

**FUZZY BASED MODELING FOR BIDDING DECISIONS  
AND MARKUP SIZE IN SAUDI ARABIA'S  
CONSTRUCTION INDUSTRY**

BY

**IBRAHIM SAEED ZAQOUT**

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DHAHRAN- 31261, SAUDI ARABIA

**DEANSHIP OF GRADUATE STUDIES**

This thesis, written by **IBRAHIM SAEED ZAQOUT** under the direction of his thesis advisor and approved by his thesis committee, has been presented and accepted by the Dean of Graduate Studies, in partial fulfillment of the requirements for the degree of **MASTER OF SCIENCE IN TELECOMMUNICATION ENGINEERING**.



Dr. Laith Hadidi 2-Feb-2022  
Department Chairman



Prof. Suliman Saleh Al-Homidan  
Dean of Graduate Studies

Date : 28/12/2021



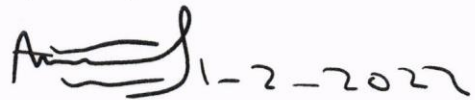
Dr. Muhammad Islam  
(Advisor)



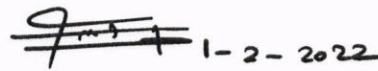
Dr. Laith Hadidi  
(Member)



Dr. Adel Alshibani  
(Member)

 1-2-2022

Dr. Awsan Mohammed  
(Member)

 1-2-2022

Dr. Ghaithan Ahmed  
(Member)





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*To the people I cherish the most in this world, who have always stood by me and have always been there for me; My beloved parents, my precious sisters, and my dear brothers, to you I dedicate this work.*

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# TABLE OF CONTENTS

## Contents

|                                                 |      |
|-------------------------------------------------|------|
| ACKNOWLEDGMENTS .....                           | III  |
| TABLE OF CONTENTS .....                         | IV   |
| LIST OF TABLES .....                            | VII  |
| LIST OF FIGURES .....                           | VIII |
| LIST OF ABBREVIATIONS .....                     | IX   |
| ABSTRACT .....                                  | X    |
| ملخص الرسالة .....                              | XI   |
| <br>                                            |      |
| 1 CHAPTER 1 INTRODUCTION .....                  | 1    |
| 1.1 Background .....                            | 1    |
| 1.2 Problem Statement.....                      | 3    |
| 1.3 Research Objectives.....                    | 4    |
| 1.4 Significance of the Study .....             | 4    |
| 1.5 Scope and Limitations of the Research ..... | 5    |
| 1.6 Structure of the Thesis.....                | 6    |
| <br>                                            |      |
| 2 CHAPTER 2 LITERATURE REVIEW .....             | 7    |

|          |                                                                           |           |
|----------|---------------------------------------------------------------------------|-----------|
| 2.1      | Factors Affecting Bid Markup Decision .....                               | 7         |
| 2.2      | Recent Models for Optimum Project and Markup .....                        | 11        |
| <b>3</b> | <b>CHAPTER 3 RESEARCH METHODOLOGY.....</b>                                | <b>16</b> |
| 3.1.     | Identifying factors affecting bidding decisions and the markup size ..... | 17        |
| 3.2.     | Collecting and Filtering Data .....                                       | 17        |
| 3.3.     | Ranking Factors .....                                                     | 17        |
| 3.4.     | Model Development.....                                                    | 18        |
| 3.5.     | Defining input and output variables .....                                 | 18        |
| 3.6.     | Defining membership function .....                                        | 18        |
| 3.7.     | Rules formulation .....                                                   | 19        |
| 3.8.     | Defuzzification and forecasting bid markup size of the project .....      | 19        |
| 3.9.     | Model Testing and Validation .....                                        | 20        |
| <b>4</b> | <b>CHAPTER 4 MODEL DEVELOPMENT AND DEMONSTRATION .....</b>                | <b>21</b> |
| 4.1      | Respondents' weights .....                                                | 21        |
| 4.2      | Importance weight and ranking critical bidding factors.....               | 27        |
| 4.3      | Decision to bid or not to bid .....                                       | 32        |
| 4.4      | Case studies for Model Demonstration .....                                | 33        |
| 4.5      | Model Testing and Validation .....                                        | 39        |
| 4.5.1    | Consistency analysis for the collected data .....                         | 39        |
| 4.5.2    | Sensitivity analysis .....                                                | 42        |
| 4.6      | Practical Guidance for Applying the Model in Real-life Projects .....     | 44        |
| <b>5</b> | <b>CHAPTER 5 SUMMARY, CONCLUSION &amp; RECOMMENDATIONS .....</b>          | <b>45</b> |
| 5.1      | Summary of the Research .....                                             | 45        |

|                           |           |
|---------------------------|-----------|
| 5.2 Findings.....         | 47        |
| 5.3 Conclusion .....      | 48        |
| 5.4 Recommendations ..... | 48        |
| 5.5 Future Research ..... | 49        |
| <b>REFERENCES.....</b>    | <b>50</b> |
| <b>APPENDIX-A.....</b>    | <b>62</b> |
| <b>VITAE.....</b>         | <b>65</b> |

## LIST OF TABLES

|                                                                                     |    |
|-------------------------------------------------------------------------------------|----|
| Table 1. List of factors affecting project bid markup.....                          | 9  |
| Table 2: Sample fuzzy rules for "Respondent Weight" .....                           | 23 |
| Table 3: Respondents' ranks and weights.....                                        | 26 |
| Table 4: Ranks and severity and frequency weights of bidding decisions factors..... | 30 |
| Table 5: Answers provided by the experts for the two case study projects.....       | 37 |
| Table 6: Chi-square and Cronbach's alpha tests for the collected data.....          | 40 |

## LIST OF FIGURES

|                                                                                                                  |    |
|------------------------------------------------------------------------------------------------------------------|----|
| Figure 1: Research Methodology.....                                                                              | 16 |
| Figure 2: Membership function for " Respondent Weight" .....                                                     | 22 |
| Figure 3: Formed rules for "Respondent Weight".....                                                              | 24 |
| Figure 4: Defuzzification process for "Respondent Weight" .....                                                  | 24 |
| Figure 5: Summary of the first model for identifying the first respondent's weight.....                          | 25 |
| Figure 6: Summary of the second model for identifying the severity and the frequency of<br>the first factor..... | 28 |
| Figure 7: The model's estimation for project markup in the “telecommunication” case<br>Study.....                | 35 |
| Figure 8: The model's estimation for project markup in the “housing project” case<br>study.....                  | 37 |
| Figure 9: model's defuzzification outcome for extreme boundary conditions.....                                   | 43 |

## **LIST OF ABBREVIATIONS**

|              |   |                                       |
|--------------|---|---------------------------------------|
| <b>FIS</b>   | : | Fuzzy Inference System                |
| <b>SW</b>    | : | Severity Weight                       |
| <b>FW</b>    | : | Frequency Weight                      |
| <b>IW</b>    | : | Importance Weight                     |
| <b>ANN</b>   | : | Artificial Neural Network             |
| <b>ANFIS</b> | : | Adaptive Neuro-Fuzzy Inference System |

## **ABSTRACT**

Full Name : IBRAHIM SAEED ZAQOUT  
Thesis Title : FUZZY BASED MODELING FOR BIDDING DECISIONS AND  
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Major Field : CONSTRUCTION ENGINEERING & MANAGEMENT  
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Previous studies mainly focused on finding factors affecting project markup and the decision to bid or not, without considering experts' weights and critical factors as input variables for forecasting. This study develops a three-step Mamdani-type of Fuzzy inference system that can give an accurate decision for contractors to bid or not, and at what markup percentage they should be bidding to realize profit. The first model develops a weight for each expert according to his experience. The second one develops a weight for each factor according to 31 respondents working in the kingdom construction industry that contributed in this study. The third model will gather all previous information as an input and is ready for contractors to enter their input and get the probability of bidding and the predicted markup size according to each project characteristics. The model is validated for two real projects in Saudi Arabia and founded to be reliable in assessing contractors bidding decisions. It is validated by sensitivity analysis and consistency test and found robust. Future research can optimize this model by incorporating other competitors' bids and enhance the prediction to guarantee the lowest price with reasonable profit.

## ملخص الرسالة

الاسم الكامل: إبراهيم سعيد عزات زقوت

عنوان الرسالة: تقدير هامش الربح واتخاذ القرار للدخول في المناقصات في المملكة العربية السعودية تبعا للعوامل المؤثرة باستخدام النمذجة المبهمة.

التخصص: هندسة وإدارة التشييد

تاريخ الدرجة العلمية: ديسمبر 2021

ركزت الدراسات السابقة على إيجاد العوامل المؤثرة على قرار المقاولين في الدخول في المناقصات وتحديد هامش الربح بدون الاعتماد على أهمية كل عامل أو عمق خبرة أصحاب القرار. تركز هذه الدراسة على إنشاء أداة محاكاة تمكن صناع القرار من تحديد تأثير كل عامل على قرار الدخول في المناقصة وتحديد هامش الربح للحصول على مشروع ناجح. في الجزء الأول من النموذج، يتم تصنيف المشاركين في الدراسة حسب خبرتهم في مشاريع البناء، خبرتهم في تقدير التكلفة، ودرجتهم العلمية. يتم هذا لتحديد وزن محدد لكل مشارك في الدراسة حتى نحصل على نتائج أفضل. في الجزء الثاني من النموذج، يتم إيجاد وزن لكل عامل مؤثر تبعا لتقدير 31 خبير شارك في الدراسة بعد تصنيفهم. وفي الجزء الأخير يقوم النموذج بجمع كل هذه البيانات وتصبح جاهزة لأصحاب القرار حتى يتمكنوا من ادخال معطياتهم الخاصة بالمشروع القادم والحصول على نسبة تقديرية لهامش الربح الذي يمكن الدخول فيه. أشارت النتائج إلى أن النموذج المطور قادر على توقع هامش الربح بدقة في أغلب الحالات ويمكن الاعتماد عليه. في مرحلة التحقق، تمت مقارنة هامش الربح الفعلي لمشروعين على أرض الواقع بواسطة النموذج. نجح النموذج في تقدير هامش الربح بدقة تزيد عن 95% لجميع المشاريع. هذا وقد تم إنشاء تطبيق على الحاسب الآلي يوظف نموذج تقدير هامش الربح لتسهيل استخدامه.



# CHAPTER 1

## INTRODUCTION

### 1.1 Background

Construction industry is considered as one of the largest industries in the current era. It is a special field due to the high risk and uncertainty bounded to it. Multiple factors play a role in this risk, including time, location, type of project, wages, economy, and even politics [2]. It can be said that any change occur in the country will be reflected on this field of work.

Due to the high risk involved, it is common that this risk is distributed on multiple parties, including owner, contractor, architect/engineer, consultant, and more [24]. This nature of work created different types of contracts, i.e., lump-sum, unit price, cost plus, incentive contracts, etc., where each of them has a certain set of risk allocation.

The most common way of awarding contracts in the world, and specifically in Saudi Arabia, is the competitive bidding [3]. In this method, the contract is awarded directly to the lowest bidder. It is believed that this approach saves the highest amount of money for the owner, i.e.; the government. Alternatively, the contractor is responsible for his bid and has to take into considerations all costs and risk involved in the contract. If a contractor fails to have the lowest bid, he will not be awarded and lose that opportunity. On the other

hand, if he gives a too low bid, he will realize high losses, may bankrupt, and eliminated from the industry.

The main objective for contractors is to realize profit, and it is the driver for them to succeed in the project. When estimating the price of a contract, contractors take into considerations every work item in the documents and compute the total expected project cost. Then they add their profit margin, which is called project markup. This markup constitutes of overhead, contingency, and profit, and is usually the main difference among bidding prices which results in awarding or losing the bid. If a contractor can identify factors influencing the project markup, then he can consider the right amount to add for each project type. This way will guarantee him winning the bid, or at least being one of the least bidders [10].

Previous studies done to determine the decision to bid or not focused on monetary criteria and the relative importance of each criterion. This was performed by distributing surveys to different contractors asking for their opinions about certain points. The results of these studies gave a general idea about most important factors to consider, such as past projects performance, technical knowledge, and cost [22]. More recent studied started to implement a variety of models to incorporate multiple factors and criteria in order to achieve higher results accuracy. Agent based models, fuzzy models, and machine learning, give researcher more capabilities to analyze and update input more frequently. These models began to appeal more to contractors, and some started utilizing their advantages of giving more accurate bidding decisions and markup percentages based on available data [13].

However, there is a high demand for implementation of such models in Saudi Arabia's construction industry due to enormous inappropriate decisions and cost overruns in current

projects [3]. Therefore, this study focuses on identifying critical bid mark-up factors influencing bidding decision and predicting the mark-up size (percentage of initial bid price) for Saudi construction contractors.

## **1.2 Problem Statement**

As stated in the study background, the determination of the suitable project markup is a crucial task for all contractors. Some contractors utilize certain models to obtain the right amount, and others use their own judgment [8]. However, neither ways can guarantee being the lowest bidder because this process is bounded to multiple factors and all of them should be taken into account.

It is also known that contractors may bid in some projects that they are not of their interest but to obtain other benefits. First, this reminds investors to consider this contractor and he is still in the market. Second, this reduces the profit of other competitors when they see many bids are given. However, a contractor may bid in some projects, but not all available projects. Thus, he has to decide on which projects to bid or not to bid regardless of his intention to win the project. If he wishes to win the competition, then he must know how to put the right percentage of bid markup for the right project depending on the criticality of the potential factors [10]. These points are the intend of this study.

### **1.3 Research Objectives**

The broader aim of this study is to find the critical decision-making factors for modelling appropriate bid mark-up size facilitating bid or no bid decision for the Saudi construction contractors. This aim will be achieved the following specific objectives:

- 1) To identify potential factors affecting contractors' decision to bid or not to bid in Saudi Arabia,
- 2) To rank the critical factors and their level of importance of affecting the decision on markup size that contractors should add in different project types in Saudi Arabia, and
- 3) To model a risk-induced contractor's bid markup size considering the identified critical factors in Saudi construction industry.

### **1.4 Significance of the Study**

Construction projects have encountered a huge progressive increase during the last two decades in Saudi Arabia. This is owing to the high oil revenues that were invested heavily in mega projects that worth 60 billion Riyals in 2012, and 150 billion Riyals in 2013 with an average growth of 4.5% among years. Saudi Arabian investment is divided into transportation, energy, and residential accommodations. [6]

In terms of country's capabilities, it utilizes 15% of its total workforce for construction, and 14% of the energy available. This can give clear evidence that construction was, and will be one of the largest investments in the current years. Currently, vision 2030 is

focusing on a variety of fields, including entertainment, transportation, and tourism. All these areas rely heavily on well-built infrastructure. Furthermore, NEOM (New Enterprise Operating Model) city project with a budget of \$500 billion is the largest project in the kingdom's history, which is under its development stage, will take a huge portion of the country budget. [22]

These future projects create numerous opportunities for the local and international contractors in Saudi Arabia. Each contractor will try to find the suitable project for him and will decide whether to bid or not to bid in certain projects. Moreover, if he decides to enter the bidding competition, he must know the appropriate markup size, which will be added to the total cost in order to win the bid and to realize profit simultaneously [5].

This thesis attempts to study factors affecting the decision to bid or not, and predicting the project markup size to be added on top of the cost considering the importance of those factors. This will give a more systematic way of estimating bid markup, increase the chances of winning the bid, and subsequently provide an economic project delivery.

## **1.5 Scope and Limitations of the Research**

The scope of this research is to study factors influencing the bid or no bid decision, and their impacts determining the markup for contractors. It is limited only in Saudi Arabian construction industry, and it is limited to competitive bidding awarding system with lump sum procurement system.

## **1.6 Structure of the Thesis**

The conducted research is organized in the following chapters:

Chapter 1: Introduction: This chapter includes a brief background on the topic of the research, a statement of the problem discussed in the research, the objective of the research, its significance, its scope, and limitations.

Chapter 2: Literature Review: Extensive literature review on the topic of the research is provided in this chapter. First, factors affecting bid markup decisions. Second, recent models developed to estimate project markup including ANN and AFNN. Finally, the previous work including the usage of fuzzy modeling in construction industry and other fields is covered.

Chapter 3: Research Methodology: This chapter illustrates the steps and phases the research is going through starting from identifying the critical factors affecting the project markup to the estimation of project markup.

Chapter 4: Model Development: This chapter illustrates the implementation of the steps listed in the research methodology to come up with the project markup and also, discusses the results obtained.

Chapter 5: Conclusion: This chapter summarizes the work done, gives a conclusion regarding the results obtained and provides possible directions for future work.

## **CHAPTER 2**

### **LITERATURE REVIEW**

In regard to competitive bidding approach, studies started since 1970s to discover its strength and weaknesses. Quantitative models were under a theoretical umbrella and never got applied in real situations. This has led contractors to depend only on their expertise and judgment rather than applying certain models.

However, in 21<sup>st</sup> century, as competition increases, studies focus on creating models that are applicable and beneficial to contractors. In this context, this part reviews the most recent literatures in two steps- (a) factors affecting bidding decisions and markup, and (b) the most recent models to choose the optimum project and markup.

#### **2.1 Factors Affecting Bid Markup Decision**

The first crucial task for a contractor is to select the proper projects to bid, especially with a large market and many available projects. This task requires a considerable amount of time and resources to be competed [7]. The bidding decision depends on internal and external factors, and selecting these factors is a complex process. Internal factors include evaluators' expertise, decision maker's interest, and his financial state. On contrary, external factors include the number of bidders, the type of project, and the economy of the country [4].

On top of that, the short time frame for bidding process makes it a very hard and critical decision. Bidding in the right project determines the success or failure for contractors. Thus, a recent study shows that many small and medium firms bankrupt within five years of their initiation. In Saudi Arabia, the contractor classification certificate is mandatory in governmental bidding. This insures and forces contractors to bid in projects according to their capacity.[29]

The decision to bid or not represents a dilemma for contractors. In one hand, if he decides not to bid, he may lose the chance of making money, resulting in an opportunity loss. In addition, even some future work with the same owner. If he keeps wasting these chances, this will result in eliminating him from the market. In the other hand, if the contractor decides to bid, he has to prepare a full estimate of direct and indirect cost, which requires time and resources. Yet, he may lose the bidding competition. Even if he won the competition but chose the wrong project, this will result in significant losses including money, reputation, and claims. Finally, to stay in the market and realize profits, a contractor has to bid in correct and beneficial projects, and to put the right markup to win the bidding competition.[7]

There are many studies conducted to find the factors affecting bid or no bid decision and to find suitable amount of bid markup. Some of the most relevant and recent studies are discussed below to find the potential factors affecting bid markup in Saudi Construction projects.

Alsaedi et al. (2019) studied the factors affecting the bidding choice of construction projects in Saudi Arabia. They collected information from previous studies around the

world, compared them, and then decided on the suitable factors to assess in the kingdom. They identified 31 factors under four categories. With these 31 factors, they developed a questionnaire and distributed over 67 contractors of different classes. By applying the relative importance index (RII) formula, the factors were ranked accordingly. According to their study, the most important factors were size and type of the job, company's strength in the industry, project cash flow, rate of return and design quality. [7]

Table 1 shows a list of related factors affecting bid markup decision and their categories with references:

Table 1. List of factors affecting project bid markup:

| <b>Related Group</b>    | <b>#</b> | <b>Factors</b>              | <b>Frequency in studies</b> |
|-------------------------|----------|-----------------------------|-----------------------------|
| Project characteristics | 1        | Project cash flow.          | 5 [2,12,22,7,24]            |
|                         | 2        | Size of contract.           | 4 [27,19,20,21]             |
|                         | 3        | Location of project.        | 2 [11,24]                   |
|                         | 4        | Type of equipment.          | 3 [3,19,20]                 |
|                         | 5        | Owner.                      | 7 [2,19,20,21,22,24,25]     |
|                         | 6        | Duration.                   | 5 [5,21,22,23,24]           |
|                         | 7        | Job start time.             | 5 [18,19,20,21,27]          |
| Project Documents       | 8        | Type of contract.           | 8 [31,19,20,21,22,23,24,25] |
|                         | 9        | Design quality.             | 6 [31,27,11,16,30,14]       |
|                         | 10       | Designer (A/E).             | 6 [31,19,20,21,22,27]       |
|                         | 11       | Owner special requirements. | 5 [5,6,14,31,26]            |

|                            |    |                                         |                                |
|----------------------------|----|-----------------------------------------|--------------------------------|
| Company<br>Characteristics | 12 | Availability of required cash.          | 6 [21,25,31,19,11,4]           |
|                            | 13 | Availability of required staff.         | 5 [31,21,9,8,15]               |
|                            | 14 | Experience in such projects.            | 7 [31,19,30,17,7,2,4]          |
|                            | 15 | Confidence in work force.               | 4 [31,19,12,27]                |
|                            | 16 | Need for work.                          | 8 [2,4,7,12,31,20,21,22]       |
|                            | 17 | Establishing long relation with client. | 7 [31,20,14,7,9,11,30]         |
|                            | 18 | Strength in industry.                   | 4 [30,31,21,25]                |
|                            | 19 | Current workload.                       | 5 [31,30,8,22,27]              |
|                            | 20 | Uncertainty in cost estimate.           | 8 [30,31,7,14,9,20,21,22]      |
|                            | 21 | Past profit in similar jobs.            | 9 [26,24,30,31,2,12,,22,24,25] |
|                            | 22 | Reliability of subcontractors.          | 2 [30,31]                      |
|                            | 23 | General overhead.                       | 3 [14,30,31]                   |
|                            | 24 | Public exposure.                        | 3 [24,25,27]                   |
|                            | 25 | Portion subcontracted.                  | 2 [30,31]                      |
| Bidding<br>Situation:      | 26 | Competition.                            | 9 [24,25,26,28,30,31,2,4,14]   |
|                            | 27 | Time to submit the bid.                 | 6 [27,24,25,30,31,2]           |
|                            | 28 | Required bond capacity.                 | 2 [14,12]                      |
|                            | 29 | Bidding documents price.                | 2 [30,31]                      |
|                            | 30 | Prequalification required.              | 2 [7,9]                        |
|                            | 31 | Time of bidding ( season ).             | 3 [20,22,23]                   |
|                            | 32 | Overall economy.                        | 4 [23,26,20,22]                |
|                            | 33 | Quality of available labor.             | 7 [12,13,14,27,21,22,23]       |
|                            | 34 | Availability of labor.                  | 7 [12,13,14,27,21,22,23]       |

|                        |    |                              |                          |
|------------------------|----|------------------------------|--------------------------|
| Economic<br>Situation: | 35 | Risk involved in investment. | 7 [11,13,22,25,28,30,31] |
|                        | 36 | Availability of equipment.   | 3 [11,22,24]             |
|                        | 37 | Governmental requirement.    | 2 [14,30]                |

## 2.2 Recent Models for Optimum Project and Markup

This section points out the most recent models applied for markup determination and their effects on profit and winning the project.

Al-Humaidi (2016) used Fuzzy-set model considering multi attributes in order to choose the right decision. It is clear that such decision depends on main factors, that are: level of experience, rank of each criterion, and its significance level. However, Al-Humaidi (2016) stated that previous studies failed to specify an uncertainty level involved in each project. In addition, the decision is traditionally dependent on monetary factors such as payback period and rate of return, but it lacks the non-monetary factors such as resources available and staying in the market. [4]

Al-Humaidi (2016) used Fuzzy Set Theory, because it is an effective tool in systems of unknown or unpredictable behavior, and in situations that require fast solutions. Thus, the technique for order preference by similarity to ideal solution (TOPSIS) was utilized, because it removes the subjectiveness of certain factors such as weight and rating of criteria, and level of expertise of decision makers. This model is also helpful for contractors

to choose among different available projects, and for owners to choose among different bidding documents – in case of non-competitive bidding-. [4]

Moselhi (2018) compared three different markup estimation models. He considered 23 factors under five categories to compare the three proposed models. For the Artificial Neural Network (ANN), the strength of using this method lies in its learning capabilities where it can update the data regularly and keep giving better results over time. It consists of an input and output layer, as well as hidden layers. For the Adaptive Neuro-Fuzzy Inference System (ANFIS), it combines the benefits of ANN and the logic of Fuzzy leading to faster learning process. It is similar to ANN with the addition of If-Then rules that filter the results and tune them in a better manner.[8]

The three models are compared with an actual 72 project with a known markup to see the closest model to the actual one. His study concludes that ANFIS is the most reliable model with the least mean square, and the most coefficient of correlation. [8]

Shem et al (2016) studied markup optimization by using cost- based items calculations. By applying linear methods and utilizing Excel and solver tool, they conducted a study on 29 construction activities and their respective markups. After calculating cash inflow and outflow and repeating the calculation, solver tools gave them the optimum markup for each cost item in the project, resulting in higher estimating accuracy Top categories considered in this study were: material and equipment, labor and others, and subcontracting costs. [27]

Elsayegh et al (2020) studied the competitive bidding by conducting a simulation model for two interacting agents, ie, projects and contractors. This study utilized AnyLogic Software to create the simulation model and then to analyze the given data. Each contractor

prepares a bid for a project, the bid value is dependent on estimation accuracy and project markup. In case of losing the project, he must review his estimation and markup to win in next projects. In case of winning, he may be realizing losses due to his bad estimation or very low markup, or he may realize profits and consider this project successful. The software takes all this data for all possible bidders and analyzes their behavior, helping bidders to have a better chance in future projects. The main factors considered in this study are capital, markup, estimation accuracy, and profit. [14]

Shafahi et al (2014) utilized Monte Carlo simulations combining project selection, markup size, and eminence. This model aimed to incorporate previous relationship with owners and compares the results of Monte Carlo with the conventional methods. By calculating the chance of winning an auction against all other competitors, authors found that the chances increase with positive relations. Main factors of this study are markup size, past projects performance, and resources availability. [24]

Ossama Hosny and Ahmed Elhakeem (2012) introduced the Optimum Mark- up Estimate Model (O-MEM) that helps in tracking bidding process and markups, analyzing competitors' input, and predicting the best possible bidding strategies for future. Using Monte Carlo simulation, the model gave better markup predictions for future projects that can result in higher profits. The study considered the surrounded market as the studying factor. [15]

Pengcheng Du and Shuxun Wang (2020) studied the effect of labor wages on project markup due to its difficulty in estimation because of lack of cost information. By utilizing instrumental variable regression and difference-in-differences methods, they found that

raising the minimum wage of labor resulted in increasing the markup, thus giving firms a higher chance of realizing profit. Main factors for this study are labor wage, productivity, and resources availabilities. [13]

Chao, L. C., & Liaw, S. J. (2017) have proposed a Fuzzy model in order to estimate project markup based on bidding position for contractors. The main factors are the need for work and the contractor's attitude towards risk. The model incorporates both factors in order to come with winning but profitable bidding price. [11]

Takano et al (2018) studied the optimal conditions for optimization model in numerical format, then examined the computed solutions and compared them with the model. By utilizing King-Mercer model, their aim was to investigate the effect of bidding markup and resource allocation on contractors' expected profit. This model indicated that both bid markup and resource allocation have to be considered for higher profit and will be helpful for decision making in a variety of bidding situations. [30]

Ye, K. et al (2014) performed a study in China using the Hotelling's T-squared (HT2) test in order to compare the difference between multiple project attributes and test the differences among them. The result of this study showed that key attributes for contractors to consider are: Project characteristic, Tendering procedure, Contract requirement, Construction plan, Client characteristic, Potential competitors, and Procurement. [31]

As stated in previous studies, most of them focused only on defining factors affecting either bidding decisions or markup size and have not combined them together. They also focused solely on ranking factors' importance and not their effect numerically on the markup size and bidding decision to bid or not. moreover, no research has studied the effect of these

factors in depth on Saudi construction industry. Thus, this study represents an effective tool for decision makers in construction industry to give them insights on most critical factors, their effect on markup size, and the decision to bid in project or not.

## CHAPTER 3

### RESEARCH METHODOLOGY

This chapter breaks out all necessary steps followed to reach the goal of the study. The results are achieved by applying the following steps in this figure:

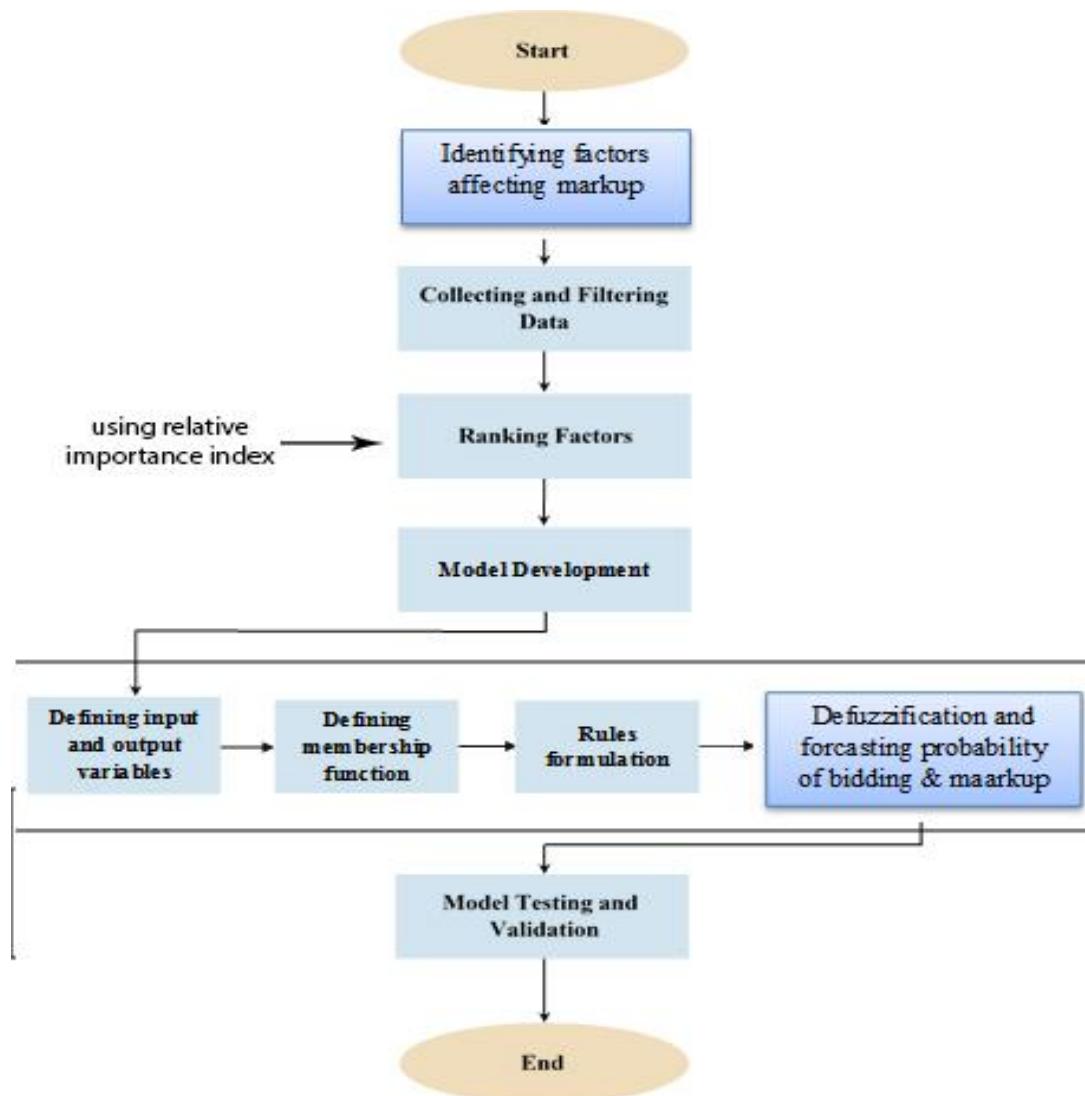


Figure 1: Research Methodology

### **3.1. Identifying factors affecting bidding decisions and the markup size**

The first step in this study is to identify the critical factors in order to rank them and test their significance. After studying the literatures, 37 factors related to bid markup are identified. These factors are categorized into five branches: Project Characteristics, Project Documents, Company Characteristics, Bidding Situation, and Economic Situation. The list of factors can be seen in Table 1 presented at the end of literature review section.

### **3.2. Collecting and Filtering Data**

Based on the factors identified by literature review and presented in Table 1, a structured questionnaire was formed for conducting online surveys followed by interviews with experts in order to measure the severity and frequency of each factor. The questionnaire consists of two parts. First part asks for general information about respondents, their position, experience in construction and bidding, and education level. The second part contains factors for evaluating their severity and frequency. A scale of 1 to 5 is made, 1 indicating very low, and 5 indicating very high importance, for assessing the frequency of occurrence and importance of the factors using experts' judgments. Then, outliers and inconsistent answers is omitted in order to ensure a more accurate model [7].

### **3.3. Ranking Factors**

After the filtration process, the factors are ranked based on the weight of each factor. For factor weight calculation, first the Severity weight (SW) and the Frequency weight (FW) are calculated, then the importance weight (IW) is calculated. The calculated importance weight values is used to weight each factor in the model. Multiplication of severity weight

and frequency weight gives the importance weight of a factor. Respondents input for each factor is aggregated in order to calculate its severity and frequency weights. Input values range between a scale of 1 to 5 and result in a factor's SW, FW, and IW ranging between 0 and 1. Higher values of IW indicate more importance for that factor, and thus more effect on the final model's output. The resulted IW values are then entered in the model as input variables and remain fixed throughout the entire model process of estimating markup size.

### **3.4. Model Development**

The development of the model is carried out thru the Fuzzy Inference System (FIS) using MATLAB. In FIS, a set of input is given in fuzzy logic in order to get the desired output. Steps to develop the model are illustrated in the following sections:

### **3.5. Defining input and output variables**

The first step in FIS is to specify all inputs and outputs of the model. The inputs in this study are respondents' weights and factors' weights. The output is the estimated project markup size.

### **3.6. Defining membership function**

The membership function here specifies the degree of fuzziness of input variables with assigning mathematical values. Inputs are fuzzified according to a variety of membership functions shapes. Each shape can serve a certain desired results depending on the nature of the study. In this study, the g bell-shaped is used since it gives smooth curve and integer values at all times. Other membership functions such as triangular and trapezoidal are valid in most cases, but they fail to give reasonable results in extreme boundaries. For example,

a project that has the lowest ranking of all critical factors (i.e. model input values are all zero) would give a model's output of 0% markup which is not practical. The real case is that a project with no critical factors to worry about is an appealing one for contractors and they can bid minimum markup size to win it and realize profits. The g-bell membership function gives a value of 8.% markup for the mentioned case which makes it the most reliable one in this study.

### **3.7. Rules formulation**

In all models, there must be some rules to govern the relationship between input values probability of occurrence and their impact on the output values probability. Rules are stated in the form of IF-THEN statements, “IF factor1 is very\_high, then Prob is very\_high”. Meanwhile, the calculated IW values are used to give weight for each factor in order to get suitable impact for each factor on the probability.

### **3.8. Defuzzification and forecasting bid markup size of the project**

This is the final step in developing the model, which is defuzzification. Fuzzy results are translated as crisp values using the centroid of area method. In this equation, the weighted average is calculated and the probability of bidding and having a suitable markup is forecasted according to this formula:

$$Z_{COA} = \frac{\int \mu_A(Z) \cdot Z \, dZ}{\int \mu_A(Z) \, dZ} \quad (5)$$

$Z_{COA}$  is the crisp output,  $\mu_A(Z)$  is the aggregated membership function, and  $Z$  is the output variable.(16)

### **3.9. Model Testing and Validation**

In order to validate this model, two real case projects are tested to compare the results. The project teams (cost estimator/manager/contractor) are asked to study the factors and evaluate those factors against their projects' bidding probabilities with a profitable markup. If the project obeys their prediction and the model resulted in similar but higher accuracy prediction, that will give a powerful indicator for the succession of the model [18,26].

## **CHAPTER 4**

### **MODEL DEVELOPMENT AND DEMONSTRATION**

The summary of the model development process, including respondents' weights, factors' ranks, and a prediction of project markup size, in addition to model testing and validation, are discussed in the following sections.

#### **4.1 Respondents' weights**

The first part of the published questionnaire collects general information of the respondents, including the respondent's experience in construction projects, experience in bidding decisions, and their highest academic degree. Each answer is assigned a significance rate ranging from 1 (very low) to 5 (very high). The experience level is clustered as 0 to 5 years, 5 to 10 years, 10 to 15 years, 15 to 20 years, and 20 years over of experience, indicating significance rating 1, 2, 3, 4, and 5, respectively. For the academic qualification, if the expert holds an academic qualification below higher secondary, his/her weight is 1 and for a Ph.D. degree, his/her weight is 5. Respondent's personal information was collected and used as inputs for the fuzzy model. The g bell shape has been used to define the fuzzy membership functions. Fig. 2 illustrates the g bell shape membership functions developed to represent the received inputs from each respondent. A total of 15 rules is formed considering three person-related factors with 5 possible answers for each. A weight of one is assigned to all rules assuming all personal questions are equally important. Table 2 presents a sample of the developed

15 rules with their assigned weights. These rules that represent the relations between the inputs, respondent characteristics, and the output as respondent importance (i.e., weight) are presented in Fig. 3. Finally, defuzzification by the “centroid of area” method takes place to estimate the weight (i.e., importance) of each respondent as an output for the purpose of using them in the next step “ranking critical bidding factors”. Fig. 4 illustrates the defuzzification process to estimate the weight of a respondent based on his characteristics. This process is done 31 times to calculate the weight of the 31 respondents. Table 3 presents the final ranking for the respondents with their weights. A summary of the steps followed to estimate the importance weight of the first respondent is presented in Fig. 6. These steps start with inputting the personal profile answers received from the first expert in the model. Then, the rules are formed to describe how each answer affects the final weight of the first respondent. After that, these fuzzy inputs are defuzzified to estimate the first respondent’s weight.

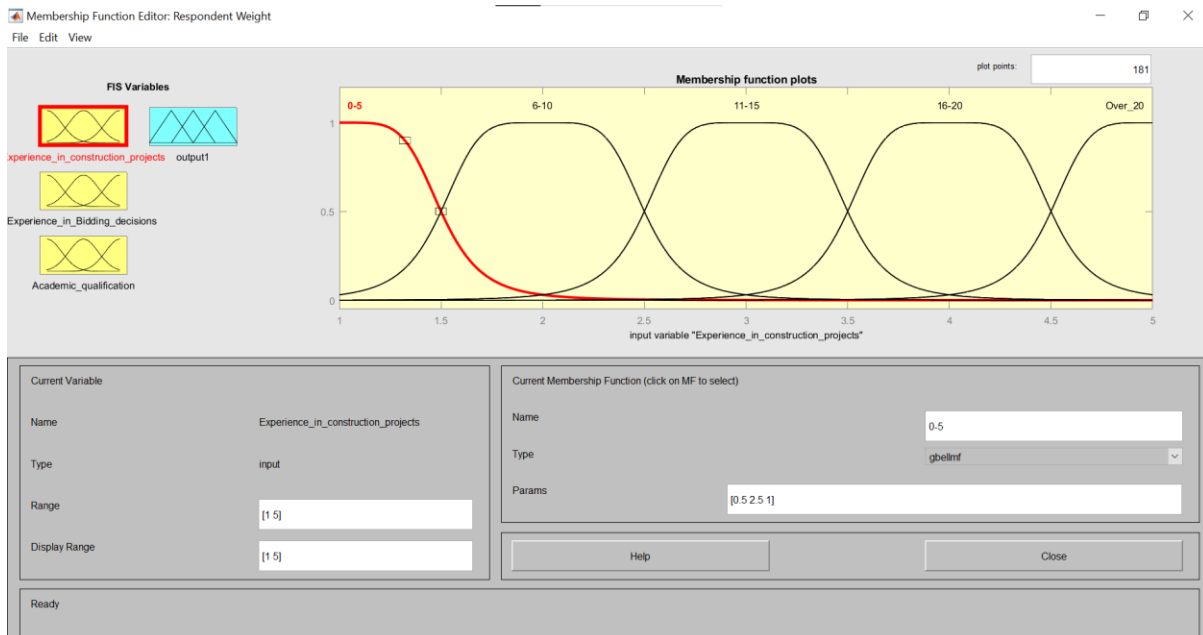


Figure 2: Membership function for " Respondent Weight ".

Table 1: Sample fuzzy rules for "Respondent Weight"

| Rule  | Inputs                                                              |           | Output                                  |
|-------|---------------------------------------------------------------------|-----------|-----------------------------------------|
|       | Antecedent                                                          | Weighting | Consequence                             |
| 1     | if "Experience in construction projects" is very high               | 1         | Then the respondent weight is very high |
| 2     | if " Experience in construction projects" is high                   | 1         | Then the respondent weight is high      |
| 3     | if "Experience in construction projects" is medium                  | 1         | Then the respondent weight is medium    |
| 4     | if "Experience in construction projects" is low                     | 1         | Then the respondent weight is low       |
| 5     | if "Experience in construction projects" is very low                | 1         | Then the respondent weight is very low  |
| ..... | .....                                                               | .....     | .....<br>...                            |
| ..... | .....                                                               | .....     | .....<br>...                            |
| 11    | if " Academic qualification" is Ph.D. degree                        | 1         | Then the respondent weight is very high |
| 12    | if " Academic qualification" is Master's degree                     | 1         | Then the respondent weight is high      |
| 13    | if " Academic qualification" is Bachelor's degree                   | 1         | Then the respondent weight is medium    |
| 14    | if " Academic qualification" is Higher secondary school certificate | 1         | Then the respondent weight is low       |
| 15    | if " Academic qualification" is below higher secondary              | 1         | Then the respondent weight is very low  |

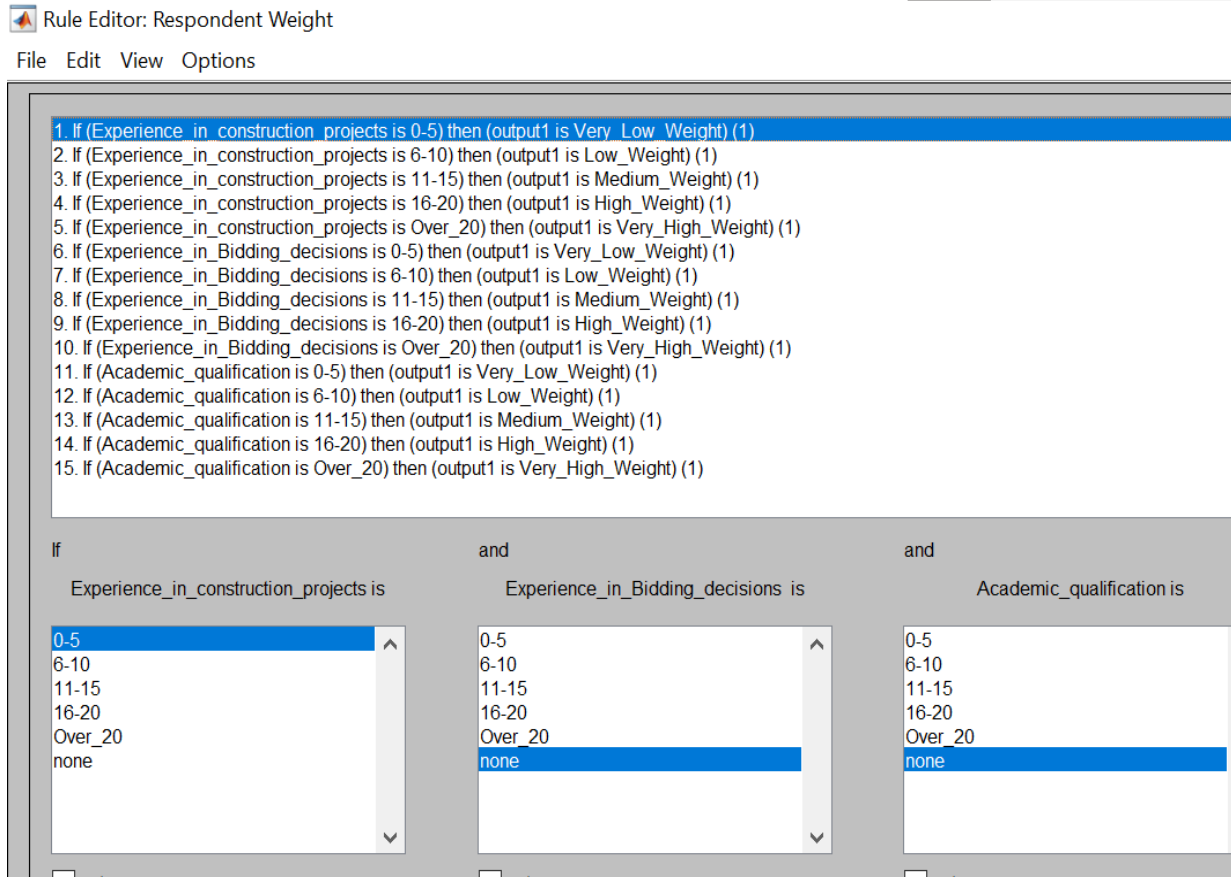


Figure 3: Formed rules for "Respondent Weight".

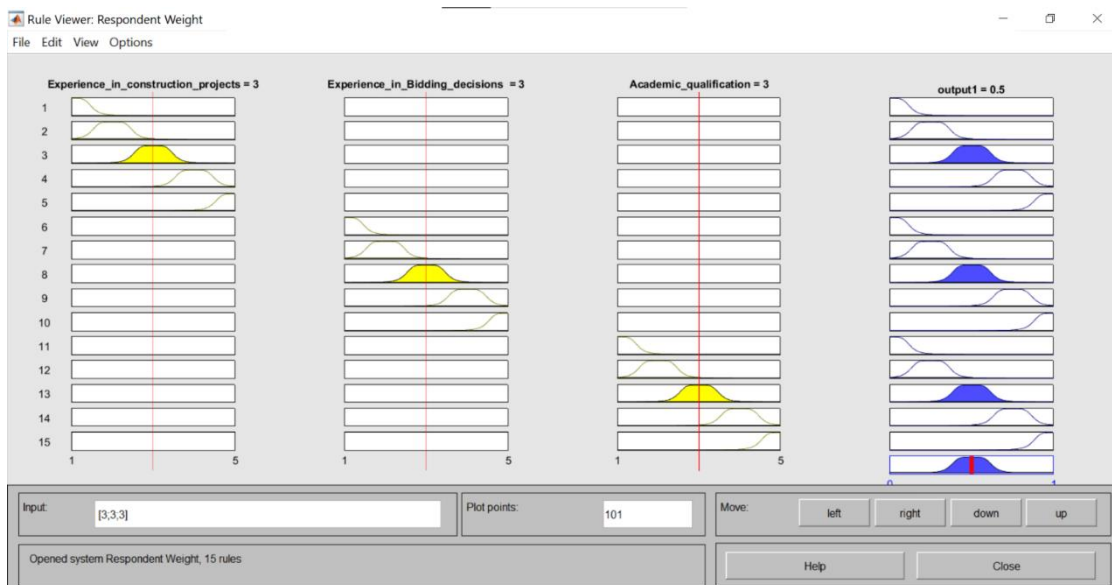


Figure 4: Defuzzification process for "Respondent Weight".

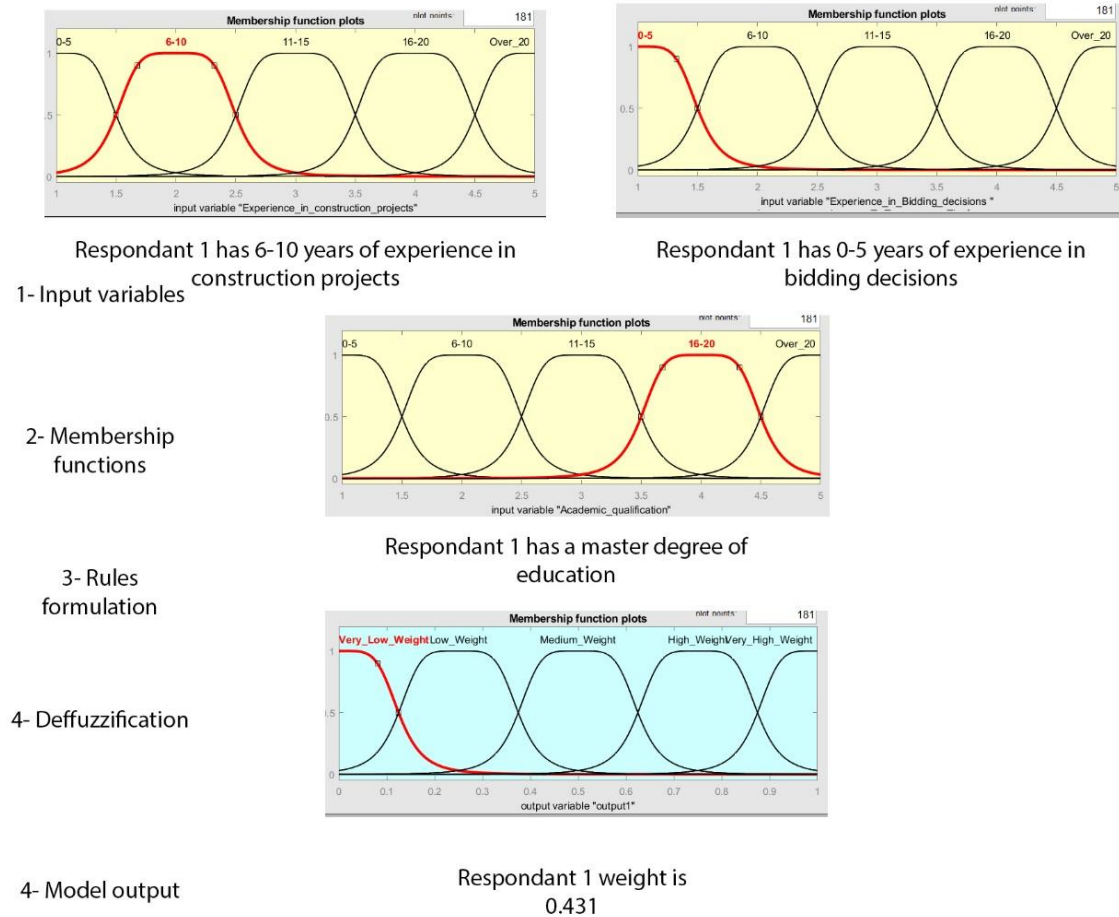


Figure 5: Summary of the first model for identifying the first respondent's weight.

The value of the model's output (i.e., estimated respondent's importance) ranges from 0 to 1. The respondents are clustered into five groups based on their weights ranges from 0-0.2, 0.21-0.4, 0.41-0.6, 0.61-0.8, and 0.81 to 1.0, meaning very low, low, medium, high, and very high weight experts successively. Table 3 shows the ranks and weights of 31 experts who participated in the questionnaire survey. Their weights indicate that one expert has a high weight (over 60%), 15 experts have medium weight, and 15 experts have low weight, and no experts have very low weight. These values represent that participated

experts have high to moderate experience and academic degrees in construction projects in Saudi Arabia. It can be noticed from Table 3 that respondent ranked 31 has a poor profile scored 0.328, which means that his opinion with ranking the factors affecting bidding decisions in the next step is going to have less impact than the respondent number 1 with a weight of 0.617.

Table 2: Respondents' ranks and weights.

| <b>Respondent Rank</b> | <b>Respondent Weight</b> | <b>Respondent Rank</b> | <b>Respondent Weight</b> |
|------------------------|--------------------------|------------------------|--------------------------|
| 1                      | 0.617                    | 17                     | 0.383                    |
| 2                      | 0.515                    | 18                     | 0.363                    |
| 3                      | 0.515                    | 19                     | 0.363                    |
| 4                      | 0.515                    | 20                     | 0.363                    |
| 5                      | 0.515                    | 21                     | 0.363                    |
| 6                      | 0.5                      | 22                     | 0.363                    |
| 7                      | 0.5                      | 23                     | 0.363                    |
| 8                      | 0.5                      | 24                     | 0.363                    |
| 9                      | 0.5                      | 25                     | 0.363                    |
| 10                     | 0.5                      | 26                     | 0.328                    |
| 11                     | 0.431                    | 27                     | 0.328                    |
| 12                     | 0.431                    | 28                     | 0.328                    |
| 13                     | 0.431                    | 29                     | 0.328                    |
| 14                     | 0.431                    | 30                     | 0.328                    |
| 15                     | 0.431                    | 31                     | 0.328                    |
| 16                     | 0.431                    | .....                  | .....                    |

## 4.2 Importance weight and ranking critical bidding factors

The second step towards developing the final model is ranking the most common critical factors by importance weight. The severity level and the probability of occurrence of each factor presented in Table 1 is assessed by the experts working in the Saudi construction industry. All the experts were requested to rate the severity and the probability of occurrence of each factor based on six possible answers on a scale of 0 to 5, indicating none to very high. The received answers for each factor are used as inputs in the second fuzzy model, “Factor’s severity weight” and “Probability of occurrence”. Similar g bell shape shown in Fig. 3 has been used to define the membership functions for ranking the bidding affecting factors.

The same concept presented in Fig. 4 to define the relations between the inputs and output in the “Respondent Weight” model is adopted in the second model [72]. Hence, alike to the rules presented in Table 2, a total of 186 ( $=31 \times 6$ ) if-then rules with their corresponding weights are formed to describe the relations between input variables, i.e., six possible answers of each of 31 respondents, and the output of the model, i.e., Factor’s importance weight. At the end of this model, the fuzzy output is defuzzified by using the “centroid of area” method to estimate the importance weight of the required bidding factor, similar to the process shown earlier in Fig. 4.

Based on the defuzzified importance weight, all the factors are ranked in descending order. The final outcome generates the ranking of the 37 bidding factors with their importance weights presented in Table 4. The resulted “factor ranking” is used for the purpose of weighting rules in the next step. Fig. 6 summarizes the process of identifying the severity

and frequency of the first bidding affecting factor "Project cash flow". It starts with inputting the first factor's severity and frequency rates collected from the 31 respondents in the developed model. Then, the rules are formed to describe how the respondent's weight and the evaluation of the factor's severity and frequency affect the output of the model, "importance weight". After that, the defuzzification process starts to convert all the cumulated 31 fuzzy inputs into a crisp value output that represents the first factor's overall importance weight.

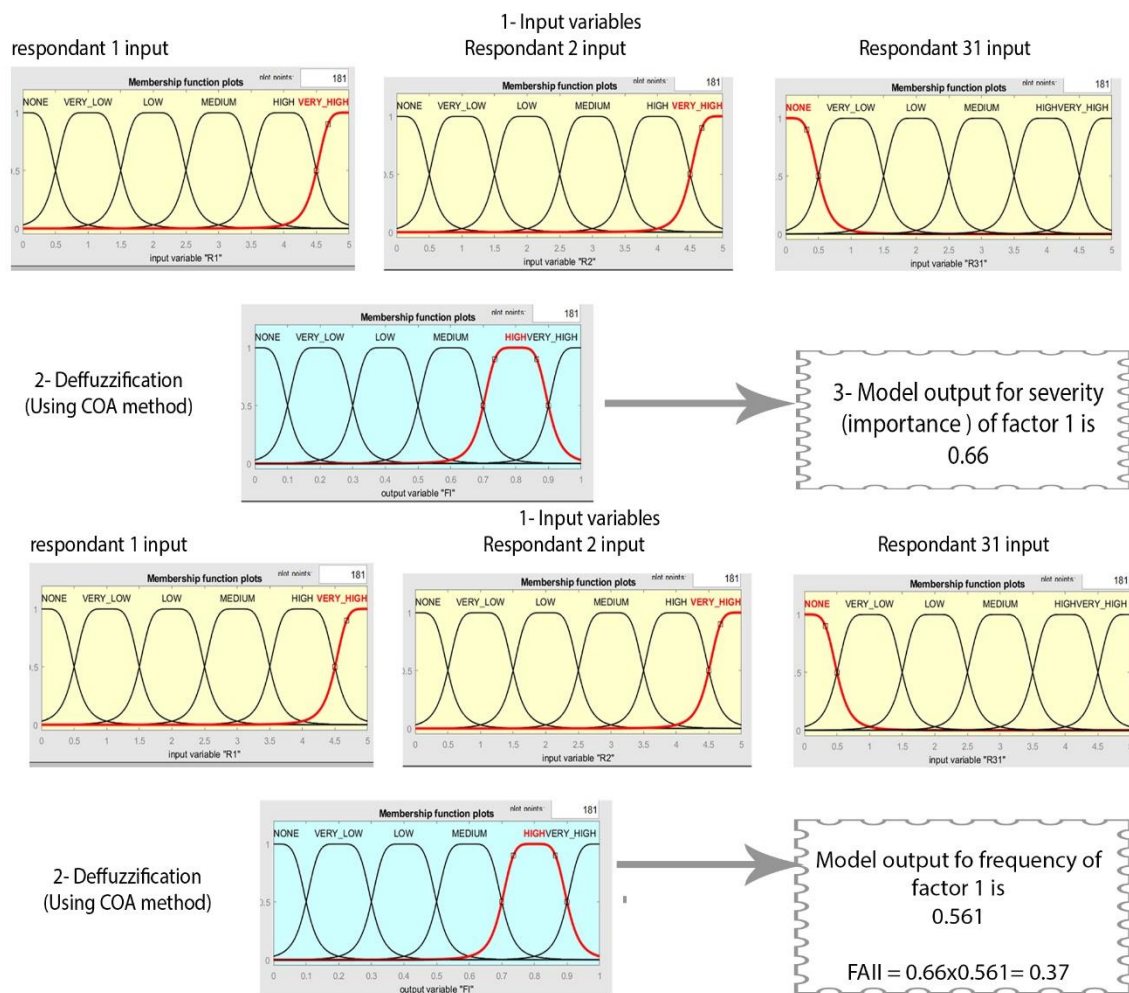


Figure 6: Summary of the second model for identifying the severity and the frequency of the first factor.

The estimated value of the model's output (i.e., factor's severity and frequency weight) ranges from 0 to 1 can be defined for understanding the severity and frequency levels of each factor influencing bidding decision prediction in the model. For example, factors with an estimated value of 0-0.16 have zero impact on the project markup and defined as none severe factors. Similarly, an IW weight 0.17-0.33 means very low, 0.34-0.49 low, 0.5-0.66 medium, 0.67-0.83 high, and 0.84-1 very high factors predicting higher project's markup size. Table 4 shows the ranking of important factors contributing to the bidding decisions in the Saudi Arabian construction industry identified by the proposed model.

After combining the importance of each factor with its probability of occurrence, the result displays that one factor has more than 50% weight, 17 factors fall between 30% and less than 50% weight, and ten factors have less than 30% weight. Thus, most of the factors listed in Table 4 are considered to have medium impact on project's markup size. The top five most important factors in the Saudi construction industry are current work load, size of contract, need for work, availability of labor, availability of required staff, owner, and duration.

This result is very much expected since the construction industry relies mostly on projects available and capacity availability [59]. The first and third factors are close to each other and reflect their importance, because contractors' decision to bid in a project is based on their current work load and their need for work. Contractors who have plenty of resources and manpower need to keep them working to cover their expenditures and avoid losses of being idle [62]. The second factor, size of contract, reflects directly on the project bid/no bid decision and markup size, because if a contractor does not have enough expertise in

larger project size, it would be difficult for him to estimate the project, rather than being able to enter the bid.

The size of contract always leads to the fourth and fifth factors which are availability of staff and labor. Again, having a successful bid with no labor or staff will cause the bidder to be eliminated, fined, or even ruin his reputation. Without skilled labor and experienced staff, the project cannot be successful [55]. Moreover, owners have a very high impact on contractors' decisions due to their abundance in all project phases including bidding, pricing, payments, and execution [45]. Finally, project duration is reflected heavily on markup size, a relaxed schedule project would have less markup compared to a shortened project schedule [33].

Table 3: Ranks and severity and frequency weights of bidding decisions factors

| <b>Rank</b> | <b>Factor</b>                  | <b>Severity weight</b> | <b>Frequency weight</b> | <b>Importance weight (IW)</b> |
|-------------|--------------------------------|------------------------|-------------------------|-------------------------------|
| 1           | Current work load              | 0.73                   | 0.733                   | 0.535                         |
| 2           | Size of contract               | 0.649                  | 0.66                    | 0.428                         |
| 3           | Need for work                  | 0.735                  | 0.57                    | 0.419                         |
| 4           | Availability of labor          | 0.641                  | 0.641                   | 0.411                         |
| 5           | Availability of required staff | 0.645                  | 0.631                   | 0.407                         |
| 6           | Owner                          | 0.734                  | 0.549                   | 0.403                         |
| 7           | Duration                       | 0.628                  | 0.64                    | 0.402                         |
| 8           | Governmental requirement       | 0.731                  | 0.547                   | 0.400                         |
| 9           | Competition                    | 0.662                  | 0.598                   | 0.396                         |

| <b>Rank</b> | <b>Factor</b>                          | <b>Severity weight</b> | <b>Frequency weight</b> | <b>Importance weight (IW)</b> |
|-------------|----------------------------------------|------------------------|-------------------------|-------------------------------|
| 10          | Availability of equipment              | 0.528                  | 0.736                   | 0.389                         |
| 11          | Project cash flow                      | 0.66                   | 0.561                   | 0.370                         |
| 12          | Experience in such projects            | 0.643                  | 0.561                   | 0.361                         |
| 13          | Availability of required cash          | 0.64                   | 0.549                   | 0.351                         |
| 14          | Risk involved in investment            | 0.529                  | 0.64                    | 0.339                         |
| 15          | Quality of available labor             | 0.631                  | 0.536                   | 0.338                         |
| 16          | General overhead                       | 0.545                  | 0.567                   | 0.309                         |
| 17          | Prequalification required              | 0.556                  | 0.547                   | 0.304                         |
| 18          | Reliability of subcontractors          | 0.561                  | 0.541                   | 0.304                         |
| 19          | Time to submit the bid                 | 0.532                  | 0.561                   | 0.298                         |
| 20          | Design quality                         | 0.533                  | 0.559                   | 0.298                         |
| 21          | Overall economy ( of the country )     | 0.542                  | 0.546                   | 0.296                         |
| 22          | Strength in industry                   | 0.539                  | 0.549                   | 0.296                         |
| 23          | Establishing long relation with client | 0.547                  | 0.527                   | 0.288                         |
| 24          | Past profit in similar jobs            | 0.561                  | 0.513                   | 0.288                         |
| 25          | Type of contract                       | 0.548                  | 0.521                   | 0.286                         |
| 26          | Location of project                    | 0.548                  | 0.514                   | 0.282                         |
| 27          | Confidence in work force               | 0.538                  | 0.515                   | 0.277                         |
| 28          | Designer (A/E)                         | 0.506                  | 0.541                   | 0.274                         |
| 29          | Owner special requirements             | 0.506                  | 0.538                   | 0.272                         |
| 30          | Time of bidding (season)               | 0.512                  | 0.528                   | 0.270                         |

| <b>Rank</b> | <b>Factor</b>                                             | <b>Severity weight</b> | <b>Frequency weight</b> | <b>Importance weight (IW)</b> |
|-------------|-----------------------------------------------------------|------------------------|-------------------------|-------------------------------|
| 31          | Uncertainty in cost estimate                              | 0.521                  | 0.513                   | 0.267                         |
| 32          | Portion subcontracted                                     | 0.502                  | 0.53                    | 0.266                         |
| 33          | Required bond capacity                                    | 0.521                  | 0.498                   | 0.259                         |
| 34          | Public exposure                                           | 0.519                  | 0.497                   | 0.258                         |
| 35          | Job start time ( time between bidding and project start ) | 0.498                  | 0.514                   | 0.256                         |
| 36          | Type of equipment                                         | 0.473                  | 0.53                    | 0.251                         |
| 37          | Bidding documents price                                   | 0.507                  | 0.486                   | 0.246                         |

#### **4.3 Decision to bid or not to bid**

The final step of this study is to develop a fuzzy model that predicts the best decision whether to bid or not in a construction project. The input variables in this model are the occurrence probability of each factor provided by decision-makers, while the output is the predicted project markup size in the studied project. A team of decision-makers can use this model by assigning a value for the occurrence probability of each factor presented in Table 1, potentially be encountered in a desired project. The occurrence probability of each factor is measured following a scale from 0 to 5, where 0 means none and 5 means very high. Subsequently, the model predicts the percentage of markup of that project based on their input.

Like the previous steps illustrated in Figures 2-4, the g bell shape has been used to define the membership functions of inputs and output. All possible relations between the 37 input

variables “the occurrence probability of each factor” and the output variable “the percentage of project markup” are represented by 222 rules ( $=37 \times 6$ ), as there are 37 factors and each factor has 6 possible chances of occurrence [72]. The “Factor’s importance weight” modeled in the previous second step is used here to weigh these 222 rules. Finally, the defuzzification process using the “centroid of area” method is applied to predict the proper markup in the required construction project.

This procedure starts with inputting the factors’ occurrence probability provided by decision-makers in the developed model. Then, the rules are formed to describe how the factor’s importance weight and the evaluation of the factor’s occurrence probability affect the model's output “percentage of markup”. After that, the defuzzification process starts to convert all the cumulated 37 fuzzy inputs into a crisp value output that represents the predicted project markup for a specific construction project. Experts concluded that a markup size of 50% and higher is unusual, unrealistic, and would indicate very high risks related to the project [57]. Subsequently, a model’s output that is higher than 50% would indicate a decision not to bid in that project due to high risk factors involved in it that might make it unsuccessful or unawarded.

#### **4.4 Case studies for Model Demonstration**

Once the individual expert weight and each factor’s severity and occurrence weight are modeled in the Mamdani-type fuzzy inference system in MATLAB, then the outcomes of these two models become the in-built weights for each factor. Now, the cost estimation experts of a project will assess the occurrence probability of each critical factor as the only input to the model. When occurrence probabilities of all 37 factors

are given to the model, the model will predict the project markup following the developed fuzzy If-then rules.

Accordingly, two case studies were carried out to demonstrate the capability of predicting the project markup of the proposed fuzzy model. Two separate interviews were conducted with the experts working on the two real construction projects in Saudi Arabia. The experts were asked to rate the occurrence probability of each critical factor considering a construction project that they have finished. Also, they were asked to estimate the project markup in the same project based on their experience and conventional practice.

The first case study project was a Telecommunication project in Saudi Arabia that was required to build an infrastructure for 5G network in one of Riyadh districts. The cost for this project was 25 million SAR, and the assigned markup was 20%. The project encountered a 4% loss at the end of it, which indicates a non-accurate estimation. The provided experts' information for the occurrence probability of the factors was inputted in the model to estimate the markup and the model provided an estimate of 26.5% using the g-bell function which is much better than the actual estimate and would eliminate losses and provided some profit. To further check the model's accuracy, the model was tested to provide the output using different membership functions and defuzzification types. The trapezoidal membership function provided an output of 24% and 25% for bisection and centroid of area types defuzzification, respectively.

On the other hand, the triangular membership function provided an output of 26% and 27% for bisection and centroid of area types, respectively. This indicates no significant

difference among different membership functions and defuzzification methods and increases the reliability of the model and its power to predict the markup accurately. Fig. 9 provides a screenshot of the defuzzification process done by the model in this case study. According to the experts, the model gave a reliable estimate for the project markup (26.3%) as it covered the encountered loss and resulted in a slight profit toward the end of the project. Table 5 presents the experts' answers for the occurrence probability of each critical factor in the studied project.

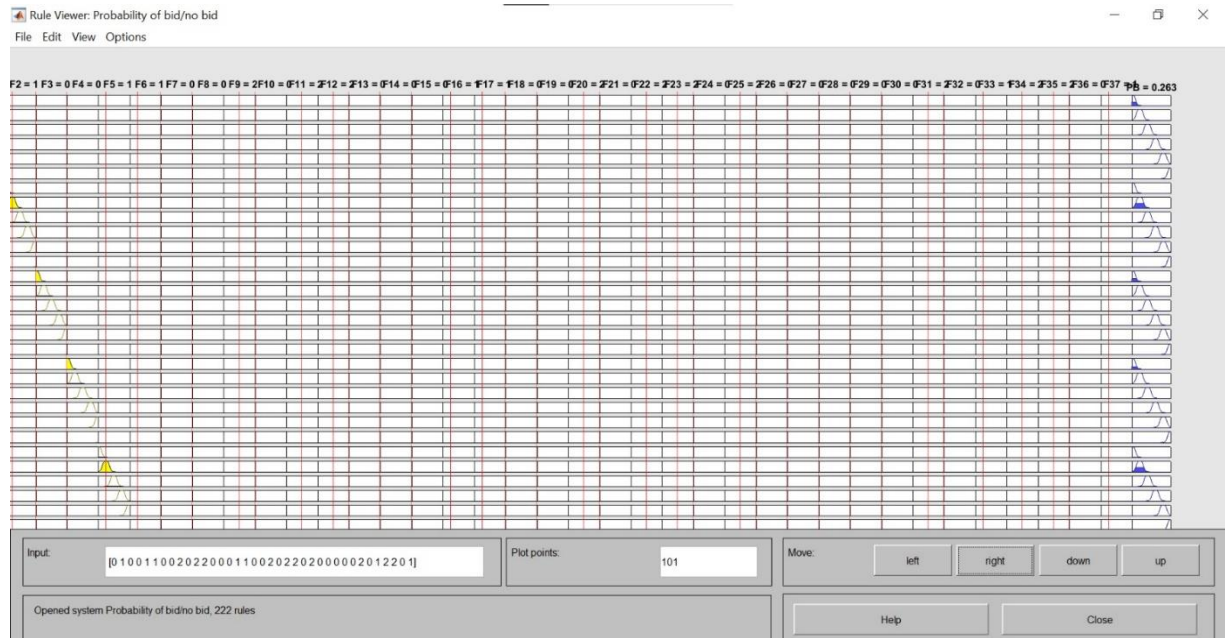


Figure 7: The model's estimation for project markup in the “telecommunication” case study.

The second case study is conducted on a different construction project type. The project was concerned about developing houses within a compound in Rabeigh city, Saudi Arabia. The estimated cost for the project was 9 million SR, and the estimated markup was 45%

due to project cash flow and the very short duration to start and execute the project. The project was profitable and performed more than expected. Experts studied the critical factors listed in our developed model and assessed the occurrence probability of each factor in the project, as presented in Table 5. With their inputs, the model predicted a project markup of 42%.

A screenshot from the defuzzification process done by the model to estimate the project markup in this case study is presented in Fig 8. According to experts, the model's outcome is acceptable since the project has finished with higher profits than expected and they won the bid at high price due to less competitors bidding. Again, the model was tested to provide the output using different membership functions and defuzzification shapes. The trapezoidal function provided an output of 42% and 45% for bisection and centroid of area shapes, respectively. And the triangular function provided an output of 41% and 44.5% for bisection and centroid of area shapes, respectively. Therefore, it can be concluded that the model can predict the markup accurately in most scenarios.

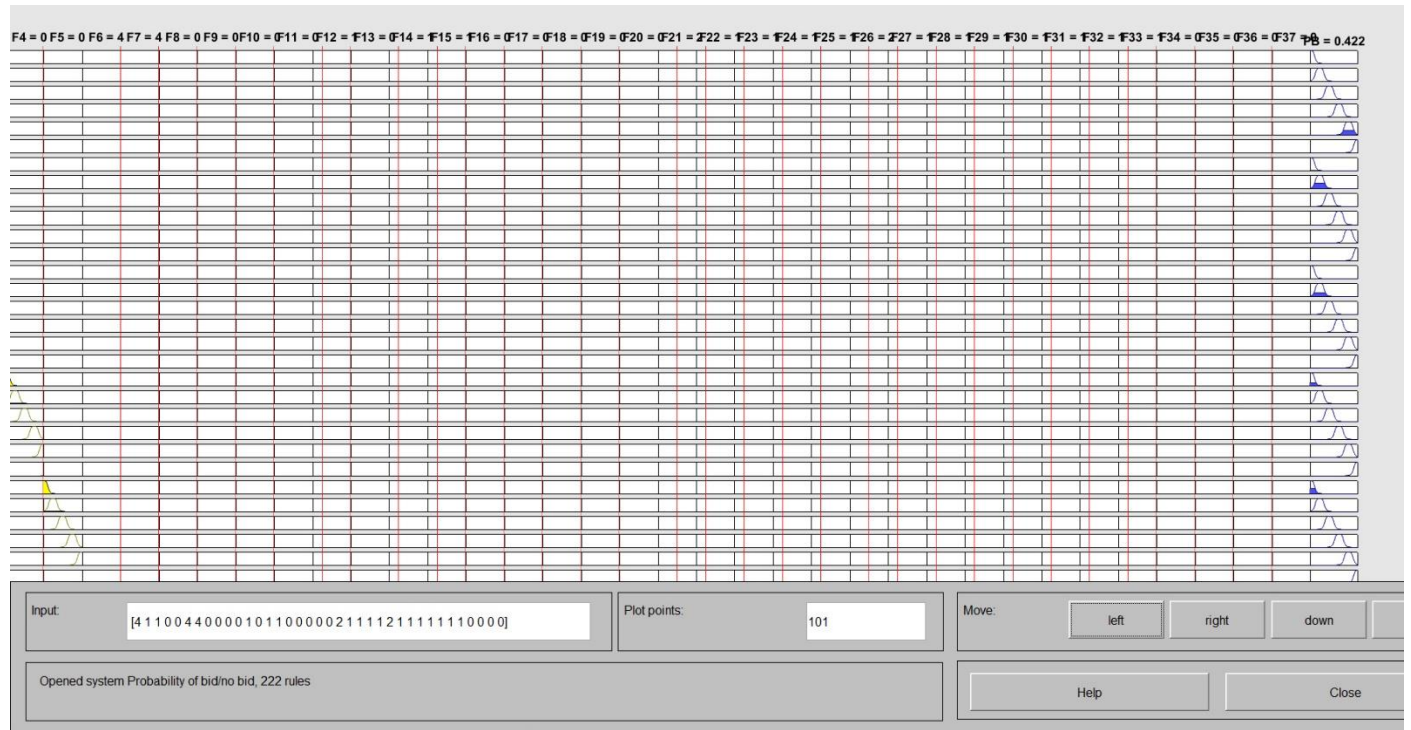


Figure 8: The model’s estimation for project markup in the “housing project” case study.

Table 5: Answers provided by the experts for the two case study projects

| Factor | Occurrence probability of each factor for case study #1 | Occurrence probability of each factor for case study #2 |
|--------|---------------------------------------------------------|---------------------------------------------------------|
| F1     | 0                                                       | 4                                                       |
| F2     | 1                                                       | 1                                                       |
| F3     | 0                                                       | 1                                                       |
| F4     | 0                                                       | 0                                                       |
| F5     | 1                                                       | 0                                                       |
| F6     | 1                                                       | 4                                                       |
| F7     | 0                                                       | 4                                                       |
| F8     | 0                                                       | 0                                                       |

| <b>Factor</b> | <b>Occurrence probability of each factor for case study #1</b> | <b>Occurrence probability of each factor for case study #2</b> |
|---------------|----------------------------------------------------------------|----------------------------------------------------------------|
| F9            | 2                                                              | 0                                                              |
| F10           | 0                                                              | 0                                                              |
| F11           | 2                                                              | 0                                                              |
| F12           | 2                                                              | 1                                                              |
| F13           | 0                                                              | 0                                                              |
| F14           | 0                                                              | 1                                                              |
| F15           | 0                                                              | 1                                                              |
| F16           | 1                                                              | 0                                                              |
| F17           | 1                                                              | 0                                                              |
| F18           | 0                                                              | 0                                                              |
| F19           | 0                                                              | 0                                                              |
| F20           | 2                                                              | 0                                                              |
| F21           | 0                                                              | 2                                                              |
| F22           | 2                                                              | 1                                                              |
| F23           | 2                                                              | 1                                                              |
| F24           | 0                                                              | 1                                                              |
| F25           | 2                                                              | 1                                                              |
| F26           | 0                                                              | 2                                                              |
| F27           | 0                                                              | 1                                                              |
| F28           | 0                                                              | 1                                                              |
| F29           | 0                                                              | 1                                                              |
| F30           | 0                                                              | 1                                                              |
| F31           | 2                                                              | 1                                                              |
| F32           | 0                                                              | 1                                                              |

| Factor | Occurrence probability of each factor for case study #1 | Occurrence probability of each factor for case study #2 |
|--------|---------------------------------------------------------|---------------------------------------------------------|
| F33    | 1                                                       | 1                                                       |
| F34    | 2                                                       | 0                                                       |
| F35    | 2                                                       | 0                                                       |
| F36    | 0                                                       | 0                                                       |
| F37    | 1                                                       | 0                                                       |

#### 4.5 Model Testing and Validation

Two steps validation processes are adopted in the following sections to justify the applicability of the developed model in the real-life construction industry. Firstly, the received data are tested to ensure their consistency. Then, the sensitivity of the model is validated by running the model in six project scenarios ranging from smooth (i.e., no risk factor emerged to affect markup) to extreme uncertain conditions (i.e., all risk factors are at very high level to affect markup) in execution phases.

##### 4.5.1 Consistency analysis for the collected data

The consistency analyses of the data received from the experts were conducted using chi-square and Cronbach's alpha tests. A chi-square test has been conducted to examine the consistency of the experts' judgments with a null hypothesis ( $H_0$ ) that experts do not agree with each other evaluating severity of each factor, and with a significance level ( $\alpha - value$ ) 0.05. Accordingly, if a factor received an  $\alpha - value$  less than 0.05, this means that the null hypothesis for this factor is rejected, and experts agree about

its severity level. Table 5 shows the chi-square test results of all data collected from 31 experts.

The test results indicate that the experts were mostly consistent in evaluating factors' severity. In a few cases where experts did not agree about a factor's severity ( $H_0$  retained). This could be the result of the experts having a wide range of expertise from different types and sizes of construction projects. Cronbach's alpha test has also been done to check the internal consistency of the Likert-scale data. The result of the test showed that the internal consistency for the collected data is excellent, with a value of 0.912 ( $> 0.9$ ), as shown in Table 6.

Table 6: Chi-square and Cronbach's alpha tests for the collected data.

| <b>Factor</b> | <b>Asymptotic significance (<math>\alpha</math>-value) for severity</b> | <b>H<sub>0</sub></b> |
|---------------|-------------------------------------------------------------------------|----------------------|
| F1            | 0.000161                                                                | Rejected             |
| F2            | 0.000018                                                                | Rejected             |
| F3            | 0.000005                                                                | Rejected             |
| F4            | 0.038837                                                                | Rejected             |
| F5            | 0.000000                                                                | Rejected             |
| F6            | 0.000067                                                                | Rejected             |
| F7            | 0.022164                                                                | Rejected             |
| F8            | 0.000001                                                                | Rejected             |
| F9            | 0.000058                                                                | Rejected             |
| F10           | 0.001404                                                                | Rejected             |
| F11           | 0.003275                                                                | Rejected             |

| <b>Factor</b> | <b>Asymptotic significance (<math>\alpha</math>-value) for severity</b> | <b>H<sub>0</sub></b> |
|---------------|-------------------------------------------------------------------------|----------------------|
| F12           | 0.000033                                                                | Rejected             |
| F13           | 0.000008                                                                | Rejected             |
| F14           | 0.000021                                                                | Rejected             |
| F15           | 0.004557                                                                | Rejected             |
| F16           | 0.000045                                                                | Rejected             |
| F17           | 0.000021                                                                | Rejected             |
| F18           | 0.000000                                                                | Rejected             |
| F19           | 0.000023                                                                | Rejected             |
| F20           | 0.027504                                                                | Rejected             |
| F21           | 0.000041                                                                | Rejected             |
| F22           | 0.000094                                                                | Rejected             |
| F23           | 0.000488                                                                | Rejected             |
| F24           | 0.008353                                                                | Rejected             |
| F25           | 0.067571                                                                | Retained             |
| F26           | 0.000014                                                                | Rejected             |
| F27           | 0.000021                                                                | Rejected             |
| F28           | 0.020137                                                                | Rejected             |
| F29           | 0.878985                                                                | Retained             |
| F30           | 0.000003                                                                | Rejected             |
| F31           | 0.001629                                                                | Rejected             |
| F32           | 0.000049                                                                | Rejected             |
| F33           | 0.000000                                                                | Rejected             |
| F34           | 0.000000                                                                | Rejected             |

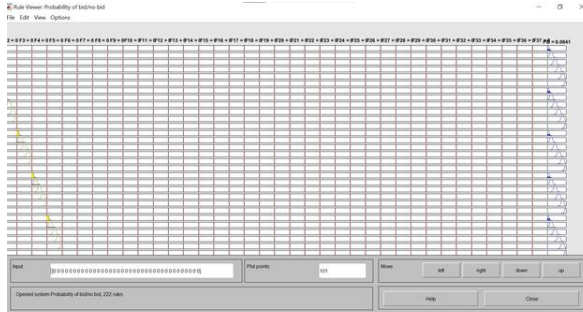
| <b>Factor</b>                                     | <b>Asymptotic significance (<math>\alpha</math>-value) for severity</b> | <b>H<sub>0</sub></b> |
|---------------------------------------------------|-------------------------------------------------------------------------|----------------------|
| F35                                               | 0.001222                                                                | Rejected             |
| F36                                               | 0.001621                                                                | Rejected             |
| F37                                               | 0.000000                                                                | Rejected             |
| <b>Cronbach's Alpha</b><br>(internal consistency) | 0.911480526                                                             | Excellent            |

#### 4.5.2 Sensitivity analysis

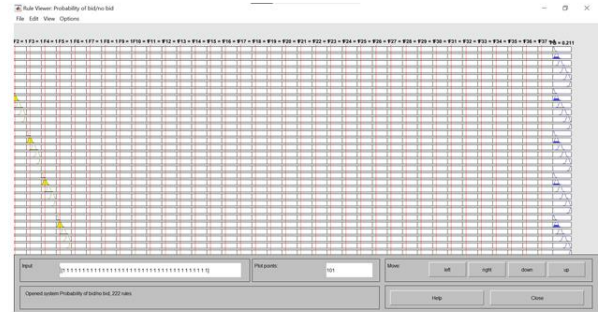
To check the sensitivity and robustness of the model and to ensure that the results of the model are reasonable, six different scenarios were tested, which are none, low, very low, medium, high, very high. The first scenario “none” assumes that no factor will be encountered in the required construction project. Thus, the input value for each factor in the model is “0”. The resulted project markup provided by the model is 8.4%, which is logical to have such a low percentage since it is assumed that the project will finish without facing any difficulties.

In the second scenario, all the factors are considered to be “very low”, and the input for occurrence probability is “1” for all factors. The model produces a reasonable probability of 21.2%. With an occurrence probability of “2” inputted in the model to represent the “low” scenario, the model forecasts a markup of 40.4%. Similarly, for the “medium” scenario, the estimated markup is 59.6%, and for the “high” and “very high” inputs, the model estimates a markup of 78.9% and 91.6%, respectively. These outcomes ensure that the model’s markup prediction performance is consistent,

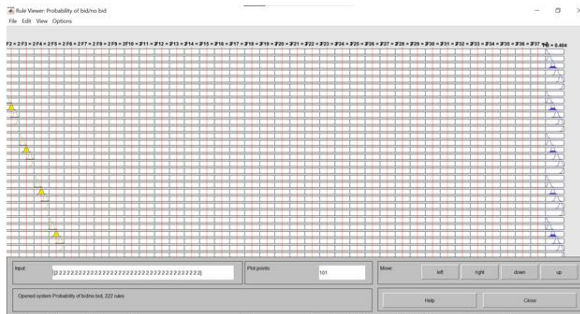
reasonable, and logical with the occurrence probability of critical factors. Figure 9 summarizes the model's defuzzification outcome for extreme boundary conditions.



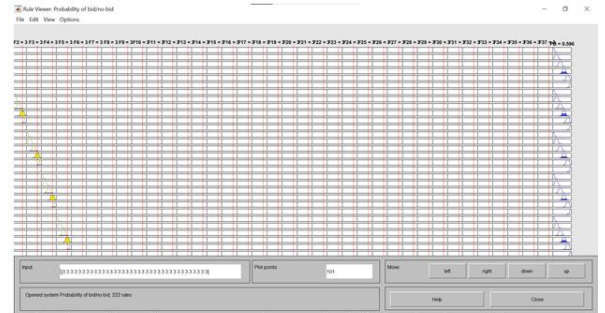
Defuzzification process for probability of 0 for all factors  
result is 8.4%



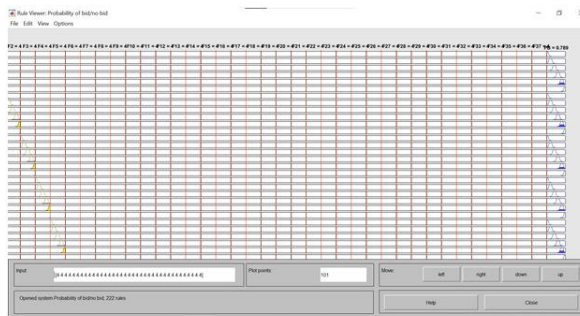
Defuzzification process for probability of 1 for all factors  
result is 21.2%



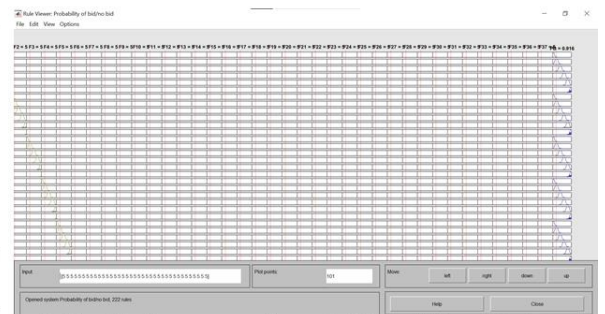
Defuzzification process for probability of 2 for all factors  
result is 40.4 %



Defuzzification process for probability of 3 for all factors  
result is 59.6 %



Defuzzification process for probability of 4 for all factors  
result is 78.9 %



Defuzzification process for probability of 5 for all factors  
result is 91.6 %

Figure 9: model's defuzzification outcome for extreme boundary conditions.

## 4.6 Practical Guidance for Applying the Model in Real-life Projects

The model can be a practical solution to the field-professionals in the following ways:

- a. The field professionals can directly apply the developed model for predicting project markup and decide whether to bid or not. Thus, they get a sense of certain factors' effect on the markup. In that case, they must assess the occurrence frequency of the potential and critical factors associated with their projects.
- b. The cost estimating teams can add, remove, or change certain factors in the model depending on their type of working field and specialization to alter the model and enhance its prediction rather than the relying exclusively on the standard model provided in this study. In that case, they can customize the model in MATLAB with minor changes following the approach introduced in this study.
- c. Suppose the expert team thought to have their own model including changes in the expert weights and severity of each risk factor based on their assessment. In that case, the proposed fuzzy-Mamdani approach can also be adopted or redeveloped accordingly. For this model revision, the experts' characteristics and numbers are needed to feed in the model, followed by the severity assessment of the risks. Then the system will link these changes to the final markup prediction model in MATLAB. The MATLAB codes provided as a supplementary file can significantly assist them in adopting a specific project-based model. Thus, the model can be applicable in different projects regardless of geopolitical boundary.

## **CHAPTER 5**

### **SUMMARY, CONCLUSION & RECOMMENDATIONS**

This chapter presents a summary of the research, findings of the research, a conclusion, some recommendations and probable directions for the future research.

#### **5.1 Summary of the Research**

Despite the importance of cost estimation, many contractors fail to have profitable bids and encounter losses. While previous studies focused on finding critical factors affecting project markup, nobody attempts to predict the markup and the decision to bid or not considering potential and critical factors. Predicting project markup is the most important step to keep contractors in the business.

This study develops a fuzzy model that forecasts project markup and the decision to bid or not in construction projects in Saudi Arabia to keep contractors profitable. The fuzzy theory has been chosen to develop the required model since it is convenient for converting the imprecise, uncertain, and incomplete linguistic data to clear and precise estimates. Towards this model development, a comprehensive literature review has been done to identify the most common markup affecting factors in Saudi Arabia. Then, expert interviews were conducted to answer a questionnaire that measures the severity and frequency of the most critical factors in the Saudi construction industry in addition to expert competence. Thirty-one experts representing a wide range of major stakeholders participated in the survey.

After that, the fuzzy-Mamdani inference system in MATLAB is applied in three steps to achieve the required output.

Firstly, this inference system is used to weigh the expert's competence based on their characteristics. In the second step, the model uses the resulted experts' weights and experts' assessments on the severity and frequency of each factor to determine the severity weights and frequency weights and ranking of the identified markup affecting factors. Then IW is calculated and entered in the model as an input weight for each factor. Lastly, the final model uses the occurrence probability of each factor in a project assessed by an expert team along with the modeled factor's IW to predict the project markup for the required construction project.

The limitations of this study are two folds. Firstly, the sample size used to rate the severity of markup-related factors and develop the model is 31 (i.e., 31 experts participated in the structured interview), which is a small number compared to the construction industry. Attempts to interview more experts have failed due to Covid-19 pandemic precautions. Therefore, the importance ranking of critical factors may not accurately reflect the whole situation of the Saudi construction industry. Secondly, the model depends mainly on the experts' judgment with evaluating the occurrence probability of each critical factor. Thus, the model's outcome can be misled by incompetent experts due to their poor evaluation of factors.

## 5.2 Findings

Towards developing the final model, the most common thirty-seven factors are identified and ranked based on the result of their severity and frequency of occurrence. The top critical factors affecting markup in the Saudi industry are current work load, size of contract, need for work, availability of labor, availability of required staff, owner, and duration. The final developed model is user-friendly and straightforward to predict the markup size of a project as it requires a crisp value from 0 to 5 as the occurrence frequency of each factor listed in the model. The occurrence probabilities of all factors are inputted in the model to get fuzzy membership functions. Afterward, the defuzzification process takes place, where the model converts the fuzzy results into a crisp value representing the estimated markup size of a construction project to bid.

The model's performance is demonstrated in two real construction projects that had an actual markup of 20% and 45% respectively. The model estimated 26.3% and 42% markup size, respectively for these projects which fall within the profitable level expected by the experts who believe that it is a reliable tool since its estimate falls in their expected range of profitability in those projects. With the outcomes of the developed model, decision-makers can make more accurate bidding decisions before entering a project by incorporating the model's output with their cost estimation process to guarantee a successful and profitable bid.

### **5.3 Conclusion**

The developed fuzzy model for estimating markup size and bidding decisions provides high accuracy results because it showed sound results and outputs. The data reliability was validated conducting two consistency tests, i.e., chi-square and Cronbach's alpha. Both tests showed that the collected data from experts are reliable and consistent. The sensitivity of the model has been validated by adopting six different scenarios ranging with their conditions from smooth to extreme, and found robust in terms of model's internal consistency.

### **5.4 Recommendations**

The model developed in this research is recommended to be used by all contractors working in the Saudi construction industry since it is not limited to a single type of construction work. It can be utilized in the early stages before bidding, and thus, will give decision makers a more sense of critical factors effect on the markup. This shall eliminate the non-profitable bids and provide a risk-induced markup size estimation to enter the bid. The model output is highly dependent on experts' input of factors occurrence in the project, hence, it requires a knowledgeable expert to rate the occurrence in order to get the most accurate results.

## **5.5 Future Research**

Further study can be conducted with many experts' interviews participating in more diversified experiences of the experts to rigorously justify the model's outcome for predicting construction projects' markups. Further research can focus on other competitors' bids and optimize the bidding price to have a higher chance of winning the project using the developed model for its broader applications. Further studies can be done on experts' weighing factors and the addition of more expert related information to enhance the results and the exact weight of each respondent.

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## Appendix-A

### Data Collection Form

This form is used to collect data construction projects in Saudi Arabia as a part of a thesis prepared at King Fahd University of Petroleum and Minerals with the title of “Fuzzy Based Modeling for Bidding Decisions and Markup Size In Saudi Arabia’s Construction Industry”. The form includes 37 factors affecting project markup decisions and requires respondents to rate each factor’s severity and frequency of occurrence using a scale of 0 to 5.

| Number | Identified Parameter | None | Very Low | Low | Medium | High | Very High |
|--------|----------------------|------|----------|-----|--------|------|-----------|
| 1      | Project cash flow.   |      |          |     |        |      |           |
| 2      | Size of contract.    |      |          |     |        |      |           |
| 3      | Location of project. |      |          |     |        |      |           |
| 4      | Type of equipment.   |      |          |     |        |      |           |
| 5      | Owner.               |      |          |     |        |      |           |
| 6      | Duration.            |      |          |     |        |      |           |
| 7      | Job start time.      |      |          |     |        |      |           |
| 8      | Type of contract.    |      |          |     |        |      |           |
| 9      | Design quality.      |      |          |     |        |      |           |

|    |                                            |  |  |  |  |  |  |
|----|--------------------------------------------|--|--|--|--|--|--|
| 10 | Designer (A/E).                            |  |  |  |  |  |  |
| 11 | Owner special requirements.                |  |  |  |  |  |  |
| 12 | Availability of required cash.             |  |  |  |  |  |  |
| 13 | Availability of required staff.            |  |  |  |  |  |  |
| 14 | Experience in such projects.               |  |  |  |  |  |  |
| 15 | Confidence in work force.                  |  |  |  |  |  |  |
| 16 | Need for work.                             |  |  |  |  |  |  |
| 17 | Establishing long relation<br>with client. |  |  |  |  |  |  |
| 18 | Strength in industry.                      |  |  |  |  |  |  |
| 19 | Current workload.                          |  |  |  |  |  |  |
| 20 | Uncertainty in cost estimate.              |  |  |  |  |  |  |
| 21 | Past profit in similar jobs.               |  |  |  |  |  |  |
| 22 | Reliability of subcontractors.             |  |  |  |  |  |  |
| 23 | General overhead.                          |  |  |  |  |  |  |
| 24 | Public exposure.                           |  |  |  |  |  |  |
| 25 | Portion subcontracted.                     |  |  |  |  |  |  |
| 26 | Competition.                               |  |  |  |  |  |  |

|    |                              |  |  |  |  |  |  |
|----|------------------------------|--|--|--|--|--|--|
| 27 | Time to submit the bid.      |  |  |  |  |  |  |
| 28 | Required bond capacity.      |  |  |  |  |  |  |
| 29 | Bidding documents price.     |  |  |  |  |  |  |
| 30 | Prequalification required.   |  |  |  |  |  |  |
| 31 | Time of bidding ( season ).  |  |  |  |  |  |  |
| 32 | Overall economy.             |  |  |  |  |  |  |
| 33 | Quality of available labor.  |  |  |  |  |  |  |
| 34 | Availability of labor.       |  |  |  |  |  |  |
| 35 | Risk involved in investment. |  |  |  |  |  |  |
| 36 | Availability of equipment.   |  |  |  |  |  |  |
| 37 | Governmental requirement.    |  |  |  |  |  |  |

For any inquiry on the form, please contact: [g201472480@kfupm.edu.sa](mailto:g201472480@kfupm.edu.sa)

## **Vitae**

Name : Ibrahim Saeed Zaqout

Nationality : Palestinian

Date of Birth : 7/26/1996

Email : izaqout7@gmail.com

Address : Taif, Saudi Arabia

Academic Background : Civil Engineering