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Owner time and cost contingency estimation for building construction projects in Egypt

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OWNER TIME AND COST CONTINGENCY ESTIMATION FOR BUILDING CONSTRUCTION PROJECTS IN EGYPT

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Abstract

Time and cost overruns are an integral part of the construction projects. Both have several associated negative consequences to the project owners. Setting the right time and cost contingency is a major contributing factor to the success of the project as it should minimize/prevent budget and time overruns. Project managers usually tend to allocate project time and cost contingency subjectively based on their previous experience and may not capture all projects specific factors that impact the contingency estimation. The competency of the project manager plays an important role in this case in determining the contingency percentage. The contingency estimation for a given project can hugely vary from one project manager to another. This research presents a fuzzy logic-based model that allows owners predict the project time and cost contingency reliably and accurately in Egypt. The most important factors affecting time and cost contingency have been identified and are defined as input variables for the model. The effect of these factors on the time and cost contingency, the output variables, have been determined and incorporated into the model via fuzzy rules. On the basis of the known effects of these factors, a fuzzy logic model is developed to automate the prediction process using MS Excel software. Several scenarios of the model are developed and subjected to initial testing using 10 actual projects data. Based on the initial testing, the best model was subjected to tuning in order to achieve the optimum model results in terms of accuracy and validity. Finally, the model is tested by applying it on new five actual construction projects which were not used in the initial testing nor tuning. The model results were found to be acceptable having an average validity percent of 84% and 81% for time and cost contingency, respectively. The proposed model allows the owners to [1] understand the effect of the project different factors on the contingency values, which in turn represent the degree of risk involved and accordingly, allows the owner to take necessary measures at the preconstruction stage to reduce the risks, [2] minimize the cost and time overrun through setting the right amount of contingency, [3] avoid tie up of excessive funds for the project, which can be used in others projects or activities, and [4] have higher confidence during the decision making process of whether to proceed or not to proceed with the project.

Table of Contents

List of Figures

List of Tables

1. Introduction

1.1 Background

The construction industry plays an important role as a major driving force for other sectors' growth (Samarghandi et al., 2016). The construction sector constitutes a significant percentage of the overall gross domestic product (GDP) of any country. In year 2005, it constituted 3.3% of Malaysia's GDP and employed circa 600,000 workers (Sambasivan and Soon, 2007). Meanwhile, in the United Arab Emirates (UAE), it constitutes 14% of the GDP (Ravisankar et al., 2014). The construction sector is one of the most dynamic and growing sectors in Egypt (Shibani, 2015). According to the Egyptian Ministry of Planning, it constituted mainly 4.8% of the total GDP in the year 2013. Ahmed (2003) (as cited by Abd El-Razek et al., 2008) states that, since 1981, the construction industry was allocated approximately 45% of the funds for the national development plans in Egypt since it is one of the most active sectors that affects the Egyptian economy to a great extent.

Completion of a construction project within the time, cost and quality targets determines whether a project is successful or not. The project manager endeavors to complete the project in its allotted time and cost frames (Rosenfeld, 2014). Various unexpected negative effects occurs in line with failure to achieve the project targets (Sambasivan and Soon, 2007). Time and cost overruns occur in most construction projects worldwide and have become an integral part of the construction industry (Rosenfeld, 2014). Delay and cost overrun of construction projects is a global phenomenon and rarely is a construction project completed following the original estimates whether time or/and cost (Assaf and Al-Hejji, 2006; Marzouk et al., 2008; Sambasivan and Soon, 2007; Wanjari and Dobariya, 2016). This can be attributed to the fact that construction projects are vulnerable to many factors, which impose significant effects on them whether positive or negative. Assaf and Al-Hejji (2006) stated that these factors usually result from many sources which may include, but not limited to environmental conditions, political conditions, market conditions, resources availability, and involvement and performance of parties. Some of those factors are predictable and controllable while others are not. Hence, uncertainty does exist in all construction projects, which in turn impose risks on achieving project targets, namely time, cost and quality.

1.2 Delay in Construction Projects

Delays in construction simply exists when the project completion date exceeds the specified completion date stipulated in the contract agreement or the date which the parties previously agreed on to complete the project (Assaf and Al-Hejji, 2006). In other words, delay in construction projects exists when there is a deviation between the actual completion date and the planned completion date. Delay is harmful to both parties of the contract of a construction project, which are mainly the employer and the contractor. From the contractor point of view, it is a loss of profit due to delay damages, higher overhead costs, and maybe higher labor and material costs in the long term (Assaf and Al-Hejji, 2006; Marzouk et al., 2008). From the owner point of view, it is a loss of revenues because by the time the project is completed and operation starts, it should be generating revenues, which will be delayed. (Assaf and Al-Hejji 2006; Marzouk et al., 2008). Accordingly, time is equivalent to money in construction projects.

1.3 Cost Overruns in Construction Projects

A common problem in the construction industry is cost overruns (Nassar et al., 2005). Cost overrun occurs when the project costs exceed its allocated budget (Wanjari and Dobariya, 2016). It is also defined as a budget overrun or increase in cost due to unexpected costs incurred. This may result from several causes which include, but not limited to, lack of project control, inefficient planning and design deficiencies. Other reasons include budget error, and additional scope not captured prior to budget sign-off (Al-Hazim and Salem, 2015). Exceeding the budget requires additional funding by the owner. In some cases, additional funding may not be available which may cause risk of project suspension. In large multinational organizations, additional funding requires approvals that take long time, efforts and needs extensive justifications by the project managers.

1.4 Problem Statement

A growing demand exists for advanced construction systems and models capable of solving complex problems in line with the complexities and rapid advancement of the industry. Duran (2006) (as cited in Gunduz et al., 2014) states that many projects are not completed on time; as a result, a very bad reputation is attributed to the construction industry regarding time adherence and usually project managers encounter the blame. Majid (2006) and Mahamid et al. (2012) (as cited in Gunduz et al, 2014) stated that the most common unfavorable outcomes are the loss of productivity, loss of revenues, cost overrun, and disputes. Exceeding budget is a dilemma as well for project managers and have several unfavorable consequences. Therefore, it is crucial that contingency should be determined accurately during the planning stage in order to enable the owner's project manager avoid exceeding project completion dates and budgets with their unfavorable consequences. However, it should be noted also that having an excessive unneeded contingency will tie up funds from being used in another potential projects or activities. To specify a time and budget contingency, project managers usually rely on traditional methods which are based on subjectivity, gut feeling, experience and intuition and do not rely on a mathematical method to support them in their decision (Gunhan and Arditi, 2007; Touran, 2003; Mohamed et al., 2009). This leads to an underestimated or overestimated contingency value.

Literature shows that cost contingency has been studied extensively more than time contingency had. However, the majority of the previous studies are from the contractors' point of view to allow them incorporate a cost contingency in their bid prices while very few are from the owner's point of view that would enable them set their contingency. In addition, few attempts has been made earlier to predict cost contingency in Egypt. Also, literature shows few research about time contingency prediction when compared to cost contingency. Similar to cost contingency, available studies are made though specifically for contractors to enable them predict the contingency and assign it to their baseline construction schedules, but very few attempts were made to predict the owner time contingency that enables them set a high level time contingency in the project master schedule. Despite the cost and schedule of construction projects are interrelated, cost and time contingency models are usually separated and independently applied (Bakhshi & Touran, 2014). Thus, this research will propose a reliable method that will enable the prediction of both time and cost contingency from the owner's point of view in an attempt to help owners and decision makers understand the effect of setting the project parameters on the contingency amount and allows them to be confident towards the agreed project cost and time.

1.5 Objective and Scope

The aim of this research is to [1] Identify factors affecting time and cost contingency from the owner side in Egypt, [2] Develop a reliable mathematical model to predict the owner time and cost contingency for their building construction projects, [3] Allow owners' decision makers to set the project contingency amounts accurately and avoid overestimation or underestimation, and [4] increase owners confidence towards the agreed project time and cost.

1.6 Research Methodology

Figure 1 shows a flow chart that demonstrates the methodology followed in this research to achieve its objectives.

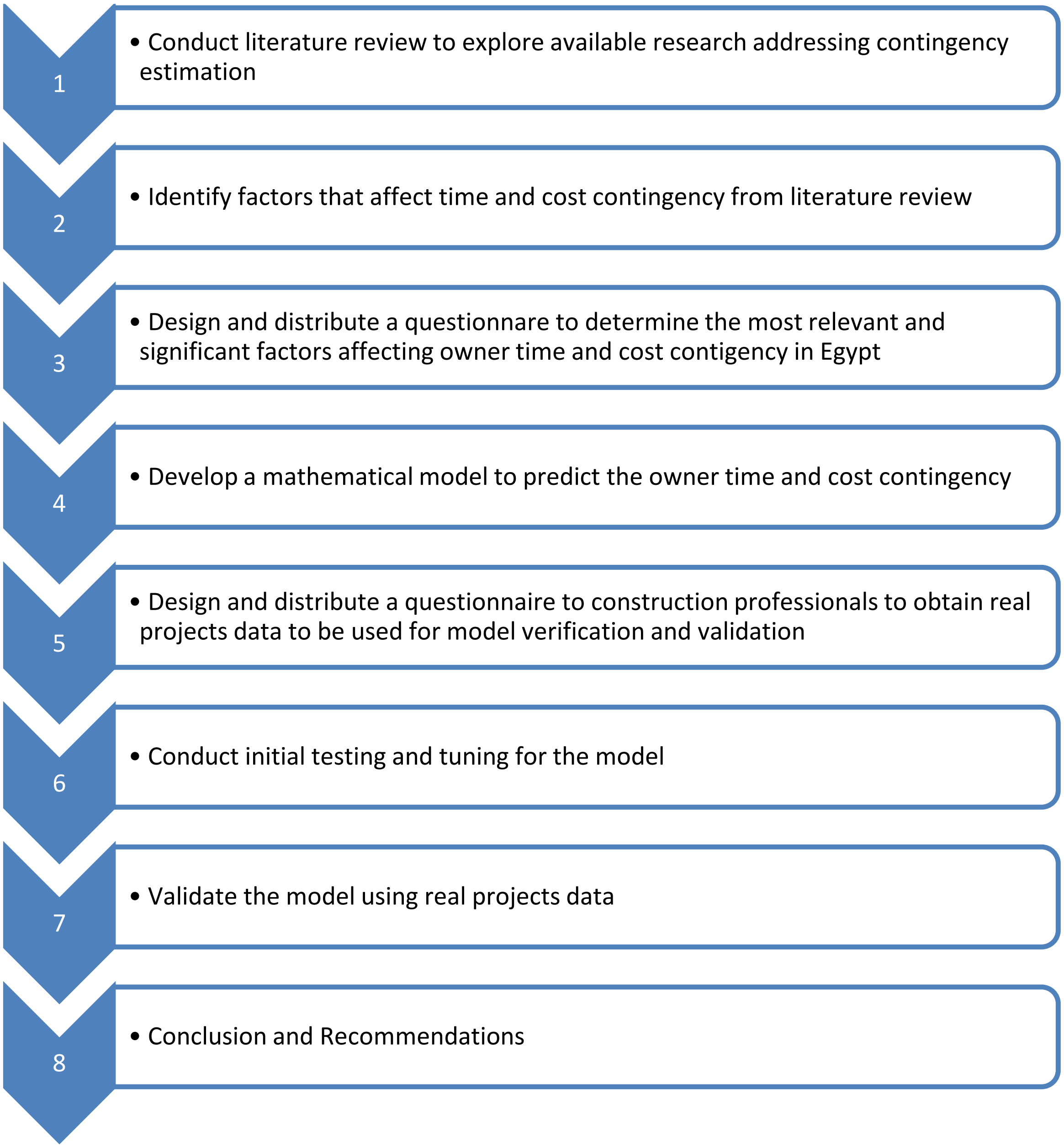

Figure 1 Research Methodology

First of all, a literature review shall be conducted to explore the available research addressing contingency prediction. Focus will be on the techniques that are used, and the summary and conclusions of the studies. A literature summary is then developed highlighting the gaps or areas that can have further research. The second step is to identify a long list of factors affecting owner time and cost contingency from literature. This long list is then subjected to elimination of factors that are considered irrelevant and/or redundant, which will result in having a shortlist. The third step is designing and disseminating a questionnaire to determine the most significant factors affecting owner time and cost contingency in Egypt using Delphi technique. The most significant factors are the ones that shall be used in the research and shall be part of the mathematical model, which is to be developed in the fourth step. Once the mathematical model is developed, a second questionnaire shall be designed and distributed in order to obtain actual projects data to be used for both verification and validation. Initial testing and tuning will be applied to the model first using real projects data to ensure the best model is developed. After choosing the best model, different real projects data will be used to validate the model and finally, conclusions, recommendation and limitations of the research are stated.

1.7 Thesis Structure

The following are the chapters of this research. All chapters serve each other in order to form a comprehensive thesis.

A- Chapter 1: Introduction

This chapter provides an introduction about the construction delays and cost overruns, the reasons they are unfavorable to project parties and the degree of their prevalence. It also contains the problem statement, objectives, scope, methodology and finally thesis organization.

B- Chapter 2: Literature Review

This chapter presents information and facts about delays and cost overuns in the construction industry. It also presents previous research done to predict construction projects' time and cost contingency including the methods used. Finally, the gap found in the literature is presented and discussed.

C- Chapter 3: Research Methodology

This chapter aims to introduce the methods used throughout this research in addition to the inputs and outputs of each step. It outlines the factors affecting owner time and cost contingency identified. It presents the model development strategy and techniques that are used. It also shows the quesionnaire design developed to gather real projects data to be used in initial testing, tuning and validation processes.

D- Chapter 4: Model Development, Initial Testing and Tuning

This chapter presents the process of the model development including design approach, different design scenarios, variables, rules, assumptions and finally results of initial testing and tuning based on real case studies.

E- Chapter 5: Case Studies Applications

This chapter contains the results of the model developed on real case studies for validation purposes through comparing the model prediction results with actual data.

F- Chapter 6: Conclusion, Limitations and Recommendations

This chapter concludes the research stating the findings, limitation of the research and finally, recommendations for future work and development.

2. Literature Review

2.1 Occurrence of time and cost overrun in construction projects

It has been reported by several researchers that delays are common in the construction sector worldwide. The average time overrun in construction projects in Saudi Arabia was between 10% and 30% and only 30% of the projects finished within the planned date of completion (Assaf and Al-Hejji, 2006). Ajanlekoko (1987) (as cited by Sambasivan and Soon, 2007) stated that performance of construction projects in Nigeria was poor in terms of time. Odeyinka and Yusif (1997) (as cited by Sambasivan and Soon, 2007) found that out of ten projects surveyed in Nigeria, only three projects finished within planned time. In India, out of 951 surveyed projects, 474 projects were found to be behind schedule and not completed within the stipulated time in the contract (Doloi et al., 2012). In Hong Kong, Chan and Kumaraswamy (1995) (as cited by Lo et al., 2006) observed that 75% of private sector construction and 60% of government related construction experienced delays and were not completed on time. According to a study conducted by World Bank in 2007, between 1999 and 2005, many projects completed worldwide with a time overrun varying between 50% and 80% (Ravisankar et al., 2014). "Modernizing Construction" report, prepared in the United Kingdom (UK) by the National Audit Office, stated that only 30% of the government department and agencies' projects were delivered on time (Ravisankar et al., 2014). Accordingly, many studies have been conducted to identify causes and rankings of delays (AlSehaimi et al., 2013).

Several research have been made in Egypt to identify and rank causes of delay, which implies prevalence of delay and its wide occurrence. Ezeldin and Abdel-Ghany (2013) reported that time overruns are a repetitive phenomenon in the Middle East and in Egyptian construction industry. Literature shows that delays in construction industry have been investigated and discussed in numerous manners. Mainly, the following are the most common topics that were covered by different studies addressing delay in construction industry.

- Causes of delay and its ranking according to project type (Al-Hazim and Salem, 2015)
- Causes of delay and its ranking according to country (Shibani, 2015; Lo et al., 2006; Abd El-Razek et al., 2008; Aziz, 2013)
- Delay Analysis (Sutrisna et al., 2016)
- Dispute related to delays and its resolution (Yates & Epstein, 2006)

- Delays mitigation (Abdul-Rahman et al., 2006)
- Prediction of future delay while construction is on-going (Li et al., 2006)
- Prediction of Time claims (Hosny et al., 2015)
- Estimating the probability of delay of construction projects (Gunduz et al., 2014)
- Estimating time contingency (Pawan and Lorterapong, 2016); however, literature shows limited coverage

One of the major contributing factors to reduce the occurrence of delays in construction projects and meet the time schedule is allocating accurate time contingency. Time contingency should be well studied to be accounted for while scheduling for construction projects.

It has been reported by several researchers that cost overruns are common as well in the construction sector worldwide. Several construction projects exceed initially set cost limits due to in ability to account for uncertainties and factors that result in cost overruns and exceeding the project budget (Ahiaga-Dagbui and Smith, 2014). In road construction projects in Australia, Baccarini (2004) (as cited by Jr. et al, 2010) reported that the average cost overrun was 9.92% and the average contingency was 5.24%. Wanjari (2016) reported that out of 410 projects that were reviewed in India, only 43% were completed on budget and 57% experienced cost overrun. Flyvbjerg et al. (2003) (as cited by Rosenfeld, 2014) analyzed 258 transportation-infrastructure projects gathered from five continents and found that the average budget escalation was 28%. Ahiaga-Dagbui and Smith (2014) reported that 50% of the projects in UK exceeded their budget according to a government-commissioned report in 1998. In the US, the General Accounting office issued a similar report indicating that 77% of the projects overspent budget (Ahiaga-Dagbui and Smith, 2014). Hartley and Okamoto (1997) (as cited by Nassar et al., 2005) states that cost overrun of 33% on average occurs in construction projects. According to the Florida Department of Transportation, the construction cost overruns for 102 completed projects were found to be 9.5% above the initial approved budget (Nassar et al., 2005). Previous studies have been conducted in Egypt to identify factors affecting cost overrun (Aziz, 2013; Shibani, 2015) in addition to studies that attempted to predict cost overrun (El-Kholy, 2015). This demonstrates the prevalence of the cost overruns in Egypt. Several research has been made to study cost overruns in construction projects. In order to reduce the occurrence of exceeding projects budget in construction projects, cost contingency should be well studied to be accounted for while setting budget in the project planning stage.

2.2 Factors affecting time and cost contingency

Previous research attempted to identify the factors that directly affect the cost and time contingency, as well as factors that affect time and cost overruns (Gunhan and Arditi, 2007; Polat and Bingol, 2013; Hosny et al., 2015; Marzouk and El-Rasas, 2014; Idrus et al., 2011; Jr. et al., 2010; Mohamed et al., 2009; Yahia et al., 2011; Marzouk et al., 2008; Abd El-Razek et al.,2008; Shibani, 2015; El-Kholy, 2015; Kholif et al., 2013; El-Touny et al., 2014; Aziz et al., 2013). Long lists of factors are usually prepared and identified from literature by researchers. In some case, the next step is the identification of the most significant factors using surveys and ranking them using an index such as the Relative Importance Index (RII), Importance Index (II), Severity Index (SI) and Frequency Index (FI). By exploring factors identified from several authors, it was noticed that many factors are the same and identified by several authors, but mainly vary in the ranking. This could be due to location of the research, the type of projects, the size of projects, and whether it is from the owner side, consultant side or the contractor side.

2.3 Prediction of time contingency in construction projects

As the construction industry is full of uncertainties and unexpected events that happen during execution, projects' parties encounter difficulties while planning for their projects prior to the construction phase. Generally, several factors should be taken into consideration to be accounted for during the planning phases. Among the main factors are the duration, the cost, the resources required for the project, the method statements to be used, the contract type, etc. Touran (2003) and Abou Rizk (2005) stated (as cited by Mohamed et al., 2009) that some factors are ambiguous and couldn't be determined accurately and they are always taken as guesstimates based on previous experience and projects' conditions. These are mainly the cost and time contingency, which are very important as construction projects always tend to deviate from the original plan (Mohamed et al., 2009).

If the schedule of the project does not account for such uncertainties, the completion date will not be achieved and the project will be considered unsuccessful. Given the construction projects are unique in nature and every project is not similar to another, the project schedule should incorporate time contingency and project specific uncertainties to accommodate any changes without affecting the overall project duration negatively (Mohamed et al., 2009). Another main reason for necessity of proper estimating time contingency is that delays have negative impacts on the project quality and budget (Mohamed et al., 2009). Time contingency is considered to be a major factor for a successful construction project (Mohamed et al., 2009). Project Management Institute (PMI, 2000) defined contingency as “the amount of money or time needed above the estimate to reduce the risk of overruns of project objectives to an acceptable level to the organization”. Time contingency is usually expressed as percentage of the original total project duration (Touran, 2003).

Previous research has been conducted to predict time contingency. Khamooshi and Cioffi (2013) (as cited by Pawan and Lorterapong, 2016) stated that CPM is the common method for scheduling and planning of construction projects; however, it has been criticized that it doesn’t account for uncertainty inherent in construction projects. As a result, probabilistic based methods, such as Monte Carlo Simulation and Programme Evaluation and Review techniques (PERT) have been introduced as more objective approaches to overcome this limitation, but they require historical project data in order to be able to generate the probability density functions (Pawan and Lorterapong, 2016; Barraza, 2011). In order to obtain historical data for these techniques, these require extensive impractical efforts and time. Due to the merge event bias, PERT may provide very optimistic project schedules in some cases (Barraza, 2011).

Barraza (2011) developed a framework that determines the total project time contingency and allocates it among the individual activities by the stochastic allocation of project allowance (SAPA) method, which is mainly based on Monte Carlo simulation. Total time allowance (TTA) is the difference between the project planned duration (PPD) and the project target duration (PTD). Probabilistic method approach is used to calculate these estimates using simulation. Simulation results in different possible activity durations from the corresponding probability distributions and accordingly different possible project durations. Typically, the possible project durations follows a normal distribution curve regardless of the distribution of the activities durations. Project duration estimates can be selected from different project duration outcomes due to different risk levels, which can be defined as the probability that the selected project duration is exceeded. Accordingly, depending on the acceptable risk level ($\propto_{pd}$) by the project manager, the PPD can be determined. For example, the chosen PPD value can be the duration with 15% chance of being exceeded, which corresponds to the 85th duration percentile. To estimate PTD, instead of using their expected or most likely values, median durations are considered where they are obtained from the simulation results easily. Having calculated both

PTD and PPD, the TTA now can be obtained as the difference between them and be allocated to the project activities as shown in Figure 2.

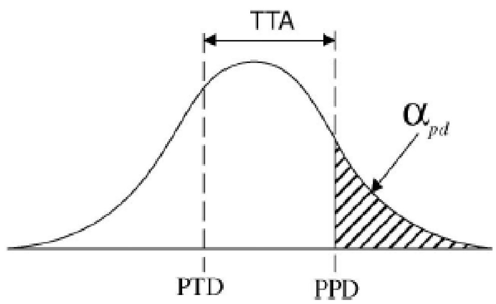

Figure 2 Project Total Time Allowance (Project Time Contingency) (Barraza, 2011)

Following the determination of the TTA, the total allowance should be allocated to the project activities. The method proposed in this research in order to estimate the PPD for each activity is that a maximum allowed duration percentile (D_{Pi}) with same risk level ($\propto_t$) for all project activities should be selected. Therefore, the PPD is the summation of the (D_{Pi}). The activity target duration (T_{Di}) shall be set as the median duration. Accordingly, the planned activity time allowance (ATA_i) can be calculated as the difference between both as per Equation (1) and as demonstrated in Figure (3). Accordingly, it is concluded that TTA is the summation of the ATAs of the activities on the critical path.

$ATA_i = D_{Pi} - T_{Di}$ ***Eq. 1***

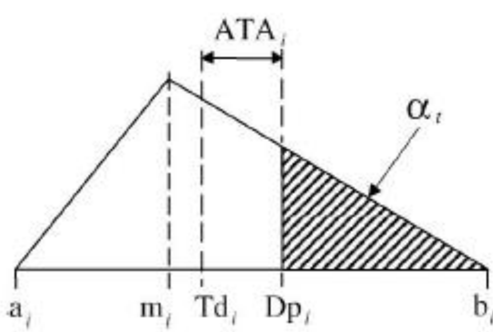

Figure 3 Activity Time Allowance (ATA) (Barraza, 2011)

This framework attempted to estimate the time contingency on the project level and its allocation on the activity level. Among the advantages of the SAPA method is that a fair distribution of the project time contingency is determined by predicting the maximum allowed duration for all project activities at the same percentile level. In other words, larger planned durations will obtained for higher risk activities. The proposed method considers only predictable risks that may affect the performance of the activity; however, doesn't consider the unforeseen conditions at the project level and the author recommended that these should be considered in a separate general time contingency prediction (Barraza, 2011).

On another note, critique has been made to probabilistic scheduling methods revealing their inability in considering non-random uncertainty (Pawan and Lorterapong, 2016). Construction projects are unique and accordingly, each project has its specific risks that may not apply to others, so the historical data incorporated in these methods may not be relevant to the future projects. In the current practice, experienced professionals tend to subjectively estimate durations incorporating contingencies; however, these subjective estimates may not be accurate and are subject to flaws and errors depending on the experience of estimators (Barraza, 2011). Therefore, advanced models are recommended to be developed that would enable reliable prediction of time contingency considering vagueness and imprecision encountered during project scheduling. Critical Chain management was also introduced to account for variations in activity durations where two types of buffers are used, the feeding buffer and the project buffer. Certain heuristic approaches are used in order to determine the size of these buffers, which are mainly the root square error method and the cut and the paste method. However, It has been proven that both methods are incapable to create robust schedules (Pawan and Lorterapong, 2016).

Given literature showed that fuzzy set theory has been successful and captured the interest of researchers through the last three decades in modeling uncertainty, Pawan and Lorterapong (2016) used fuzzy set theory in order to overcome the vagueness and imprecision when predicting time contingency. They developed a model to take into account the risks impact on construction activity duration estimation and develop a scheduling procedure that shows the effectiveness of risk response planning to reduce time contingency. Therefore, fuzzy logic was employed in order to model the time contingency needed for the execution of the activities affected by the risks. Not only does the model enable modeling of single risk impact, but also multiple risks impacts. Their framework is as follows.

a- Risk Identification: Identifying all risks that may impact to the project activities obtaining a list of risk events (R_i) for each activity.

b- Risk Analysis: Risks are analyzed by determining the probability of occurrence ($\propto_i$) and the impact of the each of the risks associated to a particular activity. The impact is the resultant extension of time in case the risk occurred to the activity, which is estimated usually by experienced construction professionals subjectively and based on imprecise linguistic expressions such as around 6 to 8 days or circa 10 days. In this research, the resultant extension of time should the risk occurred is called "Fuzzy Time Extensions" (FTE).

c- Impact Quantification: FTE determined previously are based that the risk factor will definitely occur. Accordingly, adjusted FTE (AFTE) is obtained when there is lack of confidence with the possibility of R_i to occur. AFTE can be calculated using Equation (2)

$$\text{AFTE}_i = \alpha_i(\text{FTE}_i) \qquad \textbf{\textit{Eq. 2}}$$

Where AFTE = Adjusted Fuzzy Time Extension;

FTE = Fuzzy Time Extension;

$\propto_i$ = the probability of occurrence;

d- Fuzzy Activity Time Contingency Calculation: if the activity is exposed to one risk factor, then the time contingency needed is the AFTE. If the activity is exposed to multiple risk, then the time contingency is the combined AFTE of all risks. The maximum impact is taken assuming all risks are independent. As a result, the total activity duration, which is the fuzzy activity duration incorporating the risk (RFAD) may be calculated.

e- Development of Risk Incorporated Schedules: The fuzzy project schedule is determined using the RFAD.

f- Risk Response Planning: after the schedule is developed using RFAD, the schedule duration should be compared with the contract duration ensuring that contractual milestones are achieved and met. To be able to compare both values being considered, an agreement index (AI) is developed noting its value ranges from 0 to 1 where 0 is no agreement and 1 is full agreement. Based on the organization's risk tendency, a guideline shall be set for AI values. If the AI value is below predetermined value, then immediate risk responses are required through identifying the associated activities that is resulting in the disagreement and low AI value. If the AI value is above predetermined value, then no action is required.

Moreover, Pawan and Lorterapong (2016) developed a framework involving fuzzy set theory that enables the integration of risk management into the project schedule by identifying risks associated with the project specific activities and accounting for it rather than setting a time contingency on high level basis or at the project level. The benefits of the fuzzy set theory is that it allows the modeling of the vagueness, imprecision and subjectivity usually inherent with the construction project schedules and as a result, it yields a robust project schedule. This framework is designed specifically for contractors' use when developing their detailed construction baseline schedules, but doesn't serve owners of construction projects when developing their master schedules at the planning stage before issuance of the project tender.

Mohamed et al. (2009) developed a model to estimate the time contingency for construction projects. The model involved the use of the Analytic Hierarchy Processes (AHP) where it depended on the factors that affect time contingency and their impact, which are identified through a survey and the literature. Table 1 shows the factors that have been chosen and included in the survey. The factors were categorized into project, environmental, and management conditions and the importance of each factor has been determined from the survey respondents.

Table 1 Factors affecting Time Contingency (Mohamed et al, 2009)

Criteria	Factor	Description
Project Conditions	Project Location	Location may influence the amount of risk and therefore the level of contingency.
	Project size (Design complexity)	It affects planned schedules negatively. In the large projects there are many various activities that required many different resources and involved many parties. All of these variables are interfering together which may cause delay in the project duration.
	Equipments availability (Construction technology)	Technology requirements comprising of method of construction "equipments" Issue of renting equipments, damages that may occur will increase contingency.
	Material availability (Market)	This factor is related to the site condition and storage area. Transport material from the supplier to the site is time consuming which required a prior arrangement.
Management Conditions	Amount of interference (Skills)	Any project could have stop work order because of the owner or engineer interference, this is happened due to lack of knowledge and experience from all the participants. If the amount of interference increased the delay of schedule will be increase until they make their decision.
	Number of change orders	Change of orders or extra work order usually requires long process of redesigning or modifying specification. In addition the extra work may force the contractor to accelerate work which could cause loss of the labour productivity and then caused the delay.
	Payments (Delays)	Any delay of payment may cause delay of supplying resource to the project which will affect the planned schedule.
	Time to make a decision	Owner is the main responsible in this case until he/she makes the decision of change or not. The contractor should record this delay against the owner in case of claim.
	Productivity of labor and equipments	Losing of labor productivity that caused by acceleration or extra work will affect the project schedule. Any damage of equipment will cause serious delay on the current activity consequently causes delay in project schedule.
Environmental Conditions	Weather condition	Weather in some countries has the highest impact on the schedule delay.
	Soil condition	Some unforeseen soil conditions in the site cause delay in the schedule.
	Labor strike	This stoppage will cause delay in project schedule.
	Shortage of human resources	Some unforeseen events like work accident, sickness, social, psychological and other unpredicted event may cause labor pain, or absenteeism. Hence, this factor will cause delay in the activity and schedule.

AHP has been chosen in this research to assess the weights of the factors affecting time contingency through pair-wise comparison matrices, which have important characteristics as shown in Table 2. At the intersection of each criterion and itself, the elements are all set to one.

Table 2 Typical Pair-Wise Comparison Matrix for Different Factors (Mohamed et al, 2009)

Factors	a_1	a_2	a_3	a_4
a_1	1	a_{12}	a_{13}	a_{14}
a_2	a_{21}	1	a_{23}	a_{24}
a_3	a_{31}	a_{32}	1	a_{34}
a_4	a_{41}	a_{42}	a_{43}	1

$a_{11,}\ i = 1,\ j = 1$

The weight of the factors have determined through the Equation (3) w_x is the weight of the factor, n is the pair-wise comparison matrix dimension and a_{ij} is the matrix element for i row and j column. The time contingency has been developed using Equation (4) where C_D is the time contingency, w_i is the weight factor, s_i is the score for each factor in a specific project and p_i is the factor's probability of occurrence.

$$W_x = \sum_{j=1}^{j=n} \frac{a_{ij}}{\sum_{i=1}^{n} a_{ij}} \Big/ \qquad \textbf{\textit{Eq. 3}}$$

$$C_D = \sum_{i=1}^{n} W_i * S_i * P_i \qquad \textbf{\textit{Eq. 4}}$$

Moreover, the model implementation have been according to the following steps:

a. Calculating the relative weight of each major category
b. Calculating the sub-factors' weights relative to the weight of its category
c. Calculating the 13 factors' scores to determine the most effective to the contingency value towards the least ineffective
d. Calculating the 13 factors' probability of occurrence
e. Multiplying the probability of each factor by the weight by the effectiveness score
f. Obtaining the summation of the multiplication which represents the overall time contingency of the project

The results of the study concluded that 36.78% of the original project duration should be allocated as time contingency to the project due to the effect of the contingency factors. AHP, however, considers each factor on its own and provides no correlation between the factors, which is not very representative for construction projects nature. The verification of the model was verified based on obtaining the average delay of seven projects and comparing it with the average contingency obtained from the survey results. Therefore, the model is not project specific since each project is unique and an average contingency is not accurate to be applied on all projects similarly.

Yahia et al. (2011) developed an Artificial Neural Network (ANN) model to predict the time contingency in Egypt. They performed data collection to identify the factors that affects the time contingency in Egypt. Table 3 lists all factors that have been identified through the literature. In order to identify the most important factors that would be considered in the model, the factors were ranked by construction market experts. The respondents had to insert scores for the factors. Scores were for the degree of impact of each factor and its probability of occurrence. Both scores then are multiplied by each other to get the time contingency effect. Yahia et al. (2011) used the importance index method to determine the level of importance of each factor by using the Equation (5).

Importance Index = $\sum [aX] \times 100/10$ ***Eq. 5***

Where a = constant expressing the weighting ranges from 1 to 10 having 10 as the most important and 1 as the least important;
X = is the ratio between the frequency of the respondents (n) and the total number of respondents to each factor (N).

All factors having an important index above 70% were considered to be among the most important factors affecting the time contingency in the construction market. Table 4 contains the most important factors after analyzing the survey results. As ANN model requires historical data for training and testing purposes, data gathering for 54 building construction projects executed by Class A contractors were gathered through sessions with experts.

Table 3 Factors Affecting Time Contingency based on Literature (Yahia et al, 2011)

Table 1. List of factors affecting time contingency, based on references [5-14]

Ser.	Factor	Ser.	Factor
Project Conditions			
1	Project Location	2	Project Design complexity
3	Equipments shortage [Construction technology]	4	Material shortage [Market]
5	Project location [Near from governmental Buildings i.e. embassies, ministries, .etc]	6	Preparing the plan during project preliminary Stages [i.e. Initiation, Tender phase]
7	Limited time allowed for preparation of the schedule	8	Missing Project Scope Items [conflicts between project documents].
9	High Level of Quality requirements	10	Lack of Experience in similar projects.
11	Lack of Consultant Experience	12	Unexpected onerous requirements by client's supervisors [Not a change order]
Management Conditions			
Contractual:			
13	Great Scope Changes [i.e. change scope from core & shell to complete finishing]	14	Contract Risks [Force Majeure]
15	Change orders	16	Deficiencies, errors, contradictions, ambiguities in contract documents
17	Inadequacy of detailed drawings	18	Contract type: Lump sum
19	Contract type: Re-measured	20	Context of Contract
21	Inadequacy of dispute settlement procedures		
Time:			
		22	Payments [Delays]
23	Risks related to Governmental Authority Constraints which limit the project completion date or any other stage	24	Imposed Holidays [i.e. Obama's visit to Egypt etc]
25	Inaccurate planning by any party	26	Inaccurate control & follow up
27	Workload on the contractor resources	28	Client delays commencement date.
29	Client suspend works	30	Late project changes
31	Long time to make or take a decision	32	Delays in resolving litigation/ arbitration disputes
33	High Percentage of critical activities in the baseline		
General:			
		34	Amount of interference [lack of knowledge or experience in any party]
35	Inadequate supply, quality, timing of information and drawing by designer	36	Unfavorable interference in work sequence
37	Unexpected inadequacy of pre-construction site investigation data	38	Poor dispute resolution mechanism
Environmental Conditions:			
39	Bad Weather conditions	40	Labor strike
43	Unknown geological conditions	44	Labor restrictions
Economical Conditions:			
45	Economical stability [Unexpected conditions such as Economic Crises]	46	Material Market rates [Escalation, Inflation or fluctuation]
47	Design changes due to Market Demand [i.e. town houses instead of large villas]		
Country Conditions:			
		48	Administration [Bureaucratic delays, Attitude towards foreign investment..etc]
49	Laws and regulations [e.g. Import and export regulations]	50	Unavailability & Bad Quality of Resources
51	Changes in regulations and law	52	Fraudulent and kickbacks in laws
53	Political instability	54	Influence of power groups [i.e. environmental laws]
Factors related to Contractor:			
55	Shortage of experienced staff and labors	56	Contractor start delay [i.e. project starting or concrete pouring milestones…etc]
57	Contractor poor performance	58	Efficiency of planning by contractor
59	Bad Relationship between top management and site staff	60	Bad Relationship between site management and laborers

Table 4 Most Important Factors Affecting Time Contingency (Yahia et al, 2011)

Rank	Factor	"n" Frequency [Total score]	No. of respondents "N"	Importance Index	Weight	Category
1	Change orders	241.50	50	48.300%	100.0%	Management conditions
2	Payments [Delays]	235.48	50	47.096%	97.5%	Management conditions
3	Long time to make or take a decision	201.34	50	40.267%	83.4%	Management conditions
4	High Percentage of critical activities in the baseline	185.19	49	37.794%	78.2%	Management conditions
5	Late project changes	187.89	50	37.577%	77.8%	Management conditions
6	Missing Project Scope Items due to conflicts between project documents.	185.33	50	37.066%	76.7%	Project conditions
7	Workload on the contractor resources	171.18	49	34.935%	72.3%	Management conditions
8	Inaccurate control & follow up	173.90	50	34.780%	72.0%	Management conditions
9	Unexpected onerous requirements by client's supervisors [Not a change order]	172.24	50	34.449%	71.3%	Project conditions
10	Efficiency of planning by contractor	167.09	49	34.100%	70.6%	Factors related to Contractor
11	Inadequate supply, quality, timing of information and drawing by designer	162.83	48	33.922%	70.2%	Management conditions

The most important factors listed in Table 4 were set as input nodes of the ANN model which the user should input his project specific parameters. Additionally, the user should input an additional factor, which is the project duration. In this research, back-Propagation (BP) learning algorithm, a multilayer feed-forward neural network architecture, has been used. Figure (4) shows the neural connection methodology. The error calculated at the network output is propagated through the layers of neurons to adjust the weights that would lead to the correct outputs. The BP works on minimizing the root mean square (RMS) error to link the input to the output mapping correctly. RMS is calculated using Equation (6). The model is trained when the RMS is minimized to an acceptable extent.

$$RMS = \sqrt{\frac{\sum_{i=1}^{n}(O_i - P_i)^2}{n}} \qquad \textit{Eq. 6}$$

Where O_i = Sample Actual Output
P_i = The output predicted
N = No. of samples to be evaluated in training stage

The output node of the model was set as the time contingency in days, the input node contains the factors, while the MLP is the Multi-Layer Perceptron.

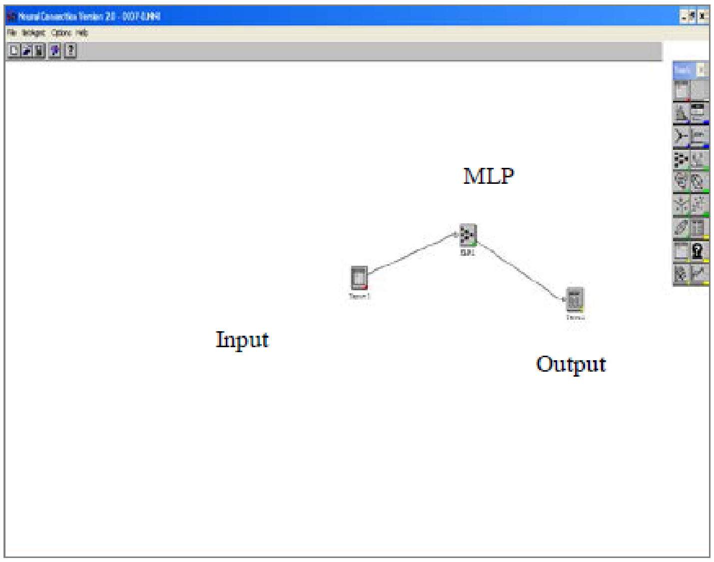

Figure 4 Neural Connection Methodology (Yahia et al., 2011)

For the model training, Forty Nine projects were used. After completion of training, the model was tested using the remaining five projects to determine the reliability and accuracy of its results. Table 5 shows the results of the testing. Yahia et al. (2011) found that the average time contingency for Egyptian Construction Projects was 28% and that the model predicted a reliable and acceptable time contingency with an absolute variance that ranged from 0% to 7.5%.

Table 5 Results of the ANN model (Yahia et al, 2011)

Project no.	Planned Duration [Months]	Time Contingency		Variance		
		Actual	Predicted*	Value	%	Absolute %
1	24	25%	25%	0%	0.0%	0.0%
2	20	30%	28%	-2%	-6.2%	6.2%
3	6	33%	31%	-3%	-7.5%	7.5%
4	22	27%	28%	1%	2.3%	2.3%
5	18	28%	29%	1%	2.8%	2.8%

* Predicted values are resulted from NC model.

This research however is dependent on factors that are hardly known at the planning stage of the project or the pre-contract stage. This model mainly serves contractors to assist them in predicting time contingency in their detailed construction schedules, but not targeted for the owners of the projects when developing their master programme. In order for the owner to determine the contingency, it should be based on information that is available and known at this early stage. The factors used in this model are known only while the construction is on-going. An example of these factors are: the no. of changes initiated in the last 25% of the project actual duration, number of Request for Information (RFIs) and Average of delay in each payment in days. Another limitation for using ANN to predict time contingency is that it has to be based on historical cases, which should be correct and accurate in order to train and teach the model predict the results reliably.

Another research done to predict contingency reliably was done by Park and Pena-Mora (2004), who criticized the usage of traditional time contingency buffering to guarantee activity or project completion time. They stated that this type of buffering results in an unnecessary resource idle time and often fails to protect the performance of the project schedule. Among the limitations of assigning a contingency buffers traditionally at the end of activities, site team usually tend to consume the contingency buffer as part of the original activity duration and hence, it is not a contingency anymore. The result is that the time contingency added results in schedule expansion. Sterman (as cited by Park and Pena-Mora, 2004) found that work productivity decreases when people know they have more time than the original time allowance to complete an activity as people tend to defer the work to the last minute. Also, Balard and Howel (1995) stated that (as cited in Park and Pena-Mora, 2004) sizing buffers is usually based on individual experience and assigned uniformly rather than considering activities characteristics. Accordingly, Park and Pena-Mora (2004) introduced “Reliability buffering” to address this issue. Reliability buffering is based on simulation and aims to result in a robust construction plan that takes into account uncertainties of individual activities and protects the schedule against them. Simulation of the model is used to determine the effectiveness of the reliability buffering. The methodology of reliability buffering is that it resizes, relocates and re-characterizes the contingency buffer and if no contingency buffer is available, a new buffer is introduced. Dynamic updates take place as well to the size and location of reliability buffers while the construction is on-going in order to account for any deviations in the schedule from the original estimates. To overcome the challenges of the traditional contingency buffering, Park and Pena-Mora tackled the limitations through introducing changes.

Starting with buffering logistics, they suggested to take-off the contingency buffers from being placed at the end of activity and assigning them in the front of the successor activity. This enables enough time to discover and rectify any problems from the preceding activity without affecting the successor activity duration. This will enable the option of dealing with ill-defined tasks issue that require time to define. Taking off contingency buffers from the end of the activities will lead to schedule pressure and to overcome the last-minute syndrome. Also, relocating buffers to the beginning of the activity duration, losses at the merging point of a schedule network are reduced. Figure (5) shows an example for the relocation of an activity buffer to the successor of the next activity.

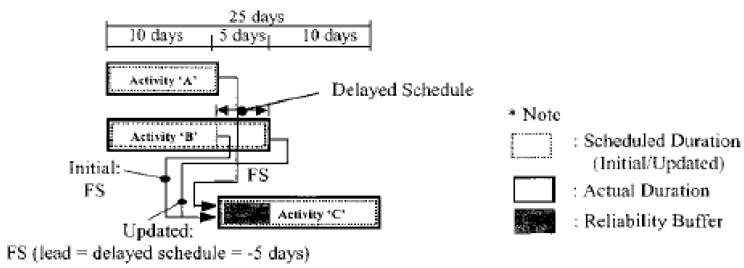

Figure 5 Reliability Buffer at Merging Point (Park and Pena-Mora, 2004)

As for buffer sizing, it should be long enough to maintain the reliability of the successor activities; however, overestimated buffer time will lead to unproductive idle time. There are three main determinants for the buffer size, which are the following.

- Production type, which is mainly the activity work progress pattern.
- Sensitivity, which is the degree of activity sensitivity to changes made externally or internally.
- Reliability, which is the degree of robustness against uncertainties and generic work quality.

Initial planned buffers needs to be dynamically updated to be able to control schedule deviations from the original plan. When using static buffer, if the predecessor activity is delayed, it will push the successor activity and delay its planned start. However, when using dynamic buffering, if the predecessor activity is delayed, the impact can be minimized on the successor activity by updating dynamically the size and the location of the buffer based on the current project progress, actual information obtained resulting for the actual performance and the remaining construction performance forecast. If the predecessor activity finished earlier than planned, dynamic buffering approach will seize the opportunity of schedule advance. Therefore, the following are the necessary steps needed to implement reliability buffering.

1- Taking off and pooling time buffers for the project activities
2- Adjusting the size of the contingency buffers or determining a new buffer considering the project activity characteristics and control policies
3- Allocating the new buffers on the beginning of the successor activities
4- Characterization of the buffers as an available time that can be used to ramp up resources for a successor activity and solving the problems of the predecessor activity that will impact the successor activity’s progress.
5- All remaining contingencies to be used as a pool buffer for the project
6- During Construction through measuring actual performance and having performance forecast, enable dynamic update of the size, and location of buffers to meet the actual situation.

In conclusion, based on Park and Pena-Mora research findings, reliability buffering can result in robust construction schedule against uncertainties and shorten the project duration with no additional costs through appropriately pooled, resized, re-characterized and relocated buffer. Reliability buffering effectiveness is examined by simulation of a dynamic project model, which integrates the network scheduling approach with the simulation approach.

In addition to the limitations mentioned for previous research, there has been limited research to predict the owner time contingency that should be incorporated in the master schedule of the project, which is usually reported to the organization top management. The construction contingency is usually determined by the contractor in his detailed baseline schedule; however, the owner time contingency is usually added in the master schedule in order to account for any project delays due to uncertainties and unforeseen conditions.

2.4 Prediction of cost contingency in construction projects

Gunhan and Arditi (2007) states that there are many factors that makes forecasting accurate owner’s budget very difficult. Funding issues, design control, management of schedules and costs, performance of parties involved in the construction, inherent uncertainity, and complexity of the project are contributing factors that affect budget determination. Accordingly, project managers include contingency funds within the budget to account and cover those uncertainites and ambiguites. Setting up the right contingency contributes to completing the project successfully.

Mills (2001) (as cited by Idrus et al., 2011) reported that traditionally many project managers determine cost contingency as 10% on the project estimated cost. Baccarini (as cited by Idrus et al., 2011) commented that this method is conventional and not easy to defend and justify.

Although high contingency ensures the design and construction will finish smoothly due to availability of sufficient funds; however, there are several drawbacks (Gunhan and Arditi, 2007). Among the major drawbacks is the tie up of funds that can be used in other activities and projects (Bakhshi and Touran, 2014). Another drawback is that large contingency sometimes can be questioned by the firm management and proper justification has to be available to defend the allocated contingency. On the other hand, underestimated contingency funds impose a risk of going over budget, which is not acceptable as well and implies lack of project planning and control, etc. Cost overruns are prevalent as demonstrated in section 2.2. Furthermore, cost estimates at the projects planning stages play important role and ranks among the highest in terms of priority (Ahiaga-Dagbui and Smith, 2014). Cost-benefit analysis, build or not-to-build decision by owner, future performances benchmark and guidance in selection of potential delivery partners are among the roles and benefits of cost estimates (Ahiaga-Dagbui and Smith, 2014). Knowing that contingency is part of the cost estimate, it has a direct impact on the end decision taken.

It is very important to understand types of cost contingency that are part of the project budget, the purpose of each, and the party in control. Contract terms as well are vital to understand and interpret correctly to enable proper and effective contract administration and reduce disputes. Gunahn and Arditi (2007) stated there are three types of contingency in construction, which are the following.

a- Designer Contingency: it is allowed in the preliminary budget for any potential cost increases during the design development phase or generally, the pre-construction phase. By the time the construction starts, the design contingency could be absorbed by any modifications in the design. In case there are elements in the design not fully complete, this contingency should serve to cover for those items later on. In an ideal situation, when the construction starts, the design contingency should be eliminated as its role should have been completed ideally assuming the design is fully complete.

b- Contractor Contingency: It is allowed in the construction budget for any cost increases during the construction phase. Cost increase may occur due to any construction unforeseen conditions, schedule related issues due to overtime works to accelerate progress, changes in market conditions, which may affect material and labor prices. This contingency is controlled by the main contractor and its accurate prediction is very important for the contractor success, which in turn will give him the capability to recover delays through overtime and additional shifts and will assist to reach the time target as well.

c- Owner Contingency: It is allowed in the budget and controlled by the owner. Its purpose is to cover for any missing scope and requirements that was not captured early and included in the contract scope during the tender stage. Generally, it covers for change orders, changing the standards/specifications of work, different site conditions when the nature of work encountered during construction is different than what's stated in the contract documents, Design errors, etc. It is vital for the owner to predict his contingency accurately that will enable him to cover additional expenses and complete the project on budget.

Gunhan and Arditi (2007) stated the most common methodology to predict any type of contingency is by previous experience and taking subjective figures. The most common method is to consider a percentage of the estimated contract value and add it as the contingency (Touran, 2003; Jr. et al., 2010). Following interviews with 12 contractors, respondents reported that none of them had any mathematical tools or any formalized techniques to evaluate and estimate contingency (Jr. et al., 2010). Some experts identified fixed cost contingency percentages for projects according to types of works. For example, experts estimated the contingency to be 15% of the original cost and duration for underground construction activities and tunneling activities, while 7.5% for the remaining project activities (Touran, 2003). The problem with this method is that it is deterministic and based on experience and subjectivity and does not consider all project-on-hand specific factors and conditions. Also, it does not quantify the contingency estimate degree of confidence. Therefore, there exists a need for a technique that predict cost contingency reliably on certain basis rather than subjectively.

Gunhan and Arditi (2007) developed a framework demonstrated in Figure (6) to determine the owner contingency budgeting, which is based on the following steps.

1- Obtaining and analyzing historical projects data and records

2- Line items' identification that consume contingency funds

3- Setting and implementing necessary measures accordingly at the preconstruction stage to minimize the likelihood of occurrence of these line items

4- Based on this information, estimate contingency funds

This framework enables the owner to determine contingency funds confidently and minimize contingency, so to avoid tie up of unnecessary value of funds while it can be used in other activities or projects.

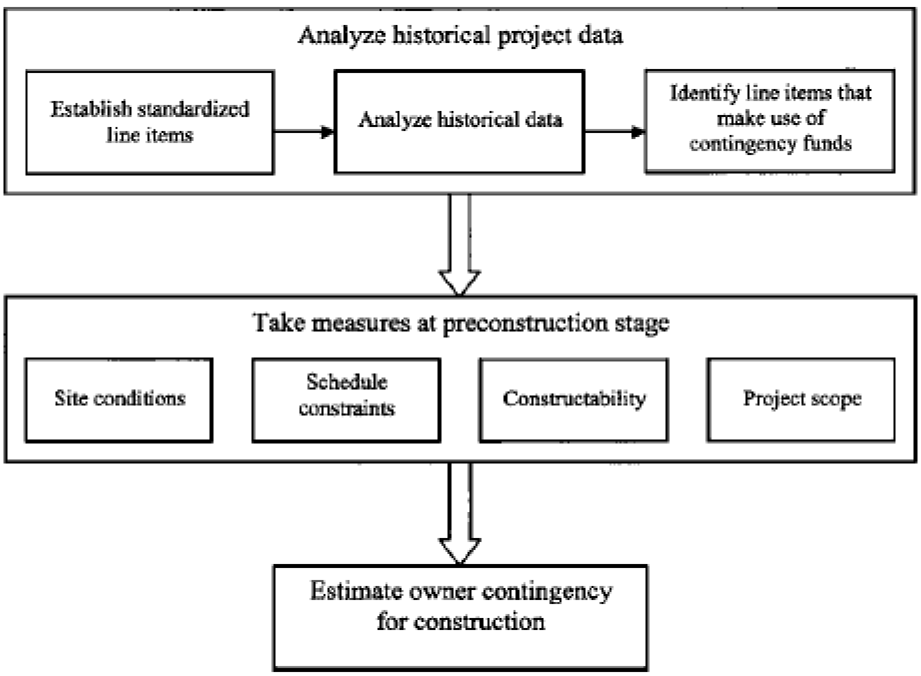

Figure 6 Budgeting Owner Contingency Methodology (Gunhan and Arditi, 2007)

Gunahn and Arditi (2007) proposed the following items to be studied thoroughly by owners for the line items during the preconstruction phase because they impact the budget of the project directly:

1- Evaluation of existing site conditions must occur. Each site is unique and has specific characteristics that influence the way which the works will be done and managed.

Accordingly, if these specifics are not accounted for in the project estimate during the preconstruction phase and design phase, this will surely impact the project cost.

2- The project schedule constraints should be early identified and accounted for the project pricing and estimation. Schedule should reflect expected scenario as much as possible, an accurate start date and all details as available. Late site handover or limited access to works have impact on the project budget.

3- Experienced engineer has to conduct a comprehensive detailed review of design drawings, specifications and construction documents is essential prior to the tender issuance. The quality of the tender documents reflects the constructability of a project. The ease in which a project can be built and the quality of the constructions documents determines the constructability level of the project. Arditi et al. (as cited by Gunahn and Arditi, 2007) concluded in a study that ambiguous, faulty or defective construction documents, incomplete design and conflicts between construction documents are major factors that affect the construability of the project and in turn affect cost and time contingency.

4- Poorly defined project scope will lead to owner changes due to missed scope and additional items needed to complete the project. Changes initiated by the owner will require extra work and efforts by the contractor and in turn additional costs. Scope definition and control is the second highest causes of the cost overruns as stated in the Construction Industry Institute (1986).

If these factors are managed effectively during the preconstruction stage and the pre-tender issuance, most probably this will reduce the contingency usage for the line items identified and will prevent the need for a large contingency, which ties up funds that can be used in other projects. The limitation of this technique is its significant dependency on the previous project data availability, accuracy and relevance. Data availability could be challenging in some markets especially if the owner was not involved in a good amount of previous projects. Also, despite reference is made to historical project data to determine contingencies of line items, the decision is still made manually based on human witness of previous records and their analysis, which can be time consuming.

Hammad et al. (2016) proposed a solution of estimating and managing cost contingency throughout the project using a probabilistic method. Since this research is about contingency estimation, only the estimation section will be covered from Hammad et al. research. A probability distribution function using Monte Carlo Simulation (MCS) is assigned to each project activity and selecting an appropriate confidence interval followed by summation of all the resultant contingencies of the activities on the critical path, which yields the overall project cost contingency. The use of MCS allows activities with high costs and uncertainties receive higher contingency with respect to others. Hammad et al. criticized the traditional method of determining the contingency subjectively as a percentage of the total project cost based on previous experience and intuition and did a case study to demonstrate the benefit of their proposed method over the traditional method. The results showed the probabilistic method yielded a more accurate contingency. The proposed method calculated a contingency of 4.2% and the traditional method yielded 7.2%, while the actual contingency used in the project was 3.2%. Accordingly, they highlighted that the overestimation of contingency could be the cause for losing a tender. This research focused on the known unknowns, or predictable factors and was specifically designed for the contractors use. In addition, they claimed that among the main benefits of this framework is simplicity, and does not require the project manager to have the knowledge of the advanced tools and methods. In a construction project, complex and time consuming models will not be used by industry professionals; accordingly, they have little value as stated by Hammad et al. (2016).

Polat and Bingol (2013) did a research to compare the performance of fuzzy logic and multiple regression analysis (MRA) in estimating cost contingency. This research provided contractors with a tool to estimate their contingency amounts to be included in their bids for international construction projects. Fuzzy logic is qualitative methodology rather than quantitative capable to represent uncertain, vague and incomplete information as it leans on rational and systematic critical thinking (Polat and Bingol, 2013). Construction projects are full of uncertainties due to several predictable and unpredictable factors. On the other hand, MRA is quantitative method with uncertain numerical data availability. The methodology used in the research was as follows.

1- Identifying factors affecting cost contingency from literature and categorizing them by risk groups as shown in Figure (7).
2- Developing a framework of the estimation model is shown in Figure (7).
The cost contingency value (CC) is modeled as shown in Equation (7) as a function of the major risk groups level in terms of risk magnitude (MR_i). MR_i is the average of the risk factors

magnitudes (RM_{ji}) in group i. The relation between both is expressed in Equation (8) where n is the number of the risk factors in major risk group i.

$$CC = f(MR_A,\ MR_B,\ MR_C,\ MR_D,\ MR_E,\ MR_F) \qquad \textbf{Eq. 7}$$

$$MR_i = \frac{1}{n}\sum_{j=1}^{n} RM_{ji} \qquad \textbf{Eq. 8}$$

Where MR is the average risk magnitude for a group of risk factors

RM is the risk magnitude of a single factor

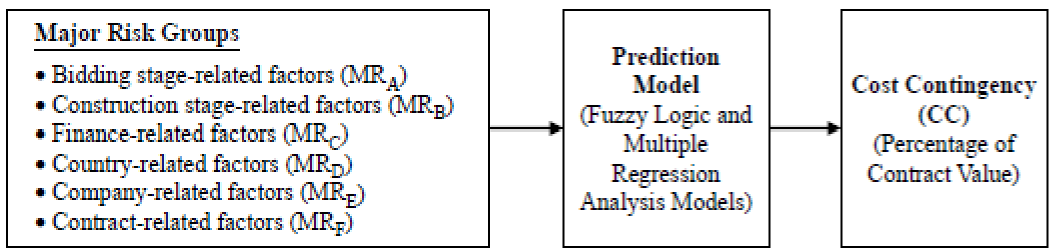

Figure 7 General Proposed Framework for Cost Contingency Estimation (Polat and Bingol, 2013)

3- Preparing a questionnaire to be distributed to experienced construction professionals to obtain previous projects data. The questionnaire consisted of two parts. The first part aimed to rate the magnitude of the factors (RM_{ji}) linguistically on a scale consisting of low, medium and high. The second part aimed to let the questionnaire's respondents state the actual contingency percentage of the contract value (CC).

4- Development of fuzzy logic model and three stepwise MRA model

5- Setting performance evaluation criteria to evaluate the performance of the models. The Root Mean Square Error (RMSE), Mean absolute percentage error (MAPE), coefficient of determination (R^2), and coefficient of correlation (R) have been chosen in this research. After calculation of these criteria, the model with the highest R and R^2 and lowest RMSE and MAPE is the best.

6- Comparison of the results obtained from both models.

Starting by the fuzzy logic model, six input variables have been defined along with six membership functions in addition to one output variable with one membership function. The input variables are the major risk groups (MR_i) while the output variable is the cost contingency (CC). The fuzzy membership functions have been determined using the assistance of three experienced construction professionals. The agreed membership functions for the input variables and the output variable are shown in Figures (8) and (9). Input variables have been assigned on a numerical scale between 1 and 3 while the cost contingency has been assigned on a numerical scale of 5% to 10% as shown on the x-axis. The y-axis however denotes the degree of membership. Low, medium and high linguistic terms have been used for representing the input and output variables. The authors stated that the triangular distribution was found to be appropriate for the input variables while trapezoidal distribution was appropriate for the output variable.

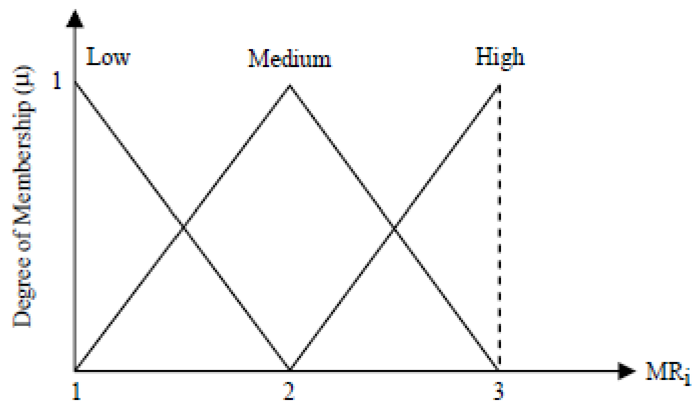

Figure 8 Membership Function for Input Variables (Polat and Bingol, 2013)

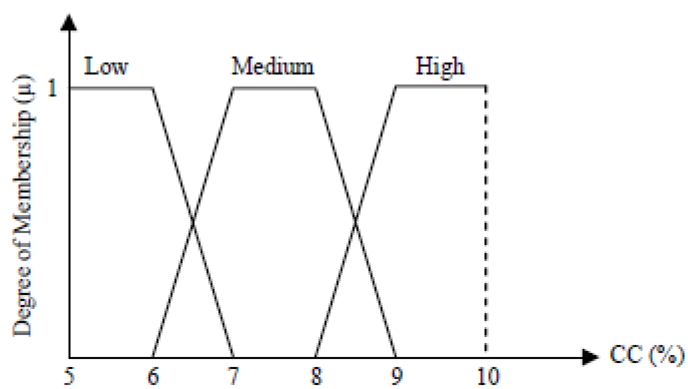

Figure 9 Membership function for the Output variables (Polat and Bingol, 2013)

87 if-then rules have been specified based on expert judgement where the conjunctive system of rules was chosen for rules aggregation. For the fuzzy inference system, Mamdani's system was chosen in this research as it has been widely accepted based on literature. The fuzzy sets in Mamdani are used as a rule consequent. The fuzzy sets must have defined rules input by the user.

The model was subjected to testing using the 36 projects data that have been obtained via the questionnaire.

Concerning the MRAM, a general multiple linear regression analysis model was aimed to be developed as per Equation (9) where CC is the cost contingency, b_0 is constant, b_{1-n} are regression coefficients and MR_{A-F} are the major group risk factors.

$$CC = b_0 + b_1 xMR_A + b_2 xMR_B + b_3 xMR_C + b_4 xMR_D + b_5 xMR_E + b_6 xMR_F \quad \textbf{\textit{Eq. 9}}$$

By doing a correlation analysis on the input and outputs variables, all inputs were found to be highly correlated to the inputs. Hence, the statistical packages SPSS was used to do a stepwise regression analysis to enable the selection of the highest correlated inputs and the best regression model. The stepwise regression technique has been used to build the MRAM models and obtain their significance levels based on the data of the 36 construction projects obtained through the questionnaire. All three MRAMs have been found to be significant as the values are less than 0.05 as shown in Table (6). Generally, the overall model can be significant, but some regression parameters may not be. Therefore, the significance level of each regression parameter is checked and shown in Table (7). All parameters values are less than 0.5, so they are significant.

Table 6 Three MRAM models and their significance levels (Polat and Bingol, 2013)

Code	Model	Significance of the model
$MRAM_1$	$CC = 4.388 + 1.515{*}MR_D$	0.000
$MRAM_2$	$CC = 3.689 + 0.985{*}MR_B + 0.899{*}MR_D$	0.000
$MRAM_3$	$CC = 3.249 + 0.827{*}MR_B + 0.488{*}MR_C + 0.798{*}MR_D$	0.000

Table 7 Regression Parameters and their significance levels (Polat and Bingol, 2013)

Code	Regression parameters	Significance
$MRAM_1$	Constant	0.000
	MR_D	0.000
$MRAM_2$	Constant	0.000
	MR_B	0.001
	MR_D	0.001
$MRAM_3$	Constant	0.000
	MR_B	0.004
	MR_C	0.017
	MR_D	0.002

Having developed both models of cost contingency estimation, performance comparison has been made between both using the pre-determined criteria, and the fuzzy logic model was found to be better in performance than the three MRAM. The results yield a CC percentage that varied in the range of 5.4 to 9.7 percent, which is matching with actual project results reported by the respondents in the questionnaire. Among the main reasons of the superiority of the fuzzy logic is its ability to deal with both linear and non-linear relationships between the input and outputs variables. Meanwhile, MRA can only estimate the relationship between output and input variables if it is only linear. In addition, for this specific parameter and industry respectively, cost contingency and construction industry, fuzzy logic seems to be more suitable because they are characterized with vagueness, incomplete and uncertain information in addition to having both linear and non-linear relationships. This study aimed to assist contractors bidding for international construction projects and provide them a tool to predict their contingency that is part of their bid amounts.

Idrus et al (2011) also developed a project cost contingency estimation model for infrastructure and building projects in Malaysia based on risk analysis and fuzzy expert system. Based on risk analysis and fuzzy expert system, the model accommodates the subjective judgement of the contractor. The risk analysis aims to identify and assess the risk level of each risk factor. The fuzzy expert system serves as the method that assess the risk and translates its effect on the determination of output variable, which is the cost contingency value. The model development passed through five stages, which are [1] conceptual model development, [2] risk factors identification and determination for the model, [3] fuzzy expert system development, [4] testing and tuning, and finally [5] validation. Fuzzy expert system is designed in this research to be applied on the level of risk, not the risk group. The inputs of the fuzzy model were the risk severity (RS) and the risk likelihood (RL) while the output is the risk magnitude (RM), which is the contingency value percentage. The results indicated that the contingency percentages ranged from 5 to 10%.

Paek et al. (1993) also developed a fuzzy set approach capable of identifying the possible risks and calculating the associated value of contingency required. Mainly, it's risk-pricing method for analyzing and pricing the project risk. Risk elements are identified at first followed by the quantification and monetary valuation process using fuzzy set approach, which is then incorporated into the bidding price decision process. Accordingly, this approach acts as a decision process for the contractors during the bidding process. The authors highlighted that this process could be iterative to consider the effect of applying risk management strategies to reduce the contingency value. The main disadvantage of this technique is the underlying difficulty in quantification and valuation of the risk given some risks can hardly be translated into a monetary value.

Another research developed by Mak and Piken (2000) is determining project cost contingency using risk analysis (ERA). Basically, this research is based on identifying project uncertainties and developing an estimate of their financial implications, so this results in a contingency for the overall project broken down by the risk events. The events are identified by the project manager and the likely costs should they occur are calculated. The risks are either defined as fixed or variable. A fixed risk event is the event that either fully happen or does not happen while a variable risk event is the event that may or may not happen but the extent to which it will happen is uncertain. An average risk allowance and a maximum risk allowance are calculated for each risk event having 50% chance of being exceeded and 10% chance of being exceeded, respectively. The relationship between both is demonstrated in Table (8) where the method of calculation of each is stated.

Table 8 Relationship between Risk Allowance and Risk Category (Mak and Piken, 2000)

Type of risk (1)	Average risk allowance (2)	Maximum risk allowance (3)
Fixed risk	Probability × maximum cost	Maximum cost
Variable risk	Estimated separately	Estimated separately
Assumption	50% chance of being exceeded	10% chance of being exceeded

A typical ERA worksheet is shown in Figure (10) where all the previous steps are applied. The maximum likely addition is the value to be paid should all the listed events occurs with maximum financial consequences. The total consumption of this figure would imply a catastrophic set of circumstances. It was recommended by the authors that this ERA sheet to be carried out several times during the pre-tender period of any project to update risks accordingly. Usually, as the project progresses forward, some events may have more clarity and their impact may soften or in some cases, the risk event can be no longer a risk.

ERA Calculation

Project: Construction of the Central Library — Date: 2 March 1995
Client: Urban Council — ERA Run: 1

(1) Risk	(2) Type	(3) Probability (Fixed Risks Only)	(4) Average Risk Allowance $	(5) Max. Risk Allowance $	(6) Spread (5) - (4) $ M	(7) Spread squared $ M
Design Development	V		8,400,000	12,600,000	4.2	17.64
Additional Space	F	.70	11,760,000	16,800,000	5.04	25.4016
Site Conditions	V		525,000	1,000,000	.475	0.2256
Market Conditions	V		4,000,000	8,500,000	4.5	20.25
A/C Cooling Source	V		250,000	1,250,000	1	1
Access Road	F	.50	250,000	500,000	.25	0.0625
Additional Client Requirements	V		1,680,000	4,200,000	2.52	6.3504
Contract Variations	V		8,400,000	12,600,000	4.2	17.64
Project Co-ordination	V		500,000	1,500,000	1	1
Contract Period	F	.60	1,000,000	1,750,000	.75	0.5625
			36,765,000			90.1326
					Sq Root	9.494

Maximum Likely Addition = $9,494,000

Base Estimate = $168,000,000
Average Risk Estimate = Base Estimate + *Total* Average Risk Allowance
= $204,765,000 (21.88% on base)

Maximum Likely Estimate = Base Estimate + Average Risk Allowance + Maximum Likely Addition
= $214,259,000 (27.54% on base)

Figure 10 ERA worksheet for a Construction project at the conceptual design stage (Mak and Picken, 2000)

The main advantages of ERA are reducing the uncertainty associated with the project, its ability to maintain the traditional method of a project cost estimate presentation as a base estimate in addition to a contingency, aids in financial control and enables more clarity for the uncertainty costs, and provides itemized contingency values for each of the risks. This model reduces the excessive contingency percentage added for the project and will result in much better allocation of resources avoid the tie up of additional funds with no need. A comparison has been made between non-ERA project and ERA projects through obtaining a summary of completed projects with full data concerning costs. 45 projects used ERA while 287 were done traditionally and classified as non-ERA. The results shown in Table (9) revealed that the ERA projects performed better in terms of cost performance. A variable, namely DEVI has been included in the comparison, which is a ratio between the final account variations value and the contingency amount. If the DEVI is 1, then all the contingency has been consumed by the variations or uncertainties. If the DEVI is higher than 1, then a surplus in the contingency fund exists and vice versa. Accordingly, it is concluded that ERA had better DEVI values which means better estimates and less misallocation of resources. The main limitation of this method is the method of estimating the financial implication of the risk event. For some risk events, valuation of their financial implications may be impossible. Therefore, this affects the reliability of the results and the confidence level as well.

Table 9 Comparison between ERA and non-ERA projects (Mak and Picken, 2000)

Statistic (1)	Non-ERA (2)	ERA (3)
Number of projects	287	45
Contract sum (minimum)	0.31M	0.99M
Contract sum (maximum)	1,331.01M	208.48M
Contingency (minimum)	0.15M	0.08M
Contingency (maximum)	110.00M	38.00M
Contingency/contract sum (minimum)	0.67%	4.02%
Contingency/contract sum (maximum)	137.40%	18.23%
Final account variation (minimum)	6.00K	41K
Final account variation (maximum)	85.98M	27.39M
DEVI (minimum)	0.10	0.30
DEVI (maximum)	45.00	6.64

Touran (2003) presented a model to calculate a contingency on the project level, which is based on a confidence level specified by the owner. He developed a probabilistic model that considers the random nature of change orders in addition to their effect on the schedule and cost of the project. The model incorporates uncertainties in cost and schedule. For the change orders, a Poisson arrival pattern is assumed by the model. Resultant additional cost due to schedule delays is considered as well in addition to the effect of correlation between costs. This model is developed for owners, who can use it at early planning stages of the project while preparing their budget. This method considers only contingency allocated for change orders and does not account for other project specifics in the research scope.

After investigation to studies found in the literature concerning cost contingency prediction, there has been limited research to predict the owner cost contingency. Most studies focus on the estimating the contractor's cost contingency that is incorporated in his bid price. Predicting owner contingency would enable setting a reliable budget contingency, which is not excessive to the extent that would lead to tie up funds that can be used in another projects and is not underestimated that may impose a risk of going over budget. Also, despite the cost and schedule of construction projects are interrelated and affect each other somehow, cost contingency and time contingency models are usually separated and independently applied

(Bakhshi & Touran, 2014). Furthermore, few studies were found for cost contingency prediction in the Egyptian construction industry.

2.5 Fuzzy logic

Fuzzy logic concept was introduced by Zadeh (1965). A classical set theory is "a set defined as a collection of objects having a general property" (Nguyen, 1985). Therefore, classical set theory deal with defined crisp values where there is no ambiguity i.e. not fuzzy. Figure (11) illustrates the difference between the crisp (classical) and the fuzzy concepts.

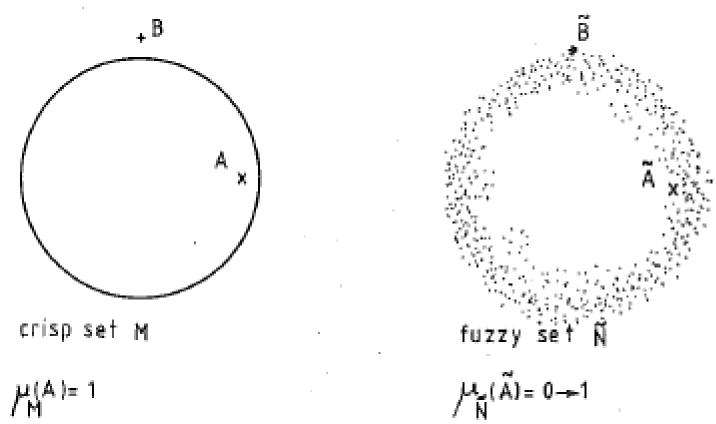

Figure 11 Difference between Crisp Set and Fuzzy Set (Nguyen, 1985)

When considering a fuzzy set theory, it doesn't deal with crisp values, but deals with variables having ambiguous answers characterized by uncertainty. If a person is 20 years old, no crisp answer is available whether the person is still young or mature. An answer for this question, which all can agree on, is hardly obtained. Fortunately, the fuzzy set theory can provide a satisfactory solution to the previous question by establishing a membership function for age defined as young, mature and/or old. Figure (12) serves as an example of a membership for a person's age. The y-axis is the degree of membership, while the x-axis is the age. From the membership function, it is concluded that having an age of 20 years has 100% degree of membership as young and 30% as mature, but 0% as old, so it is not crisp and can't be confirmed whether young or mature.

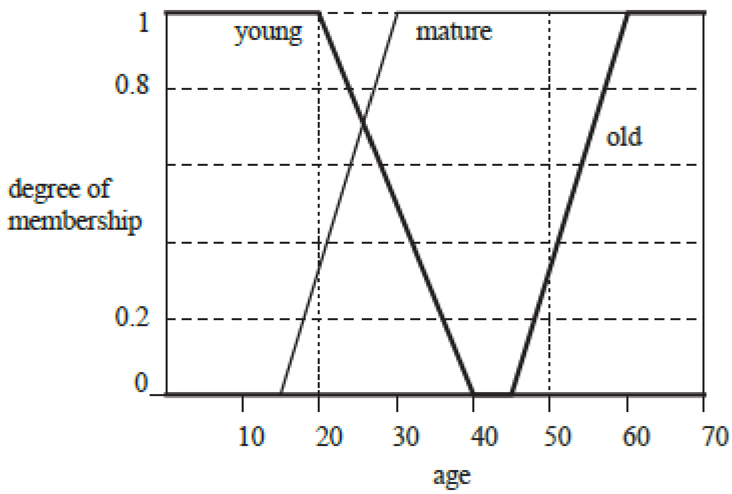

Figure 12 Age membership (Rojas, 1996)

Accordingly, uncertain and imprecise knowledge can be predicted using fuzzy sets (Gunduz et al., 2014). Ambiguous values and factors can be fully measured and determined using the fuzzy set theory (Gunduz et al., 2014). Introducing a membership function is the main difference between the fuzzy sets and the classical (crisp) sets (Rojas, 1996). In Mamdani's approach, the fuzzy set must have defined rules input by the user in the form of the following Equation (10)

$$R_i\text{: If } (x_1 \text{ is } A_{i1}) \text{ and} \ldots \text{and } (x_r \text{ is } A_{ir}) \text{ then } (y \text{ is } C_i) \quad \text{for } i = 1, 2, \ldots, L$$

Eq. 10 (Gunduz et al., 2014)

Where X_j (j = 1, 2, 3, 4…r) and L = number of rules are the variables to be input by the user. Y is the output variable derived by the fuzzy set, while A and C are factors characterized by membership function A_{ij} (X_j) and C_i (y).

The procedures of the fuzzy system design are simple in concept and are as follows (Gunduz et al., 2013)

1- The problem to be defined and well understood
2- Determine the inputs and the outputs, and define the membership functions
3- Develop the IF-Then rules, which are the fuzzy rules

4- Enter the fuzzy rules weights if applicable

5- Select the appropriate methods for fuzzification and defuzzification

6- Run the system and obtain the output variable

2.6 Previous Studies on using Fuzzy Logic in the Construction Industry

Fuzzy set theory has been used frequently in previous studies related to the construction industry (Gunduz et al., 2013). Although it was introduced in 1965 by Zadeh, there are emerging applications of using fuzzy logic in the construction industry. As will be illustrated, fuzzy logic is a very useful method when integrating it with construction industry practices due to the fact that the construction industry contains many ambiguous factors and uncertainties that have to be predicted or estimated. Table (10) provides an overview about some of the fuzzy logic applications in the construction industry. These applications were mainly developed by researchers where they succeeded to use the fuzzy logic theory in the construction industry to be able to estimate and predict unknowns such as construction costs, materials' prices, contingency, delays, etc. The following research depends basically on the same tool, which is fuzzy logic to be able to estimate unknown factors in the construction field; however, the inputs, rules and outputs are different to suit each case depending on the subject of research.

Table 10 Fuzzy logic applications in the Construction Industry

Author (Year)	Summary of the study
Nguyen (1985)	As the tender evaluation is not an easy task, especially when it is not dependent solely on the cost, Nguyen thought to develop a fuzzy set model in order to evaluate tenders. The developed approach involves non-interactive multiple criteria and may involve many decision making parties.
Oliveros and Fayek (2005)	A model was developed capable of integrating the daily site progress and occurring delays along with the update of the schedule. The outcome of the model assists the users to analyze delay effects on the completion date of the project. It also provides an approach for handling the schedule update uncertainty and the delay analysis for the activities. Finally, they introduced a technique that involves the use fuzzy logic, which incorporates the as-built information in the schedule, allows the assessment of the impacts of delays on the project schedule, and reflects the delays' consequences by updating the

	schedule so that corrective actions could be taken. The fuzzy logic in the model acts as the prediction tool for the delay durations. Moreover, an approach was developed for updating of the schedule and analyzing the delay of the activities by using the fuzzy logic tool and a set of procedures that should be followed. This method is beneficial for project control and whenever the construction is on-going.
Li et al. (2006)	Li et al developed a technique to forecast the project status by predicting both the anticipated cost overrun and the schedule delay using fuzzy logic theory. Similar to the aforementioned research conducted by Oliveros et al, this method is developed to be used while the construction of the project is ongoing; therefore, it serves as a useful tool for project control. Also, this forecasting methods allows the quantification of the performance indicators' impact on the project's profitability.
Shaheen et al. (2007)	Outlined the Monte Carlo simulation's shortcomings in cost range estimating. The study presents a fuzzy set approach to develop a cost range estimate and compare it with that of the Monte Carlo outcome. It is concluded that the fuzzy set theory is more relevant to the construction industry as it closely simulates the way in which the professionals express themselves.
Li et al. (2007)	Many traditional methods exist to analyze the construction contractors prequalification. However, Li et al. (2007) claimed that the criteria for the evaluation is vague and subjective; therefore, they are considered to be inadequate. They proposed a fuzzy framework-based fuzzy number theory to act as a tool for the contractors' evaluations. The proposed model includes decision criteria analysis, weights assessment in addition to development of a decision model.
Poveda and Fayek (2009)	Developed a fuzzy logic model capable of both prediction and evaluation of construction trades foremen's performance. The factors affecting the performance of the foremen are identified and discussed. The model is capable as well to provide benchmarks of the foreman performance, so that companies can develop plans in order to increase their foremen's experience and maintain development.

Elbeltagi et al. (2011)	Due to scarcity of formwork experts in the market and the costly outsourcing alternative, the authors developed a decision support tool to guide small/medium contractors in the selection of the appropriate horizontal formwork system using fuzzy logic. The project specific factors affecting the selection process are identified through literature and questionnaire. A knowledge based has been created accordingly based on experts' opinion, which served as the fuzzy rules. The output variable of the model is the recommended formwork system for the project-on-hand.
Elbeltagi et al. (2012)	Developed a decision support tool to guide contractors in the selection of the suitable vertical formwork system using fuzzy logic. Common vertical formwork systems in Egypt has been identified via interviews with market experts. Through literature and questionnaire, the factors that affect the formwork selection has been identified where they served as the input variables. The output variable is the most appropriate formwork system given the project parameters reflected in the input variables. The fuzzy rules were developed in a sense to determine the suitability degree of each formwork for the given project condition.
Marzouk and Amin (2013)	Estimating material prices is usually inaccurate and there is no method to guarantee accuracy. This led to the initiative to develop a method to estimate the change in prices that occur frequently. Hence, they developed a fuzzy system able to identify the most sensitive construction materials to change in prices. Also, they developed a neural networks technique in order to estimate the change in prices and amend the contract price accordingly. The outcome of the research is beneficial to both contractors and owners as they assist in estimating the expected total costs prior and during the bid stage.
Gunduz et al. (2014)	Developed a decision support tool based on fuzzy logic to be used by contractors to estimate the delay probability for construction projects taking place in Turkey. This tool is useful to be used during the bidding stage, so that contractors can plan for measures to reduce the probability of delay. Gunduz et al quantified the delay causes in the Turkish industry using the RII method. The RII value is the weight that is input in the fuzzy assessment model. The if-then rules were then set. Following that, the aggregation and defuzzification methods

	were decided to establish the model and become able to estimate the delay probability of the project.
(Salah and Moselhi, 2015)	Developed a model based on fuzzy-set theory to estimate, allocate, deplete and manage the contingency funds over the construction project life cycle on the item, package and project level. The fuzzy-set theory incorporates the experts opinions and assessments of the risks associated with the project. Both the fuzzy set theory and the expected value are used in order to perform contingency allocation and be able to break down from project level up to the item level. The model enables the users to forecast the contingency for coming period; hence, allows taking necessary corrective actions, if required.
Pawan and Lorterapong (2016)	Presented a fuzzy-based framework that enables the assessment of time contingency for project activities that are exposed to multiple risks specific to the project. In this research, fuzzy theory has been used to model the vagueness and uncertainty associated with the possibility of risk occurrence and impact on the activities durations. The developed approach allowed integration of risk management into project scheduling while using fuzzy theory to model the imprecision of the risks.

Thus, Fuzzy logic demonstrated its wide popularity among researchers and success in construction applications, mainly being used as a prediction tool and decision support system. Given this research shall be about prediction of time and cost contingency, Fuzzy Logic is the proposed method that shall be used due to its proven capability in the literature and usage in many similar applications. In addition to its popularity and proven success in construction application, the main advantages of the fuzzy logic are [1] its ability to deal with both a linear and non-linear relationship between the inputs and the outputs, [2] its ability to deal with ill-defined and complex problems associated with vague, uncertain and inherent information, which is an aspect usually associated with construction projects, [3] it does not require historical data records, [4] the simplicity of using the resultant model and easy user interface on MS Excel, which can allow project managers to use it easily as end users, and finally, [5] its use of linguistic variables to represent and model expert judgements, which are mainly non-crisp values and transforms it to crisp values and provides the experts the flexibility to express their knowledge based on their gut feeling and experience (Polat and Bingol, 2013; Salah and Moselhi; 2015).

2.7 Chapter Summary

In line with rapid and dynamic environment of the construction industry, there exists a need to develop tools and techniques to cope with such environment and enables better construction projects planning and control. The main challenge usually lies in delivering projects within the specified time frame, the stipulated budget and the desired quality. In literature, statistics show that delays and cost overruns are quite an integral part of the construction industry worldwide. Due to their unfavorable consequences, delays and cost overruns are dilemmas to project parties, mainly the owner and the contractor. Since the construction industry is characterized by uncertainty and vagueness in addition its vulnerability to internal and external factors, time and cost overruns are inevitable. Accordingly, researchers did several studies to address both issues by developing prediction models, so that an appropriate contingency is set for the project. In theory, not only does setting an appropriate contingency for the project should eliminate delays and cost overruns, but also should prevent tie up of unneeded excessive funds to the project that can used by the owner in other projects or activities.

Generally, literature shows that cost contingency has been studied extensively more than time contingency had. However, the majority of the previous studies are from the contractors' point of view to allow them incorporate a cost contingency in their bid prices while few are found from the owner's point of view that would enable them set their budget contingency at the project pre-tender stage. By reviewing the literature of estimating time contingency, limited research has been found. Available studies are also made though specifically for contractors to enable them predict the contingency and assign it to their baseline construction schedules, but very limited research is made to predict the owner time contingency that enables setting a high level time contingency in the project master schedule. Despite the cost and schedule of construction projects are interrelated, cost and time contingency models are usually separated and independently applied (Bakhshi & Touran, 2014).

Thus, this research is an attempt to propose a reliable method that enables the prediction of both time and cost contingency from the owner's point of view. A fuzzy logic model will be developed to incorporate expert judgements. Fuzzy logic is selected due to suitability for the research subject and its proven success and popularity in use of similar application as discussed in the literature. The model results will act as a tool for project owners to estimate time and cost contingency at the pre-tender stage and will enable them understand the effect of setting the project parameters on the contingency values. Accordingly, this should reduce delays and avoid exceeding budget in addition to prevent tie up of excessive funds that can be used in other projects.

3. Research Methodology

This chapter explains the methodology followed in this research and mainly addresses the steps followed throughout the execution of this study. The research methodology is composed of five main sections, which are the following:

1- Conducting literature review to identify the factors affecting time and cost contingency
2- Identifying the most relevant and important factors that affect owner contingency in Egypt using Delphi technique
3- Development of the general framework for the proposed model to estimate contingency based on literature review
4- Dissemination of a questionnaire to construction market professionals to obtain actual data of construction projects to be used for initial testing, tuning and validation of the prediction model
5- Development of fuzzy logic model using MS Excel
6- Model validation using obtained actual projects data

3.1 Factors affecting time and cost contingency

The factors affecting time and cost contingency have been determined from literature review. Several factors were identified by many researchers. Considering this research objective, the factors that are relevant only have been selected. As this study aims to predict contingency for the owners at the pre-tender stage of the project, some factors identified in the literature were not relevant. Some were found related to affect contingency of contractors, not owners. Other factors identified cannot be determined during the pre-tender stage. Also, many factors were found to be the same in different studies, but with different names and hence, some factors are removed to avoid overlap. Table 11 shows a list of 59 identified factors and the status of each factor whether it is excluded or included within this research in addition to the reason. The factors are identified from literature (Gunhan and Arditi, 2007; Polat and Bingol, 2013; Hosny et al., 2015; Marzouk and El-Rasas, 2014; Idrus et al., 2011; Jr. et al., 2010; Mohamed et al., 2009; Yahia et al., 2011; Marzouk et al., 2008; Abd El-Razek et al.,2008; Shibani, 2015; El-Kholy, 2015; Kholif et al., 2013; El-Touny et al., 2014; Aziz et al., 2013). Focus has been made towards similar studies conducted in Egypt in order to obtain the most relevant factors. The possible reasons of any factor elimination are being irrelevant, or having a different name of another factor, but having the same meaning. Accordingly, 30 factors are shortlisted while 29 are excluded. The 30 shortlisted factors are taken to the next stage, which is the identification of the most significant factors via the questionnaire. Classification have been made where all factors fall under one of the following categories; economic conditions, environmental conditions, management conditions, technical conditions, or finally, project conditions. The classification allows easier interpretation of the factors.

Table 11 Factors Affecting Time and Cost Contingency based on Literature Review

#	Category	Factors Affecting Time and Cost Contingency	Status (Included/ Excluded)	Source	Reason for Inclusion/Exclusion
1	Economic Conditions	Market conditions stability	Included	Polat and Bingol (2013); Hosny et al (2015); Marzouk and El-Rasas (2014)	Relevant
2		Extent of market investigation	Excluded	Polat and Bingol (2013)	Contractor Related
3		Market inflation	Excluded	Polat and Bingol (2013); Hosny et al. (2015); Kholif et al. (2013); El-Touny et al. (2014); Shibani (2015); El-Kholy (2015)	Overlap with factor 1
4		Owner financial capability and timing of payments	Included	Polat and Bingol (2013); Kholif et al. (2013); El-Touny et al. (2014); Shibani (2015); El-Kholy (2015)	Relevant
5		Fluctuations in exchange rates	Excluded	Polat and Bingol (2013); Hosny et al. (2015); El-Kholy (2015)	Overlap with factor 1
6		Frequent changes in regulations and law	Excluded	Polat and Bingol (2013); Shibani (2015)	Overlap with factor 1
7		Financing capability by contractor during construction	Excluded	Abd El-Razek et al. (2008); Kholif et al. (2013); El-Touny et al. (2014); Shibani (2015); El-Kholy (2015)	Contractor Related
8	Environmental Conditions	Labor strike	Excluded	Mohamed et al. (2009)	Contractor Related
9		Weather conditions	Included	Polat and Bingol (2013); Kholif et al. (2013); El-Touny et al. (2014); Mohamed et al.	Relevant

10		Resources availability	Excluded	Hosny et al. (2015); Kholif et al. (2013); Mohamed et al. (2009)	Contractor Related
11	**Country Conditions**	Political conditions stability	Included	Marzouk and El-Rasas (2014); Kholif et al. (2013)	Relevant
12		Material availability	Excluded	Mohamed et al. (2009); Kholif et al. (2013)	Contractor Related
13		Construction permits issuance	Included	Marzouk and El-Rasas (2014); Kholif et al. (2013)	Relevant
14		Availability of qualified subcontractors and suppliers	Excluded	Polat and Bingol (2013)	Contractor Related
15		Equipment availability	Excluded	Mohamed et al. (2009)	Contractor Related
16	**Management conditions**	Scope Definition and Clarity	Included	Gunhan and Arditi (2007); Polat and Bingol (2013); Yahia et al (2011); Hosny et al (2015)	Relevant
17		Contract clarity	Included	Polat and Bingol (2013); Jr. et al (2010); Hosny et al (2005); Shibani (2015)	Relevant
18		Owner/Project Manager management capability and ability to take timely decisions	Included	Polat and Bingol (2013); Idrus et al (2011); Yahia et al (2011); Mohamed et al (2009); Marzouk and El-Rasas (2014); Hosny et al. (2015); Shibani (2015)	Relevant
19		Schedule clarity and accuracy	Included	Gunhan and Arditi (2007); Polat and Bingol (2013); Kholif et al. (2013); Shibani (2015)	Relevant
20		Amount of change orders and owner behavior toward change	Included	Hosny et al. (2015); Yahia et al. (2011); Marzouk and El-Rasas (2014); Marzouk et al (2008); Kholif et al. (2013); Shibani (2015)	Relevant
21		Contract Type	Included	El-Kholy (2015); Jr. et al (2010); Yahia et al. (2011)	Relevant
22		Delivery method/procurement route	Included	Aziz (2013)	

23		Budget allocation and estimation accuracy	Included	Polat and Bingol (2013)	Relevant
24		Contractor poor planning	Excluded	Polat and Bingol (2013); Yahia et al. (2011); Kholif et al. (2013)	Contractor Related
25		Unclear contract conditions	Excluded	Polat and Bingol (2013)	Overlap with factor 17
26		Absence of PM firm	Included	Hosny et al. (2015)	Relevant
27		Late project changes	Excluded	Yahia et al. (2011)	Overlap with factor 20
28		Contractor inaccurate control and follow up	Excluded	Yahia et al. (2011); Kholif et al. (2013); Shibani (2015)	Contractor Related
29		Inadequate of dispute settlement procedures	Excluded	Yahia et al. (2011); El-Touny et al. (2014)	Overlap with factor 17
30		Owner/Engineer Amount of Interference	Included	Mohamed et al. (2009); Shibani (2015)	Relevant
31		Difficulty of coordination between various parties	Excluded	Abd El-Razek et al. (2008); Shibani (2015)	Overlap with factor 18
32		Slowness of the owner decision making process	Excluded	Abd El-Razek et al. (2008); Kholif et al. (2013); Shibani (2015)	Overlap with factor 18
33		Control of subcontractors by main contractor in the execution of works	Excluded	Abd El-Razek et al. (2008); Kholif et al. (2013)	Contractor Related
34		Type of project bidding and award (negotiation, lowest bidder)	Included	Marzouk and El-Rases (2014); Kholif et al. (2013); El-Kholy (2015)	Relevant
35		Poor site management and supervision	Excluded	Marzouk and El-Rasas (2014); Kholif et al. (2013); Shibani (2015)	Contractor Related
36		Delay in materials delivery	Excluded	Marzouk and El-Rasas (2014); Shibani (2015)	Contractor Related
37		Time allowed for project planning at pre-tender stage	Included	El-Kholy (2015)	Relevant
38	**Project Conditions**	Project complexity	Included	Polat and Bingol (2013); Jr. et al (2010); Mohamed et al (2009); Shibani (2015)	Relevant
39		Project location	Included	Mohamed et al (2009); Jr. et al (2010); Kholif et al. (2013); El-Touny et al. (2014)	Relevant
40		Project type	Included	Hosny et al. (2015)	Relevant

41		Owner safety culture	Included	Polat and Bingol (2013); Idrus et al (2011)	Relevant
42		Site obstacles	Included	Hosny et al. (2015)	Relevant
43		Unexpected onerous requirements by client's supervisors	Included	Yahia et al. (2011)	Relevant
44		Soil conditions	Included	Hosny et al. (2015); Kholif et al. (2013); El-Touny et al. (2014)	Relevant
45		Investigation of existing site conditions	Included	Gunhan and Arditi (2007); Polat and Bingol (2013); Idrus et al. (2011); Shibani (2015)	Relevant
46		Accidents during construction	Excluded	Abd El-Razek et al. (2008); Kholif et al. (2013); Shibani (2015)	Contractor Related
47		Problem with neighbors	Included	Marzouk and El-Rasas (2014)	Relevant
48		Project size	Included	El-Kholy (2015); El-Touny et al. (2014)	Relevant
49	Technical Conditions	Level of constructability and extent of design review	Included	Gunhan and Arditi (2007); Polat and Bingol (2013); Marzouk et al (2008)	Relevant
50		Potential contractor experience and capability	Included	Hosny et al. (2015); Marzouk and El-Rasas (2014); Kholif et al. (2013); El-Touny et al. (2014); Shibani (2015)	Relevant
51		Experience of personnel working in the bidding department	Excluded	Polat and Bingol (2013); El-Touny et al. (2014)	Contractor Related
52		Performance of subcontractors	Excluded	Polat and Bingol (2013)	Contractor Related
53		Low productivity	Excluded	Polat and Bingol (2013); Kholif et al. (2013); Shibani (2015)	Contractor Related
54		Incomplete Design	Excluded	Hosny et al. (2015); El-Touny et al. (2014)	Overlap with factor 49
55		Design Errors	Excluded	Hosny et al. (2015); Kholif et al. (2013); El-Touny et al. (2014); Shibani (2015)	Overlap with factor 49
56		Inadequate supply, quality, timing of information and drawing by designer	Excluded	Yahia et al. (2011); El-Touny et al. (2014); Shibani (2015); El-Kholy (2015)	Engineer Related

57		Delays in shop drawings and material samples approval	Excluded	Abd El-Razek et al. (2008); Kholif et al. (2013); El-Kholy (2015)	Contractor Related
58		Conflict in point of view between contractor and consultant	Included	Abd El-Razek et al. (2008); Kholif et al. (2013)	Relevant
59		Timely Preparation of shop drawings and material samples	Excluded	Abd El-Razek et al. (2008)	Contractor Related

The Delphi technique is proposed to be used in order to identify the most significant factors. Two rounds of questionnaires were held in order to ensure consistency of the results and achieve general consensus. The 30 shortlisted factors are included in a questionnaire that is to be distributed to Egyptian construction market professionals. The questionnaire is composed of three main sections. The first section contains questions about the respondents' personal information, which are the years of experience, the position/title, and the majority of experience whether with a contractor, consultant, owner or project manager/cost manager. The second part includes the 30 shortlisted factors in order to let the experts state the importance of the factors on a numerical scale of 0 to 10; 0 is very low importance and 10 is very high importance. The respondents were asked in the third section to advise if there are additional significant factors that affect the owner cost and time contingency in Egypt that should be considered and included in the research. The questionnaire is presented in appendix C. It has been distributed to 10 construction professionals whom the majority of their experience is either with the owner side or project manager side since the research objective is to estimate the owner's contingency. The respondents had more than 10 years of experience as well to ensure that their judgement is reasonable and based on experience. Figures 13 and 14 shows the number of the respondents demonstrating their years of experience and experience background. To ensure consistency and the respondents understood the factors in the same manner, phone calls have been made to all respondents before they fill the survey to explain the purpose of the research, and guide and elaborate on any points needed.

The size of the sample required from the targeted population has been determined using equations 11 and 12.

$$\eta_o = \frac{Z^2 pq}{e^2}$$ ***Eq. 11 (El-Kholy, 2015)***

$$\eta = \frac{\eta_o}{1+\frac{(\eta_o-1)}{N}}$$ ***Eq. 12 (El-Kholy, 2015)***

Where P is the estimated proportion of any attribute that is presented within the population;
Q is the complement of P;
Z is the abscissa of the normal curve that cuts off an area at the tails;
N is the population;
E is the allowable error;
ηo is the representative sample size for large population;
n is the sample size for small population.

The confidence level assumed is 85% therefore z is equal to 1.44 from the normality tables and E is set as 15% (El-Kholy, 2015). In the worst case scenario, the P value is assumed as 0.5, which indicates a highly heterogeneous population and a high level of variability in interests of a population. Given the research is addressing large scale construction projects, all respondents are from the same category, which are owner representatives and using the Delphi technique having two rounds of questionnaires, the P value is assumed to 0.1. The population N is the owners/project managers managing large construction projects. According to the Egyptian Federation for Construction and Building Contractors, the numbers of the contractors working in construction projects with LE 2.5 million or more are 465 contractors (El-Kholy, 2015), so the target population is definitely less given this research focus on large construction projects. Also, Cityscape Egypt, one of the largest real estate investment and property show in Egypt, had 92 exhibitors in year 2017 noting that most of them are real estate developers and project management firms (Cityscape Egypt, 2017). Accordingly, the population N can be assumed as 465. By substituting in equations 11 and 12, the resultant sample size n is equal to 8.1; therefore, participation of 10 respondents in the questionnaire using the Delphi technique is considered sufficient.

After the first round of responses' returned, a summary report of the results have been developed containing the opinions of the respondents during the first round. The summary report is distributed to the respondents in order to view the results. The relative importance index (RII) is used for the data analysis as recommended by Sambasivan and Soon (2007) and Gunduz et al. (2013). RII is calculated for each factor using Equation (13). RII values range from 0 to 1. Higher RII values reflects higher importance of the factors. Ranking has been made to the factors as well from highest importance to lowest importance.

$$RII = \sum \frac{W_i}{A*N}$$ ***Eq. 13 (Sambasivan and Soon, 2007)***

Where RII = Relative Importance Index;

W_i = Weight of each factor stated by the respondent which ranges from 0 to 10 where I = 1, 2, 3, .., N;

A = Highest weight that can be given to the factor (10 in this case);

N = Total number of participants;

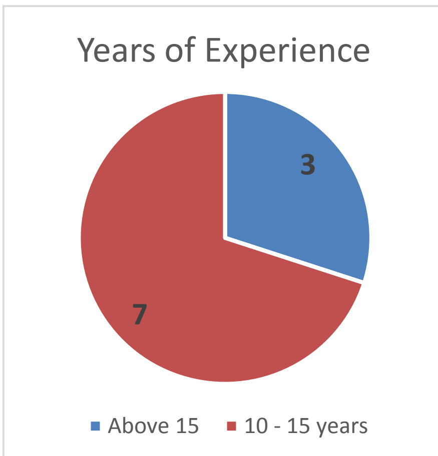

Figure 14 Years of Experience of Questionnaire Respondents

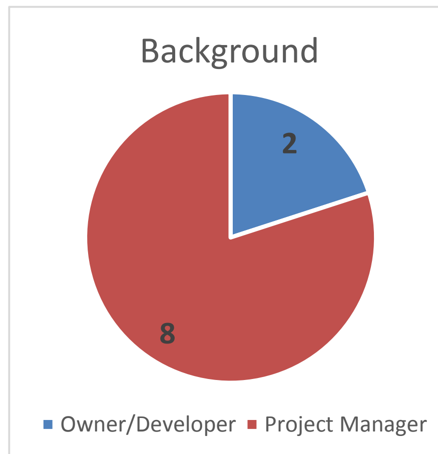

Figure 13 Background of Questionnaire Respondents

A second round is held to allow the respondents to state whether they generally agree or disagree with the findings and to revise their ratings for the importance of the factors. Table 12 shows the results of the second round of questionnaire, mainly the factors and the RIIs. Previous research about contingency prediction/cost overrun considered 10 up to 11 factors as the most important factors affecting contingency (Marzouk and El-Rasas, 2014; Yahia et al., 2011; El-Kholy, 2015). Accordingly, the top 11 factors are considered in this research and incorporated in the prediction model. It is noticed that the top 11 factors have an RII value above 80%. Factors having smaller RII values will not be considered in the predictive model in order to have a manageable number of variables (El-Kholy, 2015). Table 13 contains the top 11 factors description and an explanation of what does each factor represent and reflect. By comparing the top 11 factors with previous similar research conducted in Canada, it has been found that almost 50% of the factors are the same (Mohamed et al., 2009).

Table 12 Rating of factors obtained from Second Round of Questionnaire

No.	Factor	RII Value
1	Amount of change orders and owner behavior toward change	0.93
2	Level of constructability and extent of design review	0.93
3	Owner/Project Manager management capability and ability to take timely decisions	0.91
4	Scope definition and clarity	0.85
5	Time allowed for project planning at pre-tender stage	0.85
6	Market conditions stability	0.85
7	Potential contractor experience and capability	0.84
8	Schedule clarity and accuracy	0.83
9	Owner financial capability and timing of payments	0.83
10	Project complexity	0.83
11	Investigation of existing site conditions	0.81
12	Contract clarity	0.79
13	Budget allocation and estimation accuracy	0.78
14	Owner/Engineer Amount of Interference	0.74
15	Absence of PM firm	0.73
16	Soil conditions	0.69
17	Unexpected onerous requirements by client's supervisors	0.67
18	Owner safety culture	0.67
19	Project location	0.67
20	Delivery Method/Procurement Route	0.62
21	Type of project bidding and award (negotiation, lowest bidder)	0.61
22	Construction permits issuance	0.58
23	Site obstacles	0.55
24	Problem with neighbors	0.54
25	Contract Type	0.54
26	Political conditions stability	0.52
27	Project size	0.52
28	Conflict in point of view between contractor and consultant	0.52
29	Project type	0.51
30	Weather conditions	0.5

Table 13 Top 11 factors identified via the questionnaire

No.	Factors affecting Contingency	Description
1	**Expected amount of change orders and owner behavior toward change**	Owner's trend in making changes after signing the contract with the contractor and the tendency to do change orders. Changes usually leads to time and/or cost implications.
2	**Level of constructability and Extent of design review**	The constructability of the project reflects the ease which the project can be built and the quality of documents. Design review aims to identify any deficiencies or errors within design and specifications. Design review sessions are recommended to occur before tender issuance.
3	**Owner/Project Manager management capability, and ability to take timely decisions**	Is the owner capable to take wise timely decisions? Does the owner interfere frequently in works or suspend works? The capability of the project management team assigned on the project?
4	**Market conditions stability**	The degree of market prices stability at the time when the project is planned to be executed, the level of fluctuation of currency exchange rates and degree of changes in taxes and customs.
5	**Time allowed for project planning at pre-tender stage**	The amount of time available in project planning, compiling tender documentation, design, cost planning, time planning, etc. When the time is very tight, the possibility of errors or missing crucial items is high.
6	**Scope definition and clarity**	The level of scope definition and clarity affect time and cost. A poorly defined scope would result in time and cost implications during the execution phase of the project. A well-defined scope should not have impact on time and/or cost.
7	**Potential contractor experience and capability**	The contractor technical experience and capability to undertake the project works considering scale, type and disciplines involved have an effect on the contractor's time performance.
8	**Schedule clarity and accuracy**	Degree of Master Schedule Accuracy, Correctness and Clarity. Are the allocated durations and milestones realistic? Is the contractor site possession date accurate? Does the schedule capture all necessary details? Having an unrealistic schedule will not be achieved.

9	**Owner financial capability and timing of payments**	Financial capability of owner is an important factor. As the cycle time taken by the owner to release contractor payments is according to the contractor, this helps the contractor to progress as planned and avoid cash flow problems. Late payments affect contractors' progress.
10	**Project complexity**	The degree of the project complexity whether it is a traditional project, semi-complex or unique project.
11	**Investigation of existing site conditions**	Were investigation and proper evaluation made for the existing site conditions and have been accounted for in the design and scope. If the design and specifications don't fit the existing site conditions, this will lead to time and cost implications.

3.2 Proposed prediction model for time and cost contingency

In this research, time contingency amount (TC) and cost contingency amount (CC) are modelled as function of the factors (F_i) identified in previous section. Based on the effect of these factors, the TC and CC amounts are determined as a percentage of the project cost estimate; F_i represents the effect of the factor. Accordingly, Equation (14) expresses the relationship between TC and each factor while Equation (15) expresses the relationship between CC and each factor.

$$TC = f\ (F_1, F_2, F_3, F_4, F_5, F_6, F_7, F_8, F_9, F_{10})$$ ***Eq. 14***

$$CC = f\ (F_1, F_2, F_3, F_4, F_5, F_6, F_7, F_8, F_9, F_{10})$$ ***Eq. 15***

Figure 15 shows the proposed prediction model general framework. As demonstrated, first of all, the model inputs would be defined, which are the most significant factors affecting owner time and cost contingency are identified in Section 3.1. Similarly, the model output variables would be defined, which are the time and cost contingency. The input and output variables should be fuzzified. During the fuzzification process, there are mainly three elements, which are the membership functions, the fuzzy If-then rules and the inference system. There are several ways to develop and design the fuzzification elements according to the literature; therefore, seven models will be developed in order to test all of them and determine the best model accordingly. Generally, the seven models can differ in the membership functions, the fuzzy if-then rules and/or the inference system. Afterwards, defuzzification would result in calculation of the predicted time and cost contingency represented in the form of a percentage of the original cost and time estimate. Each of the seven models will be subjected to initial testing using real projects data. The best model will be chosen based on the least error calculated by comparing predicted contingency values to the actual contingency values. The best model will be subjected to tuning to achieve the optimum model. Last but not least, the tuned model would be validated using real projects data.

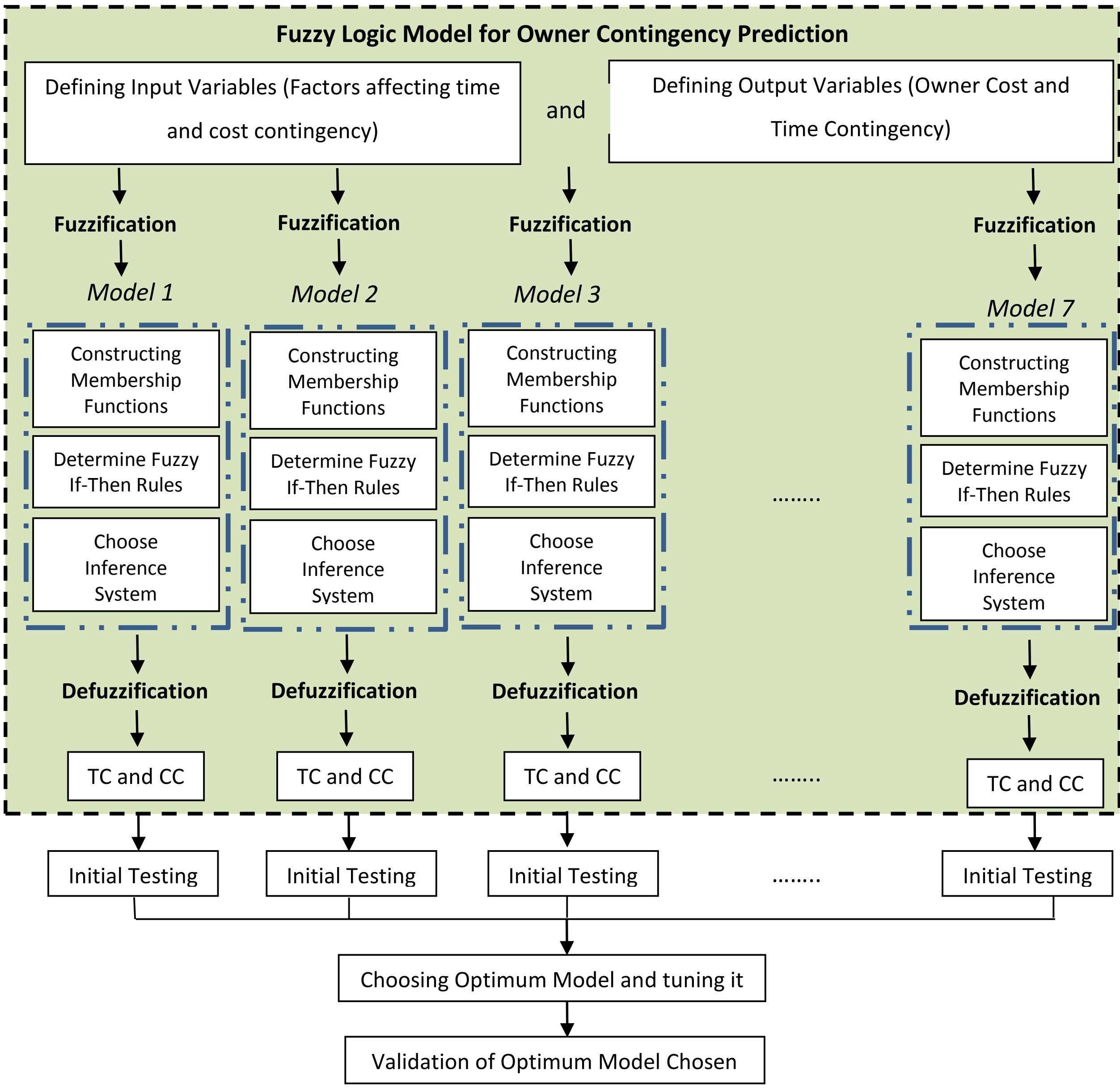

Figure 15 General framwork of the proposed contingency model

3.3 Design of questionnaire to obtain actual project data

Following determining the factors and development of the general framework for the contingency model, a second questionnaire has been designed in order to gather actual projects data to be used for testing the performance of the contingency model. The questionnaire is mainly composed of three parts. The first part had questions about respondents' personal information, which are the years of experience, and the majority of his experience whether it is with a contractor, consultant, owner or project manager/cost manager. The second part contained questions to the respondents to advise the data and information of an actual project they have managed and completed through stating the original duration vs. actual duration, and the project original cost vs. the final account value. The respondents were asked in the third part to rate each of the 11 factors for the project. In order to facilitate for the respondents rating each factor and to ensure consistency, a numerical scale of 0 to 10 was developed shown in Figure 18 and has been given to the respondents along with the questionnaire. This scale is a rating of the factors that impact contingency and a description that corresponds to each of the possible choices. The questionnaire is presented in appendix D. The questionnaire has been distributed to 25 construction practitioners. Out of the 25 construction practitioners, 15 completed the questionnaires providing data of 15 construction projects in Egypt whom their experience background and number of years of experience are demonstrated in Figures 16 and 17 respectively. All respondents had at least 10 years of experience or more so that their judgement would be reasonable mainly in the third part of the questionnaire. Table (14) shows the list of respondents showing their years of experience, position and experience background in addition to the project type, and delivery method.

Table 14 List of Questionnaire Respondents

No.	Years of Experience	Current Position/Title	Field of Experience	Project Type	Contract Type	Delivery Method/Procurement Route
1	10-15	Project Manager	Project Manager/Cost Manager	Commercial	Lump sum	Design-Build
2	10-15	Senior Project Manager	Owner	Retail, Commercial	Lump sum	Design-Bid-Build (Traditional)
3	10-15	Planning Manager	Project Manager/Cost Manager	Hospitality	Unit Price/Re-measured	Design-Bid-Build (Traditional)
4	10-15	Senior Quantity Surveyor	Project Manager/Cost Manager	Retail	Lump sum	Design-Bid-Build (Traditional)
5	15 and above	Director	Project Manager/Cost Manager	Residential	Lump sum	Design-Build

6	10-15	Senior Project Manager	Project Manager/Cost Manager	Hospitality	Lump sum	Design-Bid-Build (Traditional)
7	10-15	Associate Director	Engineer/Consultant	Residential	Lump sum	Construction Management at Risk
8	10-15	Senior Project Manager	Project Manager/Cost Manager	Commercial	Unit Price/Re-measured	Construction Management at Risk
9	10-15	Quantity Surveyor	Project Manager/Cost Manager	Residential	Unit Price/Re-measured	Design-Bid-Build (Traditional)
10	10-15	Project Manager	Project Manager/Cost Manager	Residential	Lump sum	Construction Management at Risk
11	10-15	Project Manager	Project Manager/Cost Manager	Residential	Lump sum	Design-Build
12	10-15	Senior Project Manager	Owner	Retail, Commercial, Residential	Lump sum	Design-Bid-Build (Traditional)
13	15 and above	Project Director	Project Manager/Cost Manager	Retail, Residential	Unit Price/Re-measured	Design-Bid-Build (Traditional)
14	15 and above	Associate Director	Project Manager/Cost Manager	Hospitality	Lump sum	Design-Bid-Build (Traditional)
15	10-15	Project Manager	Owner	Commercial	Lump sum	Design-Build

The projects selected by the respondents are in Egypt since the research is developed to serve the Egyptian construction market. To ensure that the respondents understood the questions and the factors in the same manner, physical (face to face) meetings took place while they were filling the survey to guide and elaborate on any points needed. Out of the 15 projects, 11 projects were Lump sum and 4 were Unit Price/Re-measured. Out of the 15 projects, delivery method of 3 projects was Construction Management at Risk, 4 projects were Design-Build and the remaining 8 projects were Design-Bid-Build (Traditional). The studied projects original values ranged from EGP 40 Million to EGP 2.2 Billion and the original durations values ranged from 7 months to 3 years.

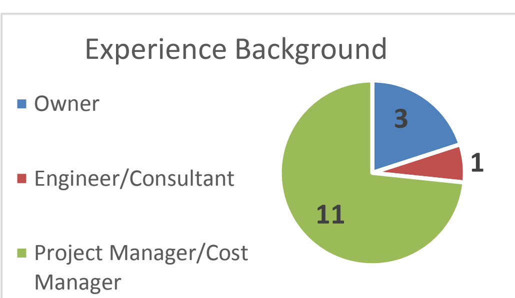

Figure 17 Respondents Experience Background

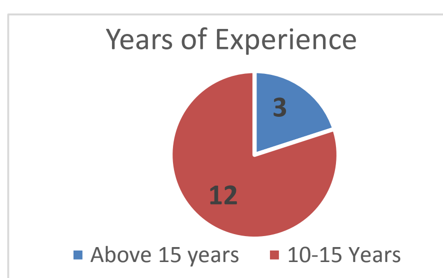

Figure 16 Respondents Years of Experience

Amount of change orders & owner behavior toward change

0	5	10
High and tendency to do change orders	Medium and minor tendency to do change orders	Low and tendency to follow original design

Level of Constructability and Extent of Design Review

0	5	10
No Design Review and Low constructability	Minimal Design Review & Moderate Constructability	Extensive and Detailed Review & High Constructability

Owner/Project Manager Management Capability

0	5	10
Weak Capability, high owner interference and does not take timely decisions	Medium Capability, Medium Owner Interference and often takes time decisions	Strong Capability, low owner Interference and usually takes timely decisions

Scope Definition & Clarity

0	5	10
Missing scope of works and not clearly defined	Moderately defined and clear	Clearly defined and clear scope

Time allowed for project planning at pre-tender stage

0	5	10
Very tight	Moderate	Relaxed

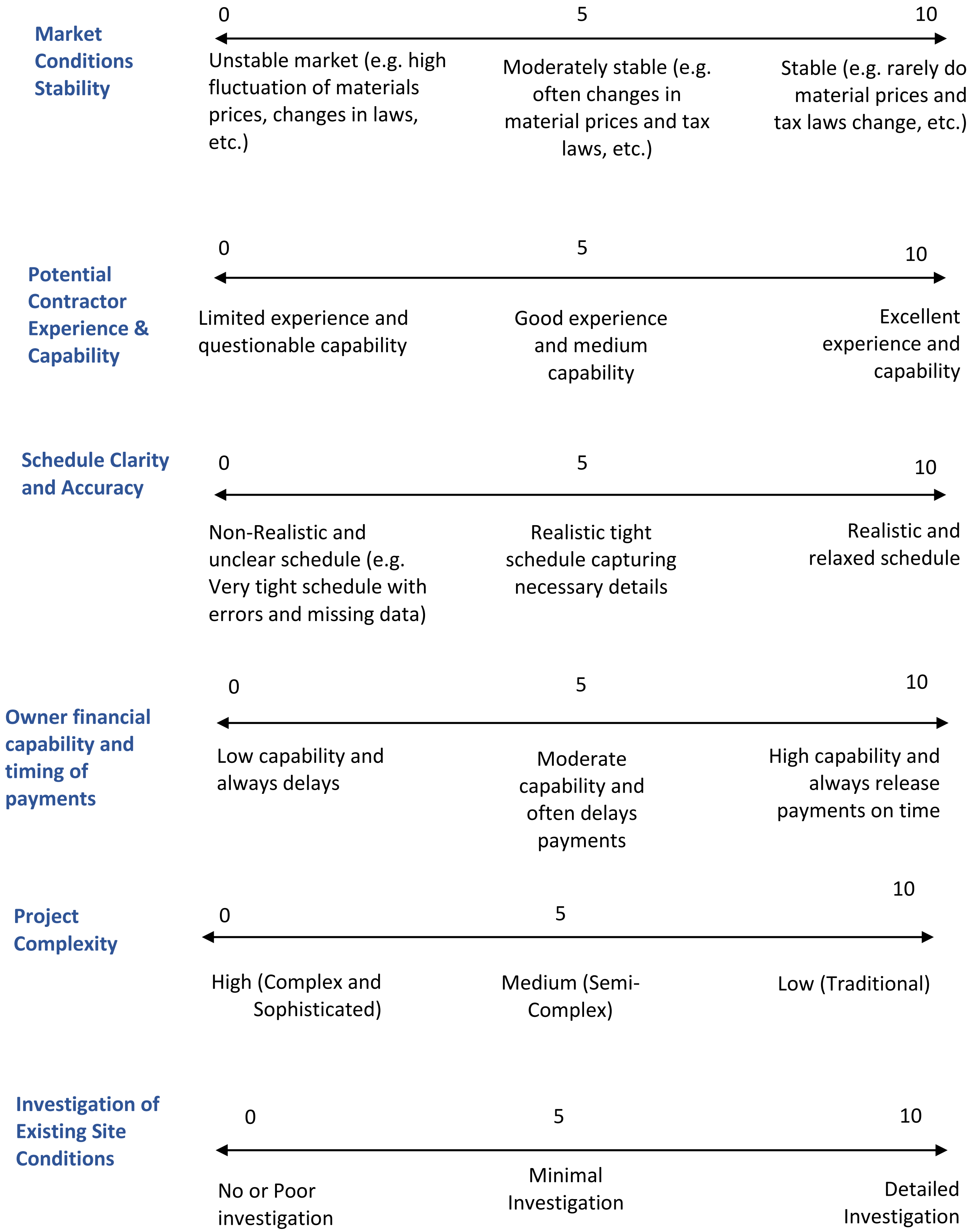

Figure 18 Numerical Scale for the possible scenarios of the factors

3.4 Model Development

As illustrated in the literature review chapter, fuzzy set theory is a tool capable to predict uncertainties, model vagueness, incorporate expert judgment and eliminate sharp boundaries of classical sets. It is also capable to deal with linguistic variables, which are usually less precise than numbers, but they work perfectly to describe situations that can't be described in traditional crisp statements. Accordingly, it has been used previously to define complex and ill-defined problems resulting from real-life problems due to uncertainties, and unclear information that cannot be determined clearly. Time and cost contingencies cannot be determined with certainty and are usually determined subjectively. Fuzzy sets eliminates subjective decisions since it represents the opinions of experts' judgment. Accordingly, a fuzzy logic prediction model is developed in order to estimate the time and cost contingencies and model their uncertainties.

To construct the proposed fuzzy prediction model, researcher had two alternatives. Fuzzy logic toolbox, MATLAB built-in software, is the first alternative. MS Excel software is the second alternative, but unlike the MATLAB, it has no built-in fuzzy logic application, so the model has to be designed manually. The main advantage of using the fuzzy logic toolbox on MATLAB is the simplicity in building the model, but in turn, imposes limitations on its design and flexibility. On the other hand, MS excel allows higher flexibility in the model design since the model is being designed from scratch. Generally, MS excel has user-friendly interface and capabilities that allows design of advanced applications and models. The following steps are followed during the model development.

1- Assigning the factors affecting the time and cost contingency as the input variables to the model, defining the possible ranges for each factor and its measurement unit
2- Assigning the time and cost contingency as the output variables to the model, defining the possible ranges for each factor and its measurement unit
3- Fuzzification of the variables by determining the preliminary fuzzy membership functions for both the input and output variables based on literature
4- Determining linguistic variables as a substitute to the numbering
5- Developing the fuzzy rules, which are the If-Then rules, the logic between inputs and outputs and the effect of the each factor relative to the other factors
6- Selection of the aggregation and defuzzification methods based on the literature

7- Developing several model scenarios and subjecting them to initial testing

8- Choosing the best model from the initial testing and application of tuning

9- Validating the model using actual projects' data

Fuzzification, fuzzy rules, inference engine and defuzzification are the four main components of the fuzzy logic system. Starting by the fuzzification, it is mainly to transform the crisp inputs to fuzzy inputs by defining membership functions. The membership functions contains all possible values that the inputs, which are the factors affecting contingency, can have on the x-axis vs. the degree of membership, which ranges from 0 to 1, on the y-axis. The shapes of membership functions vary from trapezoidal, triangular, Gaussian, etc. however literature shows that the triangular and the trapezoidal are the most widely used (Elbeltagi et al., 2012). Membership functions shapes are considered part of the link between the inputs and the outputs, and impact the model results, so they should be constructed carefully.

The second component is the fuzzy rules which represent the possible relations between inputs, the factors and, outputs, time and cost contingency. They are in the form of If-then statements. The number of rules is determined based on the number of inputs (ni) and the number of the membership functions for each input variable (MF) as shown in Equation (16).

$$\text{Number of If} - \text{Then rules } = (MF)^{ni}$$ ***Eq. 16 (Gunduz et al., 2014)***

There are two methods of rules aggregation, which are the disjunction system that connects the rules by "OR" and the conjunctive system that connects the rules by "AND". When the rules are connected by "AND", the minimum criterion is used. The maximum value is used when the rules are connected by "OR". In some cases, the number of rules resulting from Equation (13) can be impractical to define, impossible to occur in the real life and unnecessary. Also, large number of rules needs a highly advanced computer infrastructure to be able to operate the model; hence, it is recommended in the literature to define only the possible relations that would represent the link between inputs and outputs. Since there are 11 input factors and three possible options for each factor, the resultant number of rules is 177,147. In reality, all rules have the possibility to occur so none can be excluded. To edit this number of rules manually, it would be impractical in terms of effort and software capability. Therefore, Fuzzy Meta rules are proposed and shall be used in this model. Meta rules are basically rules that define how other rules operate and governs the application of other rules. They serve as a higher level of the normal rules. As a result, they will result in less number of rules. The fuzzy rules are constructed based on logic and verified by construction market experts and professionals.

The third component of the fuzzy logic is the inference system. The inference system is the engine that derives the outputs values based on the inputs fuzzification and rules components. It links both and is capable to form patterns that can be distinguished and form the basis from which decisions can be made. Mamdani and Sugeno are the two available inference systems. The fuzzy sets in Mamdani are used as a rule consequent. In Sugeno, the linear functions of input variables are employed as rule consequent. Literature shows that the most commonly used in successful similar applications is the Mamdani inference system (Gunduz et al., 2014; Polat and Bingol, 2013; Idrus, 2011).

The fourth and last component is the defuzzification. The defuzzification component is responsible from transforming the fuzzy output sets obtained from the inference system to crisp outputs. The model outputs, time and cost contingency, will be in the form of a percentage of the original project duration and the project original cost respectively.

3.5 Model Initial Testing and Tuning

By setting and defining all model parameters, a preliminary model is developed based on the best practices mentioned in the literature addressing the fuzzy logic model components. In order to ensure the best model is achieved, initial testing is recommended (Idrus et al., 2011). Several scenarios are developed for the model as well to choose the best scenario in terms of accuracy and validity. The scenarios mainly differ in the shapes of the membership functions in addition to the ranges of the linguistic terms values. The fuzzy rules are kept the same because there is no logic in changing them as well as they are based on construction professionals' judgement.

The data of actual 10 projects obtained via the questionnaire are used in order to do initial testing for the model and then choose the best model scenario. After choosing the best model using the performance evaluation criteria mentioned in the coming paragraph, final tuning takes place until the model is improved and achieves the results with great accuracy. Negnevitsky (2004) indicates that model tuning is considered an art rather than engineering technique and can be considered as an iterative process. Tuning can be done by revising membership functions, revising fuzzy rules or revising types of inference mechanisms, but Fayek and Oduba (2005) recommended to revise only the membership functions, which will be followed in this research accordingly.

The data reported for each actual project is inputted to the model, and the time and cost contingency was predicted accordingly. The results of the model are then compared to the actual contingency reported by the respondents for the actual projects. The outputs are in the form of a percentage of the original cost/time; however, a scale of very low, low, medium, high and very high is used as well as shown in Table (15). After recording the model output results, the model performance was evaluated based on the following:

1. Calculating the variance between the actual and predicted contingency percentages values as per Equation (17) where VAR is the variance, AC is actual contingency and PC is predicted contingency.
2. Developing a rating scale for time and cost contingency as shown in Table 15. The scale is based on the actual projects data obtained for the questionnaire where time contingency varied from 8.3 percent to 53.3 percent and cost contingency varied from 3.2 percent to 36.4 percent. The model results shall be compared to the actual contingencies using this rating scale.
3. Calculating the validity of the developed model using average invalidity percent (AIP) and average validity percent (AVP) as shown in Equation (18) and Equation (19) respectively (Zayed and Halpin, 2005; Mohamed et al., 2009). The average validity percentage represents the model validation percent out of 100. For instance, if the model AVP is 90%, then the model is said to be valid 90% for representing the data. According to Zayed and Halpin (2005), AVP higher than 90% is excellent, higher than 80% is good validity, higher 70% is acceptable validity and lower than 70% is poor validity.

Table 15 Cost and Time Contingency Output Rating Scale

Cost Output	Minimum	Maximum		Time Output	Minimum	Maximum
Very Low	0%	7%		**Very Low**	0%	7%
Low	>7%	15%		**Low**	>7%	20%
Medium	>15%	25%		**Medium**	>20%	40%
High	>25%	40%		**High**	>40%	50%
Very High	>40%			**Very High**	>50%	

$$VAR = |AC - PC|$$ ***Eq. 17***

Where AC = Actual contingency

PC = Predicted contingency

VAR= Variance

$$AIP = \sum_{i=1}^{n} |1 - \left({E_i}/{C_i} \right)|/n$$ ***Eq. 18 (Zayed and Halpin, 2005)***

Where E_i= Predicted Value, which will be the predicted time or cost contingency

C_i= Actual Value, which will be the actual time or cost contingency

N = the number of the cases considered in validation

$$AVP = 1 - AIP$$ ***Eq. 19 (Zayed and Halpin, 2005)***

Where AVP = Average Validity Percent

AIP = Average Invalidity Percent

3.6 Testing the model performance

After initial testing, tuning and choosing the best model scenario, it is validated by using real project cases that were not used in initial testing in order to ensure its capability, reliability and its representativeness for the real life projects. The validation is done using the best chosen model noting that all other models are disregarded in the previous step. Out of the obtained 15 actual projects data, 5 projects shall be used for validation purposes. The same procedure of testing takes place similar to what has been done during the initial testing, but no tuning is made and the results are reported as are. Finally, the model performance is finally assessed using the same criteria specified in section 3.5.

4. Model Development

4.1 Input and Output Variables

Development of fuzzy logic model mainly consists of several steps as mentioned in the methodology section. The first step of developing the model is defining the inputs and the outputs. The inputs are the 11 factors affecting time and cost contingency, and the outputs are the cost and time contingency. For practicality and presentation purposes, acronyms have been made for the factors as shown in Table 16 below. The same applies for the linguistic terms of the input variables.

Table 16 Input Variables Acronyms

Input Variables - Factors	*Acronym*
Amount of Change Orders & Owner Behavior Toward Change	Changes
Level of Constructability and Extent of Design Review	Constructability
Owner/Project Manager Management Capability and Ability to Take Timely Decisions	Management Cap.
Scope Definition and Clarity	Scope definition
Time Allowed for Planning	Time for planning
Market Conditions Stability	Market conditions
Potential Contractor Experience & Capability	Contractor Cap.
Schedule Clarity and Accuracy	Schedule Accuracy
Owner financial capability and timing of payments	Payments
Project Complexity	Complexity
Investigation of Existing Site Conditions	Investigation of site

4.2 Membership Functions

The second step is defining the membership functions. Membership functions properties consist of the membership shape, linguistic terms, numerical range of each linguistic term, the extent of overlap between each membership function and finally, the universe of discourse (Idrus et al., 2011). For this research, 11 membership functions for the 11 input variables and two membership functions for the two output variables were constructed in the model. Based on the possible options for each factor, the universe of discourse has been set as a numerical scale ranging from 0 to 10 for all 11 inputs variables. The degree of membership varies from 0 to 1 and is on the y-axis. Meanwhile, for the output variables, the universe of discourse for the cost contingency has been set as a numerical scale ranging from 0 to 50 and for the time contingency as a numerical scale ranging from 0 to 70. These represent the percentages of the original project values whether duration or cost. These values are based on the actual contingency percentages analyzed from the projects obtained via the questionnaire noting that the time contingency values range from 8.3 percent to 53.3 percent and the cost contingency values range from 3.2 percent to 36.4 percent. A study conducted by Yahia et al. (2011) revealed that the average actual time contingency based on the data collection of 54 Egyptian construction projects is 28%. Meanwhile, based on the 15 projects data obtained via the questionnaire in this research, the mean actual time contingency is 32% which is relatively close and seems reasonable. The mean actual cost contingency based on the data collected from this research is 19.1%.

The input variables, factors affecting contingency, in this model are represented through designing three linguistic terms for each of the factors in which the users can choose from. These linguistic terms represent the numerical scale for the factors demonstrated in Figure 18 in the research methodology section (Chapter3); however, they have been represented in acronyms in the model for practicality purposes which are low, medium or high. Low is the worst condition for the factor and high is the best condition. Reference to be made to Figure 18 in Chapter 3 where low represents the left side description, medium represents the middle description and high represents the right side description.

Generally, the number of the membership functions for each variable should represent the actual field condition and no clear guidance is available that serves as a decision support tool to determine this (Idrus et al., 2011). Several shapes can be used to represent the membership function shapes to develop the fuzzy expert system, such the bell function, sigmoid, trapezoidal, Z-function and triangular. Triangular shapes were used to define the membership functions since they are among the most widely used in the literature (Hosny et al., 2013; Idrus et al., 2011; Polat et al.; 2013). Therefore, they have been selected for representing the input variables in this study as a preliminary setting for the model. According to Hosny et al. (2013), triangular shapes are the most effective in formulating decision problems in which the data available is imprecise and subjective. In our case, this applies to the factors affecting contingency. The universe of discourse for the input variables ranges from 0 to 10. To illustrate, for the scope definition and clarity factor, 0 value represents missing scope of works and not clearly defined, 5 value represents moderately defined and clear and 10 value indicates clearly defined scope. The same applies for the remaining variables. In between these values, which is a value of 3 indicates somewhere between “missing scope of works and not clearly defined" and "moderately defined and clear", which may be the case for some projects.

The output variables in this model are represented through designing five linguistic terms, which are very low, low, medium, high and very high (Gunduz et al., 2013). Five linguistic terms have been chosen due to large range of contingency amounts and hence, provide more accurate and specific results. Setting three linguistic terms of low, medium and high would involve large ranges. Trapezoidal shapes were used to define the membership functions as a preliminary setting for the model since they are among the most widely used in the literature (Gunduz et al., 2013; Elbeltagi et al., 2012). For each linguistic term, the overlap between each of the membership functions ranges from 25 percent to 50 percent as recommended in the literature (Polat et al., 2013; Cox and O'Hagen, 1998).

4.3 Fuzzy Rules, Aggregation and Defuzzification Operations

The fuzzy rules of the model are if-then statements that are used to link and represent the relationship between the input and the output variables in terms of linguistic variables instead of mathematical formulas. Given that there are 11 input variables in the model and three linguistic terms representing each of the variables, the number of If-then rules should be 3^{11}, which is equivalent to 177,147 rules. Defining all the rules would be very difficult in terms of time and effort. Also, the fuzzy expert model will take very long time to process such huge number of rules due to software limitations. Therefore, the concept of Meta rules is recommended and proposed to be used in this research. Meta rules govern the application and set the boundaries for the normal rules. They are considered to be of higher level than that of the normal rules and hence should result in less number of rules (McGinn, 2002). This is one of the main reasons for building the model on MS Excel since it provides flexibility to design and modify as necessary to best suit the model rather than using an available built-in software that will impose limitations.

The Meta Rules for this model have been designed to consider the impact of each of the 11 factors on the contingency whether very low, low, medium, high or very high as shown in Table 17 and the resultant no. of very lows, lows, mediums, highs and very highs. Table 17 shows the knowledge base for the effect of each factor on the contingency that was incorporated in the model rules. The first row contains the 11 factors considered in the model and the first column contains the linguistic terms available for each factor and defined in the membership functions, which are 0, 5 and 10. The 0, 5 and 10 represent the scale and descriptions in figure 18. They represent the possible choices for the users. For instance, if scope definition and clarity is 0, this means it's missing and not clearly defined and the effect on both time and cost contingency is very high. If scope definition and clarity is 10, this means it's very well defined and clear and the effect on both time and cost contingency is very low.

Table 17 Effect of factors on the Owner Time and Cost Contingency

Value	Amount of Change Orders & Owner Behaviour	Level of Constructability & Design Review	Owner/PM Management Capability	Scope Definition & Clarity	Time allowed for project planning	Market Conditions Stability	Contractor Experience & Capability	Schedule Clarity & Accuracy	Owner Financial Capability and Timing of Payments	Project Complexity	Investigation of Existing Site Conditions
	Impact on Time										
0	Medium	Very High	High	Very High	Medium	Medium	High	Very High	Very High	Very High	Medium
5	Low	Medium	Medium	Medium	Low	Low	Medium	Medium	Medium	Medium	Low
10	Very Low	Very Low	Low	Very Low	Very Low	Very Low	Low	Very Low	Very Low	Very Low	Very Low
	Impact on Cost										
0	Very High	Very High	Very High	Very High	High	Very High	Low	Low	Low	High	High
5	High	Medium	Medium	Medium	Medium	Medium	Low	Very Low	Low	Medium	Medium
10	Low	Low	Very Low	Very Low	Low	Very Low	Very Low	Very Low	Very Low	Low	Low

In order to incorporate the effect of the number of very lows, lows, mediums, high and very highs in the model rules, a score has been assigned to each of them as shown in Table 18. The individual factor score is the score that accumulates as a result of the contingency rating yield due to this factor. The 11 factors total score is the summation of the individual factors scores. The lower and upper limits acts as the boundaries for defining the contingency rating of the rule whether very low, low, medium, high or very high. By considering a case as an example, if all 11 factors have an effect of very high contingency, then the score would be 5 x 11, which yields 55 and according to the below boundaries as shown in Table 18, the contingency is very high. Another example, if 4 factor are low, 4 are high, 2 are very high and 2 are medium, then the score would be (4 x 2) + (4 x 4) + (2 x 5) + (2 x 3) = 40, which is high contingency. Accordingly, the model rules were in the form of:

*"IF SCORE EQUALS **40** THEN COST CONTINGENCY IS **HIGH**"*

The same concept applies for the time contingency as the factors have different effect than that on the cost contingency as illustrated in Table 17. Since the minimum possible score is 11 and the maximum possible score is 55, then number of rules is 45 rules, which is significantly reduced compared to the normal method that requires input of 177,147 rule. In addition, the 45 rules represents all the possible combinations that may occur in reality. All rules have the same weightings since they are all the same and the contingency result is based on the calculated score. The 45 fuzzy rules are listed in appendix A.

Table 18 Contingency Rating Scores

Contingency Rating	Individual Factor Score	11 factors Total Score Lower Limit	11 factors Total Score Upper Limit
Very High	5	49	55
High	4	36	48
Medium	3	26	35
Low	2	15	25
Very low	1	11	14

As there are two inference systems in fuzzy logic, Mamdani's fuzzy inference system is the one that has been used in this research as it was used successfully in previous similar studies, widely accepted and well suited to human input (Idrus et al., 2011; Polat et al., 2013; Gunduz et al., 2014). The process for combining several fuzzy sets to produce a single fuzzy set is the aggregation process where the *Max* method is used due to its popularity in previous applications. Similarly, there are several methods for defuzzification, but literature shows that the *Center of gravity* method is the most common form of defuzzification (Gunduz et. al; 2014). The center of gravity method is mainly based on finding the centroid of a planar figure.

As all necessary components of the model are preliminary constructed, an initial decision-support tool is now developed that would enable the owners and project managers predict the time and cost contingency at the planning/pre-tender stage of the project and enable them realize the consequences of the project parameters setting. Figure 19 is a snapshot from the model demonstrating the model interface where the user is required to input the rating of each factor on a scale from 0 to 10 where zero is low and 10 is high. The linguistic terms are calculated automatically based on the user input values in the column no. 3 named "value" as shown in Figure 19. The effect of each factor on the contingency is determined automatically based on the ratings input by the user as shown in Figure 19. All possible combinations that may occur are automatically listed afterwards and the score of each possible combination is calculated based on the Likert scale. The resultant scores that matches with the fuzzy Meta rules will lead to fire those rules and accordingly, the contingency will be calculated. Figure 20 is a snapshot from the model demonstrating the calculated contingency based on the fuzzy logic theory and the final membership function values for all of the factors and the contingency. Snapshots for the model on MS Excel is presented in appendix B.

No.	Input Variable	Value	Linguistic term 1	Linguistic term 2	Linguistic term 3	Effect of Term 1	Effect of Term 2	Effect of Term 3
1	Changes	2	Low			M		
2	Constructability	2	Low			A		
3	Management Cap.	0	Low			H		
4	Scope definition	2	Low			A		
5	Time for planning	3	Low	Medium		M	L	
6	Market conditions	8			High			B
7	Contractor Cap.	8			High			L
8	Schedule Accuracy	0	Low			A		
9	Payments	1	Low			A		
10	Complexity	1	Low			B		
11	Investigation of Site	4	Low	Medium		M	L	

Figure 19 A snapshot of the model interface part where the user inputs the rating for the 11 factors

IV. Calculation

		Low	*Medium*	*High*
1	Changes	1	0	0
2	Constructability	1	0	0
3	Management Cap.	1	0	0
4	Scope definition	0.2	0.6	0
5	Time for planning	0.2	0.6	0
6	Market conditions	0.4	0.2	0
7	Contractor Cap.	0	1	0
8	Schedule Accuracy	0.2	0.6	0
9	Payments	0	0.6	0.2
10	Complexity	0.4	0.2	0
11	Investigation of Site	0	0.6	0.2

		Very Low	**Low**	**Medium**	**High**	**Very High**
12	**Cost Contingency**	**0**	**0**	**0.2**	**0.2**	**0**

Cost Contingency	15.00%

Figure 20 Output of Rules Calculation and Resultant Contingency

4.4 Model Initial Testing and Tuning

Following setting of initial scenarios and parameters based on popularity and recommendations in literature, a preliminary model is now developed. Before validating the model, it will be initially tested then tuned in order to verify on the model parameters setting and ensure the proposed model is the best that can be achieved. Therefore, data of 10 actual Egyptian construction projects, which has been obtained via a questionnaire survey, are used to explore the results of different scenarios for the model parameters. The obtained data for each project are the following:

1- The original and the actual project durations and accordingly, allowed the calculation of the actual project time overrun/saving
2- The original cost and the final account value and accordingly, allowed the calculation of the actual project cost overrun/saving
3- An assessment by the respondent for each of the 11 factors that affect time and cost contingency on the project mentioned. Accordingly, the choice selected by the respondent for each of the 11 factors has been entered to the model as the model input variables to calculate and predict the time and cost contingency

Tables (19) and (20) shows the actual 10 projects data reported by the questionnaire respondents. All 10 projects data are input one by one in the model on MS Excel and then the model predicts the contingency percentage automatically.

Table 19 Projects Data Obtained from Questionnaire

Project No.	Project Type	Contract Type	Delivery Method	Original Duration (Months)	Actual Duration (Months)	Original Cost (EGP M)	Actual Cost (EGP M)	Actual TC %	Actual CC %
1	Commercial	Lump sum	Design-Build	8	12	60	78	50.0%	30.0%
2	Retail, Commercial	Lump sum	Design-Bid-Build (Traditional)	9	12	91	101	33.3%	11.0%
3	Hospitality	Unit Price/Re-measured	Design-Bid-Build (Traditional)	12	14	120	150	16.7%	25.0%
4	Retail	Lump sum	Design-Bid-Build (Traditional)	36	40	400	415	11.1%	3.8%
5	Residential	Lump sum	Design-Build	18	25	680	702	38.9%	3.2%
6	Hospitality	Lump sum	Design-Bid-Build (Traditional)	36	48	220	300	33.3%	36.4%
7	Residential	Lump sum	Construction Management at Risk	10	14	91	100	40.0%	9.9%
8	Commercial	Unit Price/Re-measured	Construction Management at Risk	12	18	40	50	50.0%	25.0%

9	Residential	Unit Price/Re-measured	Design-Bid-Build (Traditional)	24	26	1,000	1,100	8.3%	10.0%
10	Residential	Lump sum	Construction Management at Risk	30	46	2,200	2,800	53.3%	27.3%

Table 20 Actual Projects Data obtained from Questionnaire

Factors	Project 1	Project 2	Project 3	Project 4	Project 5	Project 6	Project 7	Project 8	Project 9	Project 10
	Factors Rating									
Expected Amount of Change Orders & Owner Behavior Toward Change	1	7	9	7	6	3	6	4	10	0
Level of Constructability and Extent of Design Review	3	4	7	7	5	0	3	0	10	2
Owner/Project Manager Management Capability, and Ability to Take Timely Decisions	3	8	9	9	3	3	1	0	8	2
Scope Definition and Clarity	3	5	6	9	4	5	5	2	10	1
Time Allowed for project Planning	1	7	8	9	8	8	4	4	9	4
Market Conditions Stability	5	8	8	9	7	4	6	8	7	5
Potentional Contractor Experience & Capability	9	8	8	10	8	7	6	4	10	2
Schedule Clarity and Accuracy	3	7	8	8	3	2	1	0	10	0
Owner Financial Capability and Timing of Payments	4	8	3	9	3	6	0	2	10	7
Project Complexity	6	9	10	6	7	8	7	5	9	4
Investigation of Existing Site Conditions	0	8	7	7	0	1	5	2	9	1

These projects data are used for testing the different model scenarios developed to choose the best model. The scenarios mainly differ in the shape of the membership function of the input and output variables, in addition to the range of each linguistic term for the output variables. The fuzzy rules are kept the same since the logic between the outputs and inputs will not change. Table (21) shows all scenarios that are tested. Different combinations between Triangular and trapezoidal shapes are used in each scenario since they are the most popular in the literature. Several alternatives of the ranges of linguistic terms are tested as well to determine the best among them. Four alternatives were developed for the ranges of the linguistic terms of the output variables. The difference among the alternatives is the boundaries of the range of each linguistic term. Tables (22) and (23) show the model predicted results versus the actual data, in addition to the invalidity percent (IP) for each project and the average invalidity percent (AIP) for each model scenario. TC is the time contingency, CC is the cost contingency, IP is the invalidity percent (Error) and AIP is the average invalidity percent, which is equivalent to the mean absolute error. According to the test results shown in Tables (22) and (23), scenario 7 has the lowest AIP of 33.8% and 46.3% for both time and cost contingency respectively. Therefore, it is the best model that can be tuned to improve its accuracy of prediction. By analyzing the results of different scenarios, it is noticed that the trapezoidal shapes are more appropriate for the output variables. For the input variables, the triangular is better. In the initial testing, the average invalidity percent (AIP) has been only used to achieve the best model as it is a sufficient indicator to assess model validity and accuracy in this stage of testing.

Table 21 Model Scenarios Developed for Initial Testing

Scenario #	**Input Variables MF Shape**	**Output Variables MF Shape**	**Output Factors Range Alternative**
Scenario 1	Triangular	Triangular	Alternative A
Scenario 2	Trapezoidal	Triangular	Alternative A
Scenario 3	Trapezoidal	Trapezoidal	Alternative A
Scenario 4	Triangular	Trapezoidal	Alternative A
Scenario 5	Triangular	Trapezoidal	Alternative B
Scenario 6	Triangular	Trapezoidal	Alternative C
Scenario 7	Triangular	Trapezoidal	Alternative D

Table 22 Cost Contingency Results Comparison of Different Scenarios

Project No.	Actual CC %	Scenario 1		Scenario 2		Scenario 3		Scenario 4		Scenario 5		Scenario 6		Scenario 7	
		P. CC %	IP	P. CC %	IP	P. CC %	IP	P. CC %	IP	P. CC %	IP	P. CC %	IP	P. CC %	IP
Project 1	30.0%	26.1%	13%	26.1%	13%	26.3%	12%	26.3%	12%	26.5%	12%	26.6%	11%	26.8%	11%
Project 2	11.0%	16.5%	-50%	16.5%	-50%	16.2%	-47%	16.2%	-47%	15.8%	-44%	15.7%	-43%	14.4%	-31%
Project 3	25.0%	25.0%	0%	25.0%	0%	25.0%	0%	25.0%	0%	25.0%	0%	25.0%	0%	25.0%	0%
Project 4	3.8%	10.2%	-172%	10.2%	-172%	10.0%	-166%	10.0%	-166%	9.5%	-154%	9.4%	-151%	8.5%	-125%
Project 5	3.2%	10.2%	-215%	10.2%	-215%	10.0%	-208%	10.0%	-208%	9.5%	-195%	9.4%	-191%	8.5%	-161%
Project 6	36.4%	25.0%	31%	25.0%	31%	25.0%	31%	25.0%	31%	25.0%	31%	25.0%	31%	25.0%	31%
Project 7	9.9%	16.5%	-67%	16.5%	-67%	16.2%	-64%	16.2%	-64%	15.8%	-60%	15.7%	-59%	14.4%	-46%
Project 8	25.0%	26.1%	-4%	26.1%	-4%	26.2%	-5%	26.2%	-5%	26.4%	-6%	26.4%	-6%	26.1%	-4%
Project 9	10.0%	16.5%	-65%	16.5%	-65%	16.2%	-62%	16.2%	-62%	15.8%	-58%	15.7%	-57%	14.4%	-44%
Project 10	27.3%	25.0%	8%	25.0%	8%	24.9%	9%	24.9%	9%	24.8%	9%	24.7%	9%	24.6%	10%
AIP			62.6%		62.6%		60.4%		60.4%		56.8%		55.8%		46.3%

Table 23 Time Contingency Results Comparison of Different Scenarios

Project	Actual	Scenario 1		Scenario 2		Scenario 3		Scenario 4		Scenario 5		Scenario 6		Scenario 7	
No.	TC %	P. TC %	IP	P. TC %	IP	P. TC %	IP	P. TC %	IP	P. TC %	IP	P. TC %	IP	P. TC %	IP
Project 1	50.0%	40.2%	20%	40.2%	20%	40.9%	18%	40.9%	18%	42.2%	16%	42.6%	15%	41.1%	18%
Project 2	33.3%	33.1%	1%	33.1%	1%	32.8%	2%	32.8%	2%	32.1%	4%	31.9%	4%	33.8%	-1%
Project 3	16.7%	23.9%	-43%	23.9%	-43%	23.6%	-42%	23.6%	-42%	23.1%	-39%	22.9%	-37%	21.3%	-28%
Project 4	11.1%	23.1%	-108%	23.1%	-108%	22.7%	-104%	22.7%	-104%	22.1%	-99%	22.0%	-98%	20.1%	-81%
Project 5	38.9%	35.0%	10%	35.0%	10%	35.0%	10%	35.0%	10%	35.0%	10%	35.0%	10%	34.9%	10%
Project 6	33.3%	33.1%	1%	33.1%	1%	32.8%	2%	32.8%	2%	32.1%	4%	31.9%	4%	33.8%	-1%
Project 7	40.0%	38.3%	4%	38.3%	4%	38.7%	3%	38.7%	3%	39.5%	1%	39.7%	1%	39.3%	2%
Project 8	50.0%	40.2%	20%	40.2%	20%	40.9%	18%	40.9%	18%	42.2%	16%	42.6%	15%	41.1%	18%
Project 9	8.3%	23.9%	-187%	23.9%	-187%	23.6%	-183%	23.6%	-183%	23.1%	-177%	22.9%	-175%	21.3%	-156%
Project 10	53.3%	40.2%	25%	40.2%	25%	40.9%	23%	40.9%	23%	42.2%	21%	42.6%	20%	41.1%	23%
AIP			41.8%		41.8%		40.5%		40.5%		38.5%		37.9%		33.8%

After choosing the best model during the initial testing, it has been tuned. Tuning can be done using several ways such as revising membership functions shapes, the ranges of the linguistic terms, types of inference mechanism, and changing the fuzzy rule base. The fuzzy rule base shall remain the same given it is based on experts logic. In this research, tuning was performed by revising the membership functions as recommended by Fayek and Oduba (2005). Since changing the membership functions shapes was explored during the initial testing, tuning will involve specifically shifting the ranges of the linguistic terms of the membership functions to improve the accuracy of the model. This is an iterative process where several scenarios are tested until the optimum solution is reached. After several iterations, the best model achieved has an AIP of 28.6% and 20.6% for time and cost contingency, respectively. Figure 21 shows a sample of a final input variable "Scope definition" membership function showing its shape, the linguistic terms and the range on the x-axis. Figure 22 and 23 shows samples of the final tuned output variables membership functions showing its shape, the linguistic terms and the range on the x-axis. A demonstration of the defuzzification process as well is shown on the graph where the line named "Output set" is the resultant area aggregated from the rules' true values calculations and accordingly, the centroid is shown accordingly. The resultant area in this graph means the cost contingency has a 0.4 membership degree of "Medium" and a 0.2 membership degree of "Low".

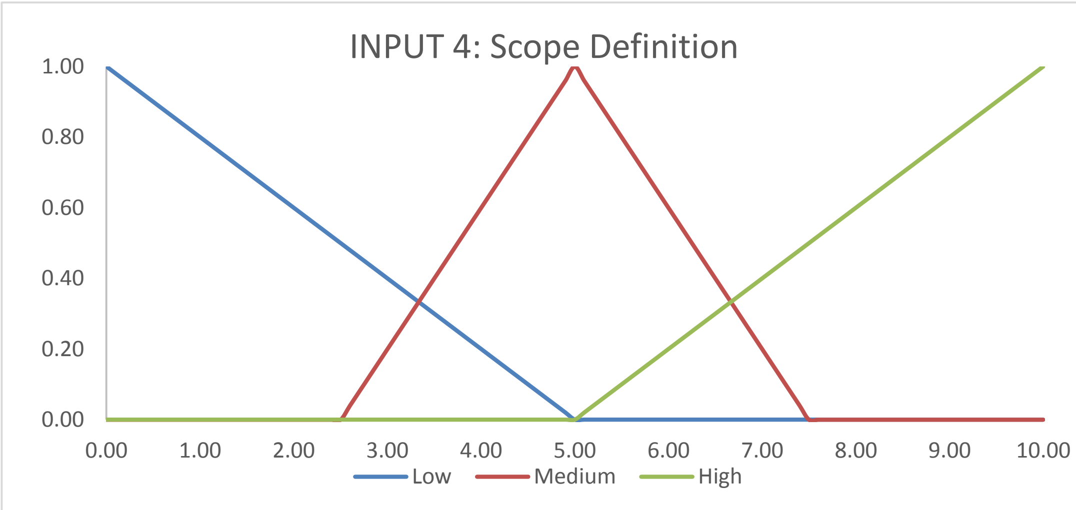

Figure 21 Membership Function of the Input Variable "Scope Definition"

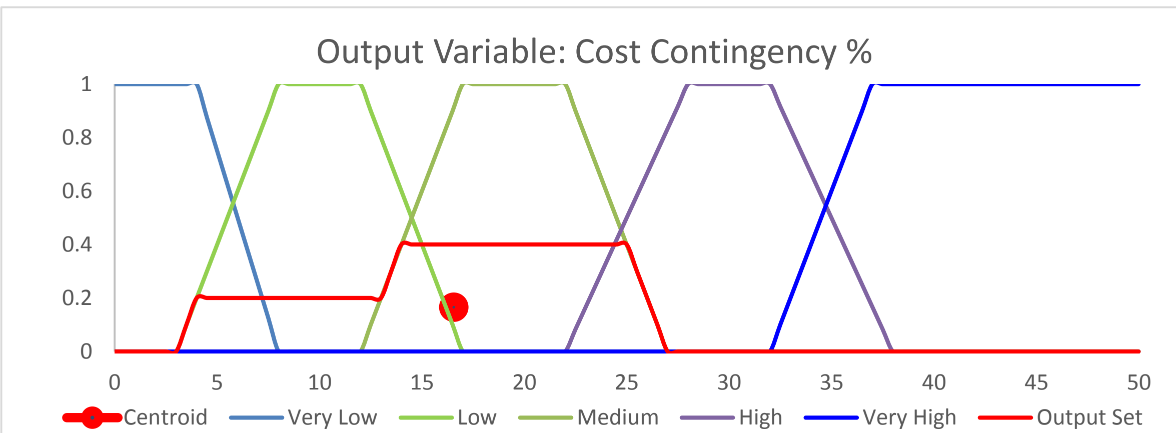

Figure 22 Cost Contingency Membership Function Sample

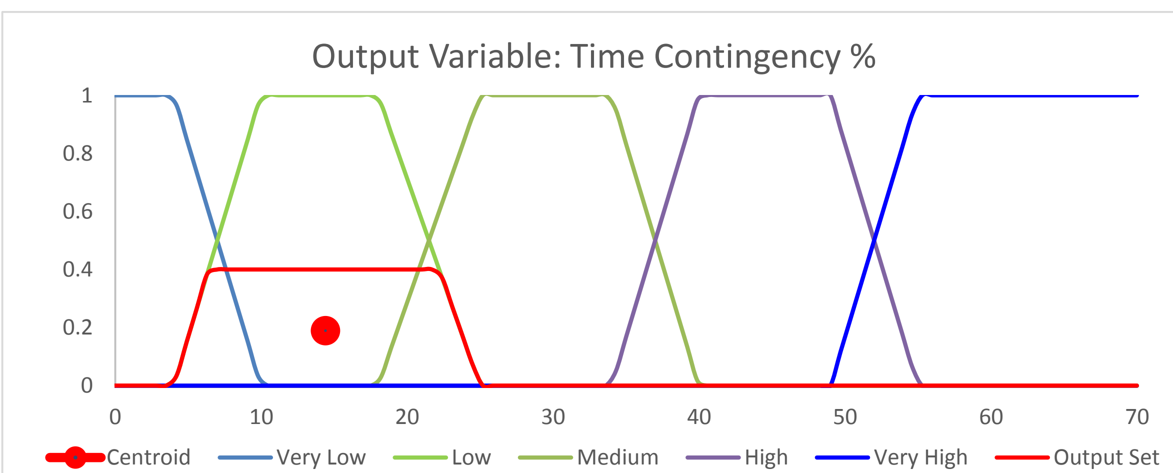

Figure 23 Time Contingency Membership Function Sample

Table 24 Model Results in Prediction of Time Contingency and Performance Measurement

Project No.	Actual TC %	Predicted TC %	Actual TC Rating	Predicted TC Rating	VAR (TC)	AIP (TC)	AVP (TC)
1	50.0%	42.0%	H	H	8.0%	16.0%	84.0%
2	33.3%	36.2%	M	M	-2.9%	8.6%	91.4%
3	16.7%	19.0%	L	L	-2.3%	14.0%	86.0%
4	11.1%	18.2%	L	L	-7.1%	63.8%	36.2%
5	38.9%	35.6%	M	M	3.3%	8.5%	91.5%
6	33.3%	36.3%	M	M	-3.0%	8.9%	91.1%
7	40.0%	39.7%	M	M	0.3%	0.7%	99.3%
8	50.0%	42.0%	H	H	8.0%	16.0%	84.0%
9	8.3%	19.0%	L	L	-10.7%	128.0%	-28.0%
10	53.3%	42.0%	VH	H	11.3%	21.3%	78.8%
Average					**5.7%**	**28.6%**	**71.42%**

As shown in Table 24, three criteria are used to evaluate the performance of the proposed model in terms of indication for time contingency. Based on comparison of the predicted and the actual results, the variance ranges from 0.3% to 11.3%. The average absolute variance however is 5.7%.

The model average validity percent (AVP) is 71.4%. By considering the AVP for each project, four projects are above 90%, which indicates excellent validity and high level of fitness (Zayed and Halpin, 2005). Three projects are above 84% which indicates good validity and level fitness. One project is above 78% which indicates acceptable validity and fitness. Finally, projects 4 and 9 are below 70% which indicates poor validity and fitness. This is mainly due to their relatively low values of contingency compared to other contingency values; hence, the variance constitutes a significant amount of their original values and results in low AVP. Accordingly, 80% of the results are predicted with more than 78% fitness.

By comparing the rating on a scale composed of very low, low, medium, high and very high, the actual and predicted ratings are all similar expect for project 10. Consequently, the overall results are acceptable and the application of the fuzzy logic to the time contingency estimation performs its goals.

Table 25 Model Results in Predicting Cost Contingency and Performance Evaluation

Project No.	Actual CC %	Predicted CC %	Actual CC Rating	Predicted CC Rating	VAR (CC)	AIP (CC)	AVP (CC)
1	30.0%	26.5%	H	H	3.5%	11.7%	88.3%
2	11.0%	10.4%	L	L	0.6%	5.4%	94.6%
3	25.0%	25.2%	M	H	-0.2%	0.8%	99.2%
4	3.8%	6.0%	VL	VL	-2.3%	60.0%	40.0%
5	3.2%	6.0%	VL	VL	-2.8%	85.5%	14.5%
6	36.4%	25.7%	H	H	10.7%	29.3%	70.7%
7	9.9%	10.5%	L	L	-0.6%	6.2%	93.8%
8	25.0%	26.1%	M	H	-1.1%	4.4%	95.6%
9	10.0%	10.4%	L	L	-0.4%	4.0%	96.0%
10	27.3%	27.0%	H	H	0.3%	1.0%	99.0%
Average					**2.2%**	**20.8%**	**79.18%**

As shown in Table 25, the same three criteria are used to evaluate the performance of the proposed model in terms of indication for cost contingency. Based on comparison of the predicted and the actual results, the variance ranges from 0.2% to 10.7%. The average absolute variance is 2.2%.

All projects variances are lower than 3.5% except for project 6, which has a variance of 10.7%. The model average validity percent (AVP) is 79.18%. By considering the AVP for each project, six projects are above 90%, which indicates excellent validity and high level of fitness (Zayed and Halpin, 2005). One project is above 88% which indicates very good validity and level of fitness. One project is above 70% which indicates acceptable validity and fitness. Finally, projects 4 and 5 are below 70% which indicates poor validity and fitness. This is mainly due to their low values of contingency; hence, the variance constitutes a significant amount of their original values and results in low AVP. Accordingly, 70% of the results are predicted with more than 88% fitness and 80% of the results with more than 70%.

By comparing the rating, the actual and predicted ratings are all similar expect for project 3 and 8. Consequently, the overall results are acceptable and the application of the fuzzy logic to the time contingency estimation performs its goals. The model has a higher validity to predict the cost contingency with respect to time contingency.

5. Model Validation via Case Study Applications

After completing initial testing and tuning of the model, it has to be validated to ensure the reliability of the results and the degree of the indication. For the purpose of validation of the developed and proposed fuzzy logic model, actual data of five completed Egyptian construction projects have been obtained via the questionnaire survey that was filled during face-to-face meetings. These five projects were not used in the initial testing of the model and they are new cases. The same procedure adopted during the initial testing is applied in the validation except that no tuning shall be done to the model at this stage of testing. The outputs results of the model shall be evaluated using the same performance evaluation criteria used during the initial testing. Tables (26) and (27) show the actual projects data reported by the questionnaire respondents.

Table 26 Actual Projects Data Used for Validation

Project No.	Project Type	Contract Type	Delivery Method	Original Duration (Months)	Actual Duration (Months)	Original Cost (EGP M)	Actual Cost (EGP M)	Actual TC %	Actual CC %
1	Residential	Lump sum	Design-Bid-Build	16	22	140	164	37.5%	17.1%
2	Retail, Commercial, Residential	Lump sum	Design-Build	7	10	36	48	42.9%	33.3%
3	Retail, Residential	Unit Price/Re-measured	Design-Bid-Build	22	34	400	490	54.5%	22.5%
4	Hospitality	Lump sum	Design-Bid-Build	30	34	830	1030	13.3%	24.1%
5	Commercial	Lump sum	Design-Build	26	31	251	272	19.2%	8.4%

Table 27 Actual Projects Data Obtained from Questionnaire for Validation

Factors	Project 1	Project 2	Project 3	Project 4	Project 5
	Factors Rating				
Expected Amount of Change Orders & Owner Behavior Toward Change	8	2	10	5	9
Level of Constructability and Extent of Design Review	9	2	5	6	10
Owner/Project Manager Management Capability, and Ability to Take Timely Decisions	3	0	2	9	6
Scope Definition and Clarity	2	2	1	3	10
Time Allowed for project Planning	2	3	3	3	8
Market Conditions Stability	9	8	0	5	9
Potentional Contractor Experience & Capability	10	8	9	10	7
Schedule Clarity and Accuracy	3	0	0	10	10
Owner Financial Capability and Timing of Payments	2	1	2	9	8
Project Complexity	2	1	5	8	6
Investigation of Existing Site Conditions	3	4	1	7	7

As shown in Table 28, three criteria are used to evaluate the performance of the proposed model in terms of indication for time contingency. Based on comparison of the predicted and the actual results, the variance ranges from 1% to 10.1% while the average absolute variance is 5.5 %. The model average validity percent (AVP) is 83.91%.

Table 28 Model Outputs Results in Predicting Time Contingency

Project No.	Actual TC %	Predicted TC %	Actual TC Rating	Predicted TC Rating	VAR (TC)	AIP (TC)	AVP (TC)
1	37.5%	29.9%	M	M	7.6%	20.3%	79.7%
2	42.9%	39.2%	H	M	3.7%	8.6%	91.4%
3	54.5%	44.5%	VH	H	10.1%	18.4%	81.6%
4	13.3%	14.4%	L	L	-1.1%	8.0%	92.0%
5	19.2%	14.4%	L	L	4.8%	25.1%	74.9%
Average					**5.5%**	**16.1%**	**83.91%**

By considering the AVP for each project, two projects are above 90%, which indicates excellent validity and high level of fitness (Zayed and Halpin, 2005). One project is above 80% which indicates very good validity and level fitness. Two projects are above 70% which indicates acceptable validity and fitness. Accordingly, 40% of the results predicted with more than 90% fitness while 20% with more than 80%, and 40% of the results with more than 70% fitness.

By comparing the rating on a scale composed of very low, low, medium, high and very high, the actual and predicted ratings are all similar expect for project 3. Consequently, the overall results are acceptable and the application of the fuzzy logic to the time contingency estimation performs its goals and valid.

As shown in Table 29, the same three criteria are used to evaluate the performance of the proposed model in terms of indication for cost contingency. Based on comparison of the predicted and the actual results, the variance ranges from 1.6% to 7.6%. The average absolute variance is 3.8%.

The model average validity percent (AVP) is 81.41%. By considering the AVP for each project, one project is above 90%, which indicates excellent validity and high level of fitness (Zayed and Halpin, 2005). Three projects are above 80% which indicates very good validity and level of fitness. Project no. 4 is below 70% which indicates poor validity and fitness. Accordingly, 20% of the results are predicted with more than 90% fitness, 60% with more than 80% fitness, and finally, 20% of the results with less than 70%.

Table 29 Model Output Results in Predicting Cost Contingency

Project No.	Actual CC %	Predicted CC %	Actual CC Rating	Predicted CC Rating	VAR (CC)	AIP (CC)	AVP (CC)
1	17.1%	19.5%	M	M	-2.4%	13.8%	86.3%
2	33.3%	30.0%	H	H	3.3%	10.0%	90.0%
3	22.5%	26.6%	M	H	-4.1%	18.3%	81.7%
4	24.1%	16.5%	M	M	7.6%	31.4%	68.6%
5	8.4%	10.0%	L	L	-1.6%	19.5%	80.5%
Average					**3.8%**	**18.6%**	**81.41%**

By comparing the rating, the actual and predicted ratings are all similar according to the proposed rating scale. Consequently, the overall results are acceptable and the application of the fuzzy logic to the cost contingency estimation performs its goals and valid. The model has a higher validity to predict the time contingency compared to cost contingency, but this may change when the number of projects used in testing is increased, so this statement cannot be generalized.

6. Conclusion and Recommendations

A. Summary and Conclusion

Setting the contingency correctly is one of the major factors to achieve project success. Assigning time and cost contingency values in the planning/pre-construction project stage is a dilemma encountered by owners and project managers. It is usually based on expert judgment, which is subjective and not based on a mathematical model that considers project specific factors. Determination of the correct contingency amounts is crucial to avoid budget and time overruns as well as to avoid tie up of funds that can be used in other projects and activities by the owner. Time and/or budget overrun have many associated negative consequences for the owner such as loss of revenues, delay in staff move-in, loss of opportunities, etc. Many studies have been done earlier to estimate project contingencies; however, most of them address contingency from different point of views, mostly from the contractor point of view.

This study basically proposed a model to predict the owner time and cost contingency using fuzzy logic approach for large Buildings construction projects in Egypt. The proposed model enables the owners and projects managers estimate the contingency reliably based on a mathematical model that compiles experts' judgement based on literature and questionnaires. Accordingly, a fuzzy logic model has been developed. The 11 most significant factors affecting time and cost contingency have been set as the input variables of the model. The output variables of the model haven been set as the time and cost contingency as a percentage from the project original time and cost. The model runs based on set of input data by the user, which is mainly rating each of the 11 factors for the project. The model can be used in the pre-tender stage before setting the budget and the project master schedule.

To determine the most significant factors, a list of 59 factors affecting time and cost contingency have been identified from literature. The 59 factors were subjected to review process to exclude irrelevant and redundant factors. Following elimination process, a shortlist of 30 factors has been achieved and inserted into a questionnaire that was distributed to construction professionals in the Egyptian market to rank the importance of the factors on a scale from 0 to 10. The Delphi technique was used for the data gathering where two rounds have been held to achieve convergence of the results. Following analysis of the results, the most 11 significant and relevant factors, ranked from most significant to less significant, were found to be;

1. The amount of changes and owner behavior towards changes
2. Level of constructability and extent of design review
3. Owner management capability and ability to take timely decisions
4. Scope definition and clarity
5. Time allowed for project planning
6. Market conditions
7. Contractor capability and experience
8. Schedule accuracy
9. Owner financial capability and timing of payments
10. Project complexity
11. Investigation of existing site conditions

45 Meta rules have been set as the fuzzy rules in order to incorporate the wide range of possibilities, which is equivalent to 177,147 possibility. The Meta rules considered the effect of the factors on the time and cost contingency on a scale of very low, low, medium, high and very high, and considered the no. of the resultant to yield a total score. Based on the total score, the cumulative effect of the factors on the contingency is determined.

During the development phase of the model, seven models have been developed, mainly differing in the design of the membership functions as there is no clear guidance on the best model settings. Fuzzy rules were kept the same since they are based on logic. The seven models were initially tested using actual data of 10 real projects, which has been gathered via a questionnaire distributed to Egyptian Construction professionals. Following initial testing, the best model was subjected to tuning. After the tuning process, the model performance increased, and further modifications were not allowed. Finally, the model was validated using actual data of five real projects that was obtained via the questionnaire as well. The results of the model was found to be acceptable and yielded an AVP of 84% and 81% for time and cost contingency respectively.

Accurate determination of contingency values will reduce/avoid budget and time overruns, avoid tie up of funds that can be used in other projects and avoid owners project managers receiving blame from top management. Another important factor is that the model enables the user to visualize and understand the effect of the setting of project parameters in terms of time and cost effect. Therefore, the owner/project manager may consider to work on taking necessary actions to reduce the value of the contingency and accordingly, reduce the risks of the project that may lead to exceeding the budget and/or slippage of the completion date. As the total project value affects decision making by the owner whether to proceed or not to proceed, incorporating a reliable contingency would be helpful and increase confidence in such decision. The developed model is specifically designed to work for large Building construction projects in Egypt and can be used by owners and project management firms to assign the budget and time contingency during the pre-construction stage of the project. It should also be noted that time changes may also affect the project cost, which is considered in the model while calculating the cost contingency.

B. Limitations

It should be noted that the research has some limitations that should be taken into consideration.

1- This research address buildings construction projects only and is not applicable to infrastructure projects, industrial projects, etc.

2- In the model, all 11 factors must have input values to estimate the contingency, so the user must be aware of the conditions of all the 11 factors not only some of them for any given project.

3- The proposed model level of usage is dependent on the extent of the user familiarity with fuzzy logic; however, the model interface on MS Excel is very simple to be used in terms of inputs and outputs. A need exists for further collaboration with professionals to clarify and confirm how the models can more suit their requirements.

4- The developed model can only handle trapezoidal, triangular and linear membership functions. In addition, the defuzzification method is centroid. Further model development is needed in order to incorporate other fuzzy logic techniques of operation.

C. Recommendations for Future Research

There is still room for further development of several aspects related to this research despite the proposed model. Further development could be done in future research by:

- Developing models for specific building project types such as retail, commercial, residential, hospitality, etc.
- Considering other construction projects categories such as infrastructure, industrial, etc.

- Incorporating additional project parameters in the prediction model such as prediction of project quality and the relationship behavior between the owner and contractor and adding them to the model outputs.

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8. Appendices

Appendix A: Fuzzy Meta Rules

No.		Score of Input Variables		Score Value		Output Variable		Rating
1	IF	SCORE	equals	55	Then	Cost Continge	is	VH
2	IF	SCORE	equals	54	Then	Cost Continge	is	VH
3	IF	SCORE	equals	53	Then	Cost Continge	is	VH
4	IF	SCORE	equals	52	Then	Cost Continge	is	VH
5	IF	SCORE	equals	51	Then	Cost Continge	is	VH
6	IF	SCORE	equals	50	Then	Cost Continge	is	VH
7	IF	SCORE	equals	49	Then	Cost Continge	is	VH
8	IF	SCORE	equals	48	Then	Cost Continge	is	H
9	IF	SCORE	equals	47	Then	Cost Continge	is	H
10	IF	SCORE	equals	46	Then	Cost Continge	is	H
11	IF	SCORE	equals	45	Then	Cost Continge	is	H
12	IF	SCORE	equals	44	Then	Cost Continge	is	H
13	IF	SCORE	equals	43	Then	Cost Continge	is	H
14	IF	SCORE	equals	42	Then	Cost Continge	is	H
15	IF	SCORE	equals	41	Then	Cost Continge	is	H
16	IF	SCORE	equals	40	Then	Cost Continge	is	H
17	IF	SCORE	equals	39	Then	Cost Continge	is	H
18	IF	SCORE	equals	38	Then	Cost Continge	is	H
19	IF	SCORE	equals	37	Then	Cost Continge	is	H
20	IF	SCORE	equals	36	Then	Cost Continge	is	H
21	IF	SCORE	equals	35	Then	Cost Continge	is	M
22	IF	SCORE	equals	34	Then	Cost Continge	is	M
23	IF	SCORE	equals	33	Then	Cost Continge	is	M
24	IF	SCORE	equals	32	Then	Cost Continge	is	M
25	IF	SCORE	equals	31	Then	Cost Continge	is	M
26	IF	SCORE	equals	30	Then	Cost Continge	is	M
27	IF	SCORE	equals	29	Then	Cost Continge	is	M
28	IF	SCORE	equals	28	Then	Cost Continge	is	M
29	IF	SCORE	equals	27	Then	Cost Continge	is	M
30	IF	SCORE	equals	26	Then	Cost Continge	is	M

31	IF	SCORE	equals	25	Then	Cost Continge	is	L
32	IF	SCORE	equals	24	Then	Cost Continge	is	L
33	IF	SCORE	equals	23	Then	Cost Continge	is	L
34	IF	SCORE	equals	22	Then	Cost Continge	is	L
35	IF	SCORE	equals	21	Then	Cost Continge	is	L
36	IF	SCORE	equals	20	Then	Cost Continge	is	L
37	IF	SCORE	equals	19	Then	Cost Continge	is	L
38	IF	SCORE	equals	18	Then	Cost Continge	is	L
39	IF	SCORE	equals	17	Then	Cost Continge	is	L
40	IF	SCORE	equals	16	Then	Cost Continge	is	L
41	IF	SCORE	equals	15	Then	Cost Continge	is	L
42	IF	SCORE	equals	14	Then	Cost Continge	is	VL
43	IF	SCORE	equals	13	Then	Cost Continge	is	VL
44	IF	SCORE	equals	12	Then	Cost Continge	is	VL
45	IF	SCORE	equals	11	Then	Cost Continge	is	VL

Appendix B: Model Snapshots

1. Inputs

I. Independent Variables

No.	Name	Range: Lower End	Range: Higher End	Unit
1	Changes	0	10	1
2	Constructability	0	10	1
3	Management Cap.	0	10	1
4	Scope definition	0	10	1
5	Time for planning	0	10	1
6	Market conditions	0	10	1
7	Contractor Cap.	0	10	1
8	Schedule Accuracy	0	10	1
9	Payments	0	10	1
10	Complexity	0	10	1
11	Investigation of Site	0	10	1

Figure 25 User Interface to define the input variables, ranges and unit

II. Independent Variables Fuzzification

Variable No.	Name	Set No.	Linguistic Description	Membership Function: Select Type	Parameters: 1	2	3	4	5	6	7	8
1	Changes	1	Low	Linear	0	1	5	0				
1	Changes	2	Medium	Triangle	2.5	0	5	1	7.5	0		
1	Changes	3	High	Linear	5	0	10	1				
2	Constructability	1	Low	Linear	0	1	5	0				
2	Constructability	2	Medium	Triangle	2.5	0	5	1	7.5	0		
2	Constructability	3	High	Linear	5	0	10	1				
3	Management Cap.	1	Low	Linear	0	1	5	0				
3	Management Cap.	2	Medium	Triangle	2.5	0	5	1	7.5	0		
3	Management Cap.	3	High	Linear	5	0	10	1				
4	Scope definition	1	Low	Linear	0	1	5	0				
4	Scope definition	2	Medium	Triangle	2.5	0	5	1	7.5	0		
4	Scope definition	3	High	Linear	5	0	10	1				
5	Time for planning	1	Low	Linear	0	1	5	0				
5	Time for planning	2	Medium	Triangle	2.5	0	5	1	7.5	0		
5	Time for planning	3	High	Linear	5	0	10	1				
6	Market conditions	1	Low	Linear	0	1	5	0				
6	Market conditions	2	Medium	Triangle	2.5	0	5	1	7.5	0		
6	Market conditions	3	High	Linear	5	0	10	1				
7	Contractor Cap.	1	Low	Linear	0	1	5	0				
7	Contractor Cap.	2	Medium	Triangle	2.5	0	5	1	7.5	0		
7	Contractor Cap.	3	High	Linear	5	0	10	1				
8	Schedule Accuracy	1	Low	Linear	0	1	5	0				
8	Schedule Accuracy	2	Medium	Triangle	2.5	0	5	1	7.5	0		
8	Schedule Accuracy	3	High	Linear	5	0	10	1				
9	Payments	1	Low	Linear	0	1	5	0				
9	Payments	2	Medium	Triangle	2.5	0	5	1	7.5	0		
9	Payments	3	High	Linear	5	0	10	1				
10	Complexity	1	Low	Linear	0	1	5	0				
10	Complexity	2	Medium	Triangle	2.5	0	5	1	7.5	0		
10	Complexity	3	High	Linear	5	0	10	1				
11	Investigation of Site	1	Low	Linear	0	1	5	0				
11	Investigation of Site	2	Medium	Triangle	2.5	0	5	1	7.5	0		
11												

Figure 24 User Interface to Define Membership Functions

The user to input the coordinates of the membership functions vertices.

3. Single Case

I. User Input

No.	Input Variable	Value	Linguistic term 1	Linguistic term 2	Linguistic term 3	Effect of Term 1	Effect of Term 2	Effect of Term 3
1	Changes	5		Medium			H	
2	Constructability	6		Medium	High		M	L
3	Management Cap.	9			High			B
4	Scope definition	3	Low	Medium		A	M	
5	Time for planning	3	Low	Medium		H	M	
6	Market conditions	5		Medium			M	
7	Contractor Cap.	10			High			B
8	Schedule Accuracy	10			High			B
9	Payments	9			High			B
10	Complexity	8			High			L
11	Investigation of Site	7		Medium	High		M	L

Figure 26 User Interface to input the rating of a factors for a given project to calculate the contingency

The user is required to input a value from 0 to 10 for each of the 11 factors in the column named "Value".

IV. Calculation

		Low	*Medium*	*High*
1	Changes	0	1	0
2	Constructability	0	0.6	0.2
3	Management Cap.	0	0	0.8
4	Scope definition	0.4	0.2	0
5	Time for planning	0.4	0.2	0
6	Market conditions	0	1	0
7	Contractor Cap.	0	0	1
8	Schedule Accuracy	0	0	1
9	Payments	0	0	0.8
10	Complexity	0	0	0.6
11	Investigation of Site	0	0.2	0.4

		Very Low	**Low**	**Medium**	**High**	**Very High**
12	**Cost Contingency**	**0**	**0.2**	**0.4**	**0**	**0**

Cost Contingency	**16.54%**

Figure 27 Resultant Cost Contingency Calculation Sample based on rules aggregation

Appendix C: Questionnaire 1- Ranking of Factors affecting Owner Time and Cost Contingency

Ranking of Factors Affecting Owner Time and Cost Contingency

Dear Respondent,

Thank you for your time and effort to complete this questionnaire. Your valuable input is highly appreciated.

The aim of this questionnaire is to rank the importance of factors that affect owner time and cost contingency in Egypt

The results shall be used for an on-going research in the American University in Cairo. The research aims to provide the project owners and project management offices a reliable tool to enable them predict the owner project time and cost contingency confidently via defining project parameters.

The questionnaire is composed of the following four sections and shall not take more than 10 minutes of your time.
1- Information about Respondent
2- Ranking of Factors affecting Time and Cost Contingency
3- Feedback/Comments (if any)

Confidentiality Statement:

Your responses will be kept strictly confidential. The data from this research will only be reported in aggregate form. All your information will be coded and will remain confidential.

If you have any questions about the survey, please contact me through:

Name: Seif Nawar
M: +20100 5450005
E-mail: seif_nawar@aucegypt.edu

Respondent Information

1. **Name (Optional)**

____

2. **Contact Details (E-mail/Phone)**

____

3. **Years of Experience**
Mark only one oval.

- ◯ 0-5 years
- ◯ 5-10 years
- ◯ 10-15 years
- ◯ 15 years and above

4. **Current Position/Title**

____

5. **Background Experience**
(Based on majority)
Mark only one oval.

- ( ) Developer/Owner
- ( ) Engineer/Consultant
- ( ) Project Manager/Cost Manager
- ( ) Contractor

Ranking of Factors

Please rate the below factors on a scale from 0 to 10. 0 is not important/no effect and 10 is the very important/high effect.

6. **Contract clarity**
Mark only one oval.

1	2	3	4	5	6	7	8	9	10
( )	( )	( )	( )	( )	( )	( )	( )	( )	( )

7. **Amount of Change orders and owner behavior toward change**
Mark only one oval.

1	2	3	4	5	6	7	8	9	10
( )	( )	( )	( )	( )	( )	( )	( )	( )	( )

8. **Scope definition and clarity**
Mark only one oval.

1	2	3	4	5	6	7	8	9	10
( )	( )	( )	( )	( )	( )	( )	( )	( )	( )

9. **Time allowed for project planning at pre-tender stage**
Mark only one oval.

1	2	3	4	5	6	7	8	9	10
( )	( )	( )	( )	( )	( )	( )	( )	( )	( )

10. **Weather conditions**
Mark only one oval.

1	2	3	4	5	6	7	8	9	10
( )	( )	( )	( )	( )	( )	( )	( )	( )	( )

11. **Market conditions stability**
Mark only one oval.

1	2	3	4	5	6	7	8	9	10
◯	◯	◯	◯	◯	◯	◯	◯	◯	◯

12. **Potential contractor experience and capability**
Mark only one oval.

1	2	3	4	5	6	7	8	9	10
◯	◯	◯	◯	◯	◯	◯	◯	◯	◯

13. **Schedule clarity and accuracy**
Mark only one oval.

1	2	3	4	5	6	7	8	9	10
◯	◯	◯	◯	◯	◯	◯	◯	◯	◯

14. **Level of constructability and extent of design review**
Mark only one oval.

1	2	3	4	5	6	7	8	9	10
◯	◯	◯	◯	◯	◯	◯	◯	◯	◯

15. **Absence of PM firm**
Mark only one oval.

1	2	3	4	5	6	7	8	9	10
◯	◯	◯	◯	◯	◯	◯	◯	◯	◯

16. **Owner financial capability and timing of payments**
Mark only one oval.

1	2	3	4	5	6	7	8	9	10
◯	◯	◯	◯	◯	◯	◯	◯	◯	◯

17. **Project complexity**
Mark only one oval.

1	2	3	4	5	6	7	8	9	10
◯	◯	◯	◯	◯	◯	◯	◯	◯	◯

18. **Investigation of existing site conditions**
Mark only one oval.

1	2	3	4	5	6	7	8	9	10
◯	◯	◯	◯	◯	◯	◯	◯	◯	◯

19. **Owner/Project Manager management capability and ability to take timely decisions**
Mark only one oval.

1	2	3	4	5	6	7	8	9	10
◯	◯	◯	◯	◯	◯	◯	◯	◯	◯

20. **Delivery Method/Procurement Route**
Mark only one oval.

1	2	3	4	5	6	7	8	9	10
◯	◯	◯	◯	◯	◯	◯	◯	◯	◯

21. **Problem with neighbors**
Mark only one oval.

1	2	3	4	5	6	7	8	9	10
◯	◯	◯	◯	◯	◯	◯	◯	◯	◯

22. **Political conditions stability**
Mark only one oval.

1	2	3	4	5	6	7	8	9	10
◯	◯	◯	◯	◯	◯	◯	◯	◯	◯

23. **Soil conditions**
Mark only one oval.

1	2	3	4	5	6	7	8	9	10
◯	◯	◯	◯	◯	◯	◯	◯	◯	◯

24. **Budget allocation and estimation accuracy**
Mark only one oval.

1	2	3	4	5	6	7	8	9	10
◯	◯	◯	◯	◯	◯	◯	◯	◯	◯

25. **Owner safety culture**
Mark only one oval.

1	2	3	4	5	6	7	8	9	10

26. **Conflict in point of view between contractor and consultant**
Mark only one oval.

1	2	3	4	5	6	7	8	9	10

27. **Type of project bidding and award (negotiation, lowest bidder)**
Mark only one oval.

1	2	3	4	5	6	7	8	9	10

28. **Project Type**
Mark only one oval.

1	2	3	4	5	6	7	8	9	10

29. **Owner/Engineer Amount of Interference**
Mark only one oval.

1	2	3	4	5	6	7	8	9	10

30. **Unexpected onerous requirements by client's supervisors**
Mark only one oval.

1	2	3	4	5	6	7	8	9	10

31. **Construction permits issuance**
Mark only one oval.

1	2	3	4	5	6	7	8	9	10

32. **Project location**

Mark only one oval.

1	2	3	4	5	6	7	8	9	10
◯	◯	◯	◯	◯	◯	◯	◯	◯	◯

33. **Site obstacles**

Mark only one oval.

1	2	3	4	5	6	7	8	9	10
◯	◯	◯	◯	◯	◯	◯	◯	◯	◯

34. **Contract Type**

Mark only one oval.

1	2	3	4	5	6	7	8	9	10
◯	◯	◯	◯	◯	◯	◯	◯	◯	◯

35. **Project size**

Mark only one oval.

1	2	3	4	5	6	7	8	9	10
◯	◯	◯	◯	◯	◯	◯	◯	◯	◯

Feedback/Comments

36. **Please list any factors that should be added to the above list (if any)**

Appendix D: Questionnaire 2 - Obtaining Actual Projects Data

Factors Affecting Construction Time and Cost Contingency in Egypt

Dear Respondent,

Thank you for your time and effort to complete this questionnaire. Your valuable input is highly appreciated.

The aim of this questionnaire is to explore the occurrence of delay and cost overruns in Egyptian Construction Projects and rank the factors that affect project time and cost contingency.

The results shall be used for an on-going research in the American University in Cairo. The research aims to provide the project owners and project management offices a reliable tool to enable them predict the project time and cost contingency confidently via defining project parameters.

The questionnaire is composed of the following four sections and shall not take more than 10 minutes of your time.
1- Information about Respondent
2- Previous Construction Project Data in Egypt
3- Ranking of Factors affecting Time and Cost Contingency
4- Feedback/Comments (if any)

Confidentiality Statement:

Your responses will be kept strictly confidential. The data from this research will only be reported in aggregate form. All your information will be coded and will remain confidential.

If you have any questions about the survey, please contact me through:

Name: Seif Nawar
M: +20100 5450005
E-mail: seif_nawar@aucegypt.edu

* Required

Section 1 of 4: Respondent Information (1 min.)

1. **Name**
   (Optional)

2. **Contact Details (E-mail or Phone)**
   (Optional)

3. **Years of Experience** *
   Mark only one oval.
   - 0 - 5 years
   - 5 - 10 years
   - 10 - 15 years
   - 15 years and above

4. **Current Position/Title**
(Optional)

____

5. **Field of Experience** *
(Based on majority of your experience)
Mark only one oval.

- ◯ Owner/Developer
- ◯ Project Manager/Cost Manager
- ◯ Engineer/Consultant
- ◯ Contractor

Section 2 of 4: Previous Construction Project Data in Egypt (1 - 2 mins)

For the largest project you have worked on in Egypt and managed, please state the following: (Values are not necessarily accurate, but should be close)

6. **Project Type** *
Check all that apply.

- ☐ Retail
- ☐ Hospitality
- ☐ Commercial
- ☐ Residential
- ☐ Industrial
- ☐ Infrastructure
- ☐ Educational/Institutional
- ☐ Other: _______________________________

7. **Contract Type** *
Mark only one oval.

- ◯ Lump sum
- ◯ Unit Price/Re-measured
- ◯ Cost Plus
- ◯ Other: _______________________________

8. **Delivery Method/Procurement Route** *
Mark only one oval.

- ◯ Design-Build
- ◯ Design-Bid-Build (Traditional)
- ◯ Construction Management at Risk
- ◯ Other: _______________________________

9. **Original Project Duration** *

10. **Actual Project Duration** *
The duration taken for project completion

11. **Original Project Budget** *
Approved Budget before Project Tender

12. **Actual Cost/Final Account Value** *

Section 3 of 4: Rating of factors affecting project time and cost contingency (6-7 mins)

Listed below are 11 factors that have a direct effect on project time and/or cost contingency.

For each factor, choose the case that existed in your project that you have mentioned in the previous section.

13. **Expected Amount of Change Orders & Owner Behavior Toward Change** *
Please describe the case of your project
Mark only one oval.

	1	2	3	4	5	6	7	8	9	10	
High and tendency to do change orders	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	Low and tendency to follow original design

14. **Level of Constructability and Extent of Design Review** *
Constructability reflects the ease with which a project can built and the quality of its construction documents. Extent of design review reflects the level of checking design for errors, completeness, deficiencies, conflicts between design documents, etc.
Mark only one oval.

	1	2	3	4	5	6	7	8	9	10	
No Design Review & low Constructaibility	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	Extensive and Detailed Review & High Constructability

15. **Owner/Project Manager Management Capability, and Ability to Take Timely Decisions** *

Amount of Owner Interference is the frequency which the owner stops/hold the works

Mark only one oval.

	1	2	3	4	5	6	7	8	9	10	
Weak Capability, high owner interference and does not take timely decisions	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	Strong Capability, low owner Interference and usually takes timely decisions

16. **Scope Definition and Clarity** *

Mark only one oval.

	1	2	3	4	5	6	7	8	9	10	
Missing scope of works and not clearly defined	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	Clearly defined and clear scope

17. **Time Allowed for Project Planning** *

Mark only one oval.

	1	2	3	4	5	6	7	8	9	10	
Very Tight and insufficient	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	Relaxed and more than sufficient

18. **Market Conditions Stability** *

Choose the state of Market condition at the time of the project execution. Market conditions include material prices, currency exchange rates, customs and taxes laws, etc.

Mark only one oval.

	1	2	3	4	5	6	7	8	9	10	
Unstable (e.g. High fluctuation of material prices, exchange rates and changes in laws)	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	Stable (e.g. rarely do material prices and tax laws change, etc.)

19. **Potentional Contractor Experience & Capability** *

Potential contractor is the contractor who will most likely execute the project

Mark only one oval.

	1	2	3	4	5	6	7	8	9	10	
Limited experience and questionnable capability											Excellent experience and capability

20. **Schedule Clarity and Accuracy** *

Does the schedule reflect accurate date for site possession? Is the schedule realistic or non-realistic, compressed or relaxed? Does it reflect necessary milestones for coordination, etc.?

Mark only one oval.

	1	2	3	4	5	6	7	8	9	10	
Non-realistic, unclear schedule and missing details											Realistic and relaxed schedule

21. **Owner Financial Capability and Time of Payments** *

Mark only one oval.

	1	2	3	4	5	6	7	8	9	10	
Low capability and always delays payments											High capability and always release payments on time

22. **Project Complexity** *

Mark only one oval.

	1	2	3	4	5	6	7	8	9	10	
High (Complex and Unique in Nature)											Low (Traditional)

23. **Investigation of Existing Site Conditions** *

Were the existing site conditions investigated and evaluated properly such that all necessary works have been accounted for in the tender package? e.g. conflicts between As-built drawings and site condition

Mark only one oval.

	1	2	3	4	5	6	7	8	9	10	
No or poor investigation	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	Detailed Investigation

Section 4 of 4: Feedback/Comment (if any)

24. **Please provide feedback/comments/recommendations on the survey (if any)**

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