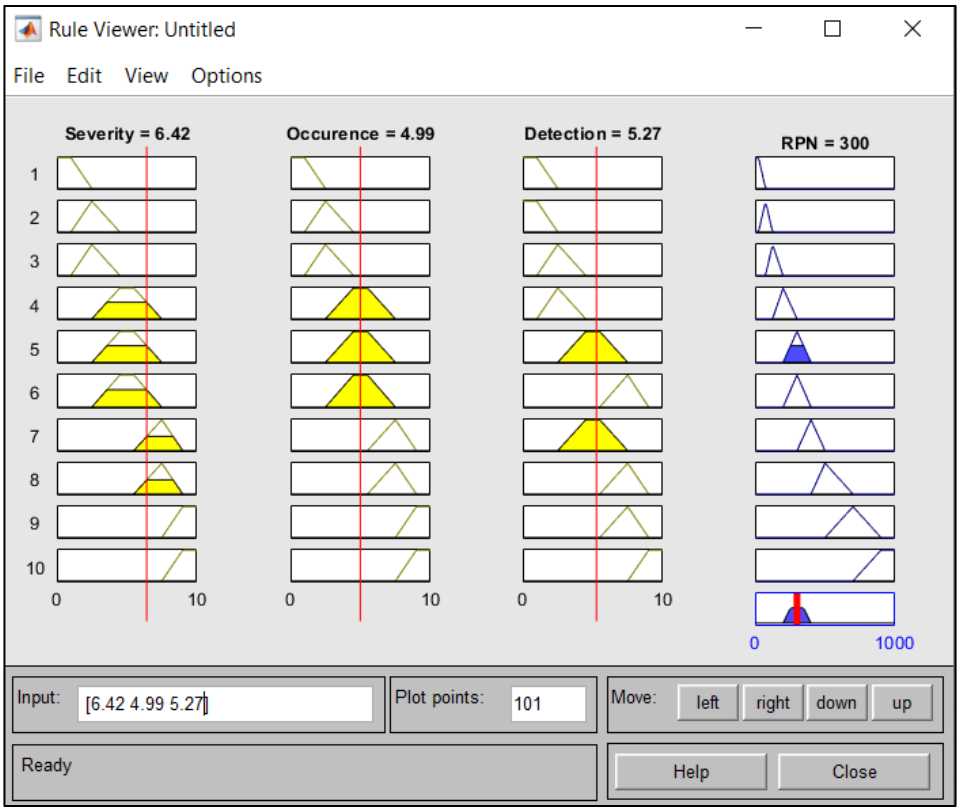

Figure 43: Results of safety accidents on site using fuzzy RPN

Appendix B: Questionnaire Survey Questions

The below are the questions that were included in the second questionnaire survey that essentially compared risk management process with failure mode and effect analysis. It initially proposed a brief description about both techniques. (Risk Management: It is the common approach used in the construction sector according to project management institution where it involves four major stages: risk identification, risk assessment, risk response and risk control. Risks are assessed according to their impact on the project and probability of occurrence. On the other hand, FMEA is another risk analysis method used in the manufacturing industry and risks are assessed according to their impact, probability, and another third factor known as Detection (which is the capability of detecting the risk before it results in a severe impact). It also has a large table to visualize all risks including their potential effect on the project, what causes this risk, the recommended actions to be taken, and the party responsible on this action. Therefore, it has a very good visualization of risks and results that could make it valuable to the construction industry).

Q1) What is the specialization of your company?

- Contractor
- Developer / Owner
- Consultant
- Other / Please specify

Q2) Did you hear about Failure Mode Effect Analysis (FMEA) before?

- Yes
- No

Q3) Do you think that we need better or other methods to analyze risks in construction projects?

- Strongly agree
- Agree
- Neither agree or disagree
- Disagree
- Strongly disagree

Q4) Please rate the following characteristics in FMEA:

a) Efficiency

- Very Poor
- Poor
- Moderate
- Good
- Excellent

b) Simplicity

- Very Poor
- Poor
- Moderate
- Good
- Excellent

c) A high range of ranking (for example 1-1000)

- Very Poor
- Poor
- Moderate
- Good
- Excellent

d) Better visualization of risks

- Very Poor
- Poor
- Moderate
- Good
- Excellent

Q5) Please rate the following characteristics in Risk Management:

e) Efficiency

- Very Poor
- Poor
- Moderate
- Good
- Excellent

f) Simplicity

- Very Poor
- Poor
- Moderate
- Good
- Excellent

g) A high range of ranking (for example 1-1000)

- Very Poor
- Poor
- Moderate
- Good
- Excellent

h) Better visualization of risks

- Very Poor
- Poor
- Moderate
- Good
- Excellent

Q6) Determine which technique is more beneficial for the construction sector?

- Risk Management (RM)
- Failure Mode and Effect Analysis (FMEA)
- Both are similar

Q7) Please rate the capability of using FMEA in the construction sector (5 Extremely possible) (1 not possible).

- Not applicable
- Could be possible
- Moderate
- Possible
- Very possible