Developing a Fuzzy-based Model to Assess and Allocate Risks in Syrian Construction Projects

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☐ ABSTRACT ☐

Construction industry has always been a place of growing interest. It is mostly known, however, for its poor reputation for managing risks that inevitably come across a great number of the activities it involves. Some of those risks can be impactful in a way that cannot be foreseen and would be catastrophic for the client and for the contractor. Assessing and allocating risks in a construction project is then a key component of an integrated, efficient, and successful risk management of every construction project. It is, however, shrouded with ambiguity, uncertainty, human judgment, and natural expressions. This makes fuzzy-based approaches more suitable to make a final assessment. This paper aims to develop a fuzzy-based model to predict major risks liability and magnitude in residential projects based on a series of questionnaire with experienced engineers in Lattakia, Syria. This prototype model is developed using Matlab and fuzzy-set theory to make more reliable decisions and to avoid costly overruns especially in the early phases of the project where few or no information is available. The prototype is then verified through case studies.

Keywords: Risks, Construction projects, Syria, Fuzzy logic

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تطوير نموذج يستند إلى المنطق الضبابي لتقييم وتوزيع مسؤولية المخاطر في مشاريع التشييد في سورية

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ملخّص

لطالما حظيت صناعة التشييد باهتمام كبير من قبل المستثمرين والباحثين على حد سواء. إلا أنها ورغم ذلك معروفة بلا شك بسوء قدرتها على إدارة المخاطر التي لا يمكن تجنبها في عدد كبير من أنشطتها. بعض المخاطر قد تؤثر بشكل لا يمكن توقع آثاره بل وقد تكون ذات آثار كارثية على أطراف المشروع كافة. لذا يعد تقييم وتوزيع مسؤولية الخطر في حال حدوثه جزء أساسي وحاسم للوصول إلى عملية إدارة مخاطر فعالة وناجحة في كل مشروع تشييد. لكن وكما هو من المعروف أن المخاطر وإدراتها عملية تعتريها حالة من الغموض والشك وعدم اليقين والكثير والكثير من التعابير اللغوية الغامضة والتي تعتمد على التفسيرات التي تختلف من خبير ومن مشروع إلى آخر. يجعل هذا تطوير نماذج تستند إلى المنطق الضبابي أسلوباً أكثر موائمة لتقييم المخاطر. تهدف هذه الورقة البحثية لتطوير نموذج يستند للمنطق الضبابي ونظرية المجموعات الضبابية للتنبؤ بشدة المخاطر الرئيسية في صناعة التشييد في سورية وتحميل مسؤولية كل منها بالاعتماد على سلسلة من المقابلات والاستبيانات مع مجموعة الخبراء الهندسيين في اللاذقية، سورية. يتم تطوير النموذج باستخدام الماتلاب ويستخدم لاتخاذ قرارات أكثر موثوقية وخصوصاً في المراحل الأولية من حياة المشروع ما يمكن صناع القرار من تجنب الانحرافات المكلفة. يتم بعدها التحقق من النموذج باستخدام مجموعة من الحالات العملية.

الكلمات المفتاحية:المخاطر، مشاريع التشييد، سورية، المنطق الضبابي

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Introduction:

Construction industry is mainly driven by private investors looking for an opportunity to make a profit by executing projects. However, these projects are born into a complex, dynamic and continuously shifting environments[1]. Evidently, it is safe to say that a contract is some sort of settlement or a compensation between the contractor's price for carrying the risk and his ability to deal with both the controllable and the uncontrollable Risks[2]. The final results of uncertainty in terms of cost, time and quality is called a "Risk" [1]. From the very moment the designing process of a new project is taken and up until the intended project is put in actual use, the final and exact outcome, its cost, and its termination along with other Characteristics are ambiguous for the client[3]. This means great uncertainties and with it a greater susceptibility to risks[1]**.** And as every industry is entitled to its own complicated risks, the construction industry in particular due to its unique nature, is possibly susceptible more than others to various technical and business-related risks[1][4]. For example, a continuous change on building environment, direct exposure to multiple dangerous sources, stressful and rigorous timelines and costs, and a constant adaptation and utilization of more and more sophisticated construction techniques[5]. Those risks can result in poor performance, increased cost, costly time delays and ultimately project failure[4]. A risk becomes problematic when it interrupts a rather the Natural and normal behavior of a task, work package, or a project[6].

1. Risk Assessment and Risk Allocation:

Risk assessment is used as a tool to properly identify the risks and to manage them later on[1]. Luckily, the number of risks that are notable and substantial in terms of likelihood or impact is not large[3].According to Porter, the number of individual risks needed to incorporate the majority of the risks is not substantial. For instance, considering the top eight largest risks will cover approximately 90% of the total risks [7]. In most cases, the design of ordinary buildings is accomplished with very little consideration to minimizing construction risks[3]. Risk allocation, on the other hand, can be defined as the process of identifying and assigning, to at least one party, the responsibility of a possible future gain or loss if a number of theoretical, unplanned scenarios were to happen[8] . An improper risk allocation can be detrimental for the success of every construction project [9]. Just like all management ideologies and practices, risk allocation fundamentals consistently use natural and fuzzy language to express them, which can be inconclusive and ambiguous when put in real-life applications used by different industries and different managers[9]. Extravagant cost and time overruns in construction projects made "Risk in construction" under the microscope of excessive attention [10]. In Syria, Jrad et al. (2015), examined the risks associated with implementation of dam projects in Syria. Using Surveys and interviews with engineering consultants, project managers and experts within the industry, authors were able to rank forty four risks affecting dam projects using "Risk Criticality Number" and incorporating fuzzy set theory into failure mode and effect analysis (FMEA) to measure the occurrence, severity of risks and the ability to detect them. The model was developed using C sharp, Microsoft access and OLDB. According to the model, the most important risks were improper geological site investigations as well as tremendous cost overruns. As for the response, it is recommended to transfer or even avoid these risk. Coming up next, high soil porosity was identified as a main risk and it is also suggested to transfer this risk as a response [11]. Mustafa. M (2017), had studied risks of cost overrun in Syrian Road Projects. The author examined the risks impacting the construction of highways connecting Syrian governorates executed by the general firm of transportation and roads in Damascus Syria using "Bayesian Theory" as a tool to model the cause-effect relationship between risks associated with such type of projects [12]. This is especially beneficial in projects and industries shrouded with uncertainty and vagueness as it is the case for construction projects. Experts with over 16 years of experience evaluated forty seven risks in terms of occurrence likelihood and impact or severity of the risk. The final ranking of risks was based on Shen's (2001). The following table is used to demonstrate the top ten risks and their importance.

Table- 1 :Top ten risks associated with constructing road projects [12]

Rank	Factor/ Cause	Importance
1	Increase in Material Cost	High
2	Appropriation Barriers	High
3	Inflation	Moderate
4	Quarter works	Moderate
5	Changes in currency prices	Moderate
6	Additional work packages which were not included in the original contract	Moderate
7	Inefficient equipment	Moderate
8	Slow decision-making process	Moderate
9	Shortage in equipment	Moderate
10	Change in specification and quantity of materials	Moderate

Khaddour. L (2022), evaluated sustainability threats in Mega-scale residential projects from the perspective of construction companies in Damascus, Syria. The research identified and assessed sustainability risks. Private, public and private public partnership companies were included in the survey [13]. Table-2 demonstrates the top ten risks. In conclusion, various risk assessment techniques are carefully examined in the literature, however, risk assessment using fuzzy logic in normal residential projects executed by public firms must be further explored with the help of advanced and user-friendly computerized software such as Matlab and fuzzy tech. This research aims to develop such prototype which can be used to predict risks based on several input variables in addition to assigning risks' responsibilities amongst contractual parties.

Table- 2: Top Ten risks in Mega-scale Residential projects[13]

Risk	Magnitude
Delayed process of providing alternative houses options	0.40
Unexpected Increase costs and or lack of finance	0.35
unclear role and responsibilities distribution among contractual parties	0.34
Lack of qualified Professionals	0.33
Unavailability of technologies and material needed to create a green residential building	0.30
absence of appropriate Strategies, policies and criterion regarding sustainable building	0.27
Inappropriate specifications and designs	0.25
Energy Consumption	0.25

Table- 2: Top Ten risks in Mega-scale Residential projects[13]	
Risk	**Magnitude**
Safety Risks	0.25
Low productivity	0.24

2. Construction Industry and Fuzzy Set Theory:

The assessment of a risk is filled with inevitable uncertainty, ambiguity and vagueness. This is mainly because the subjective opinion and the imprecise linguistic expression are used to express risk magnitude[6]. Real life situations are very often uncertain or vague in a number of ways. Due to lack of information, the nature of the system might not be completely known. This type of uncertainty (stochastic character) has long been handled appropriately by probability theory and statistics. In contrast to the vagueness concerning the description of the semantic meaning of the events, phenomena, or statements themselves, which will be referred to as fuzziness. When modeling uncertainty, the observer does not perceive information about the event he/she desire to model directly, but only after it has been "filtered" by the uncertainty theory used[14]. As Figure-1 depicts uncertainty as a situational property:

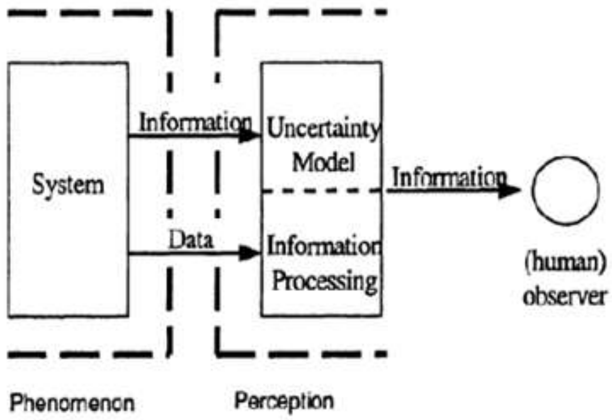


Figure- 1 Uncertainty as a situational property [**14**]

Zimmer et al. (2011) define a Fuzzy set theory to be a theory of graded concepts- a theory in which everything is a matter of degree or, in other words, everything has elasticity [14]. The theory of fuzzy sets has tremendously expanded in both its application and the methods to deal with it, since it has first been founded 20 years ago. Fuzziness can be found in many areas of daily life. However, it is particularly frequent in all areas in which human judgment, evaluation, and decision are important. These are the areas of decision making, reasoning, learning, and so on. Applications of this theory can be found, for example, in artificial intelligence, computer science, decision theory, and expert systems. One distinct field, however, in which fuzzy sets had been applied considerably is for modeling decision making for managers [14]. This is certainly the case in construction industry and in risk assessment which is highly dependent on the people's personal judgment and assessment especially in the early stages of the project's life cycle when few reliable and consistent information is present. Beltrao. L and Carvalho. M (2019) used a modified AHP technique by combining the analytical hierarchy processing techniques with the principles of the fuzzy set theory to create a model that prioritize 54 risks in Brazilian public enterprises [15]. According to Zeng et al (2007), the advantages of a fuzzy-based approach to risk assessment in construction projects are [16]:

- ✓ The ability to handle risks with the expert knowledge, engineering judgment and the previous data collected from risk management.
- ✓ The ability to evaluate risks using qualitative, non-numerical terms which can be utilized to assess risks.

The Distinction between crisp, traditional set theory and fuzzy set theory can be summarized in the following paragraph. In classical (crisp) set theory, each single element x in a universal set X can either belong to or not belong to a subset A, $A \subseteq X$. The member elements can be defined by using a characteristic function. It assigns a dichotomous value (either 1 or 0) to each element$x \subseteq X$, 1 indicating membership and 0 for non-membership. In fuzzy set theory, the characteristic function allows different degrees of membership for the elements. Larger values mean higher degrees or grades of set membership. Such a generalized function is called a membership function,$\mu(x)$ with a range of values within a unit interval$[0,1]$. Then a fuzzy subset $\check{A}$ in a universal set X is a set of ordered pairs $\check{A}= \{(x, \mu(x)) \mid x \in X\}$ (Buckley 1985).
The survey consisted of top thirty risks in residential projects based on the past available research and related literature. The response rate was 74 percent and experts with over 10 years of experience were included in the survey. The final ranking was then based on the formula for calculating the fuzzy weights (Schmucker 1984; Tah et al. 1993), then it was used to develop an prototype model to allocate those risks and to predict their magnitude based on the project phase and the available information at the time of assessment, the availability of a risk plan, the impact of each risk on the project's objectives, how risks are interrelated, risk liability, risk frequency, and the In-time available flexibility with resources and project performance measures to minimize and control risks in case they happened in reality. A common language for describing the risks is presented and linguistic terms were used to define the fuzzy variables sets. The final prototype model is utilized to make better decisions in the future and to improve the traditional way of assessing and allocating risks. To determine the variables influencing risk magnitude and likelihood, a questionnaire was dispensed to five experts from one of the most concerned companies with executing and supervising residential projects in Lattakia, Syria. Their response is then used to develop the weights of the variables and to define the impact of each of the previous proposed factors on each of the ten risks. A rule base is developed and is used to create a fuzzy-based model using Matlab works.

Research Tools and Methods:

3. Research Methodology:

The methodology of research in Figure-2 and the used steps will be explained in further details. This aim of this study is to develop a model to predict the magnitude of major risks in the Syrian construction industry and to assign the responsibility of each risk as the contractor's, the owner's or as a shared responsibility. First, an expert survey was conducted to determine the top ten risks in the Syrian Construction Industry. A total of 37 out of 50 experts answered the survey.

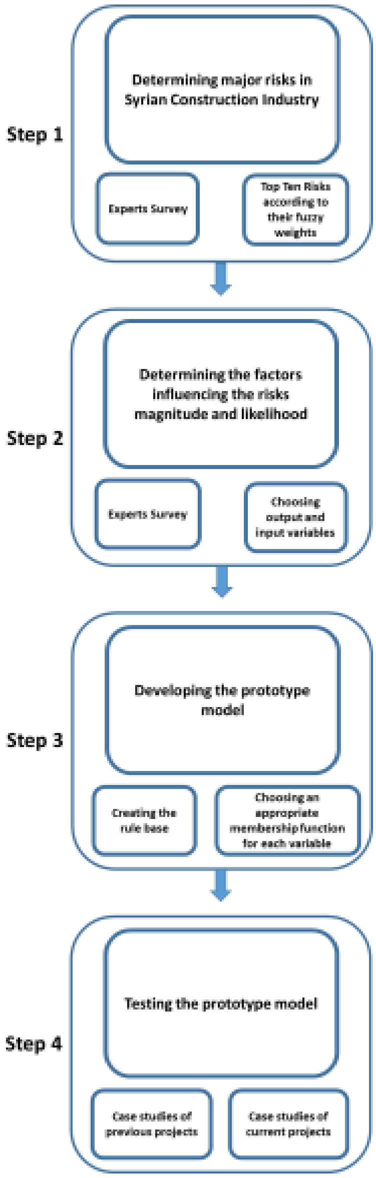


Figure-2: Research Methodology

3.1. Determining major risks in Syrian Construction Industry

In order to determine the major risks in residential projects, a survey of experts was used to rank the top ten risks according to their Fuzzy weights $\mathbf{F_{wi}}$. Which will be based on the overall impact of the risks on the project and based on the formula is (Schmucker 1984; Tah et al. 1993):

$$\bar{W} = \frac{\sum_{i=1}^{n} wi * Ri}{\sum_{i=1}^{n} wi}$$

Where:

- $\mathbf{R_i}$ is the likelihood of the risk i happening and is calculated as follows:

$$Ri = \frac{\sum_{n=1}^{n=37} Rn}{37}$$

- $\mathbf{W_i}$ is the impact risk i has on the project and is calculate as follows:

$$Wi = \frac{\sum_{n=1}^{n=37} Wn}{37}$$

A fuzzy weight index Fwi is then calculated based on the next equation:

$$F_{Wi} = \frac{Wi}{\overline{W}}$$

- **Fwi** is the fuzzy index for risk i.

Table-3 shows the top ten risks according to their fuzzy weight:

Table- 3: Top Ten risks in residential projects

Symbol	Description	F_{wi}	Rank
R1	An unprecedented increase in raw material prices	1.352522733	1
R2	Loss due to an increase in petroleum prices	1.236176691	2
R3	Contractual breaches	1.151825811	3
R4	Losing critical work teams/forces at a critical time in the project schedule	1.14891716	4
R5	Improper specification	1.14891716	5
R6	Improper and inadequate designs	1.11983065	6
R7	Incorrect feasibility study	1.090744139	7
R8	Subcontractor leaving or quitting	1.032155597	8
R9	Improper cost estimation	1.004663791	9
R10	Unavailability of sources	1.002238043	10

Those top ten risks will be used to develop the prototype in this paper as porter stated that considering the top eight largest risks will cover approximately 90% of the total risks [7]. As for the rest of the risks, they are deemed to be insignificant and minor in terms of magnitude. According to Barnes. M, those risks can be allocated to the contractor [3].

3.2. Determining the factors influencing the risks magnitude and likelihood

Six linguistic input variables were chosen which were derived from the risk assessment classification and the factors described in the literature reviews and then through a questionnaire with five experts. Each expert is a civil engineer with accumulated experience of over 10 years. The questionnaire was designed to determine both the general weight of those input and the individual weight against each of the top previously Mentioned risks. The six inputs are defined and coded as following:

Project Phase at the time of assessment (C1): A risk may be mitigated in a certain phase of the project's life cycle and may not be in another which ultimately means a variation in its severity and impact. Subsequently, a risk is highly expected in a phase and not in the other.

The amount available information at the time of assessment (**C2**): the amount information available at a certain time may mean more or less certainty of the made decision and thus the likelihood and severity of the following Complications of that decision.

A contingency plan that takes this risk into consideration (**C3**): A reasonable expectations and assumptions of the project is anticipated before taking any action[17]. This means that when assuming the risk had actually occurred, one must know the counter measures that can be done to reduce its impact on the project's objective or performance measures (cost, time, safety and quality).

How risks are interrelated (**C4**): If a risk is linked to another then the occurrence of one happening affects both the likelihood and the severity of the other. In some cases, several risks can be tangled together.

In-time available flexibility with resources and project performance measures (C5): Additional time or resources available which make it possible to mitigate the risk without losing critical time, quality, labor teams, and equipment, or affecting the resources of the project.

Risk occurring frequency in the same project (C6): Is it the first time that this specific risk had happened in the project? If not, how many times did it actually occur? How did it affect the project performance measures? How did both parties deal with it?

As for the outputs of this model, both risk magnitude and risk liability are chosen and explained further as follows:

Risk magnitude (**O1**): How does the risk impact the (time, cost, safety and equality) of the project but most importantly and specifically which one does it affect the most? Risk Magnitude is then derived by multiplying the risk likelihood of happening and its impact on the project's performance measures[1].

Risk liability (O2): the party responsible for the risk is crucial when determining the way, it is being managed, mitigated and dealt with. The principal guideline in determining whether a risk should be transferred to another party, should be based upon whether the party assuming the risk has both the competence to assess the risk and the Expertise necessary to control or minimize it. Both parties of the contract are also expected to have not only a clear but also a similar understanding of the risk. Confusion can result in mismanaging the risk event because of a false perception of whose responsibility the risk is[18]. The very large number of minor (low severity and unlikely to happen) risks can be allocated to the contractor without any significant effect upon his total risk. This is the case with most standardized conditions of contract[3]. The six variables which were introduced earlier were inserted as input variables with an additional seventh variable known as "Risk". This is used to help the user define the risk he/she may be pondering whether to consider into their future plans and if so, figuring the chances of it happening and the consequences in terms of cost, time and quality if such event end up happening in reality. The input and output variables and their final linguistic terms and membership functions are introduced in the following Tables.

Table- 4: Elements included in O1 Fuzzy Set

Risk Magnitude (O1)		
Minimum	Moderate	High
0-25	15-50	25-100

Table- 5 : Elements included in O2 Fuzzy Set

Risk liability (O2):		
Contractor	Owner	Shared
1	2	3

Table- 6: Input variables Linguistic Terms

Input variable	Linguistic terms
Project Phase C1	· Very Conceptual
	· Sort of Conceptual
	· Slightly Conceptual
	· Less than Slightly Conceptual
	· Not Conceptual
	· Not Conceptual at all
Information C2	· Very much Available
	· Sort of Available
	· Slightly Available
	· Less than Slightly Available
	· Not Available
	· Not Available at all
Risk Plan C3	· Very Considered
	· Sort of Considered
	· Slightly Considered
	· Less than Slightly Considered
	· Not Considered
	· Not Considered at all
Relationships C4	· Very Related
	· Sort of Related
	· Slightly Related
	· Less than Slightly Related
	· Not Related
	· Not Related at all
Resource Flexibility C5	· Very much Available
	· Sort of Available
	· Slightly Available
	· Less than Slightly Available
	· Not Available
	· Not Available at all
Frequency C6	· Very Frequent
	· Sort of Frequent
	· Slightly Frequent
	· Less than Slightly Frequent
	· Not Frequent
	· Not Frequent at all
Risk C7	· R1, R2, R3……….R10

3.3. Developing the prototype model

3.3.1. Choosing an appropriate membership function for each variable:

For input variables, the membership function chosen for each of linguistic term of the first six variable is based on Michio Sugeno and Takahiro Yasukawa’s work (1993):

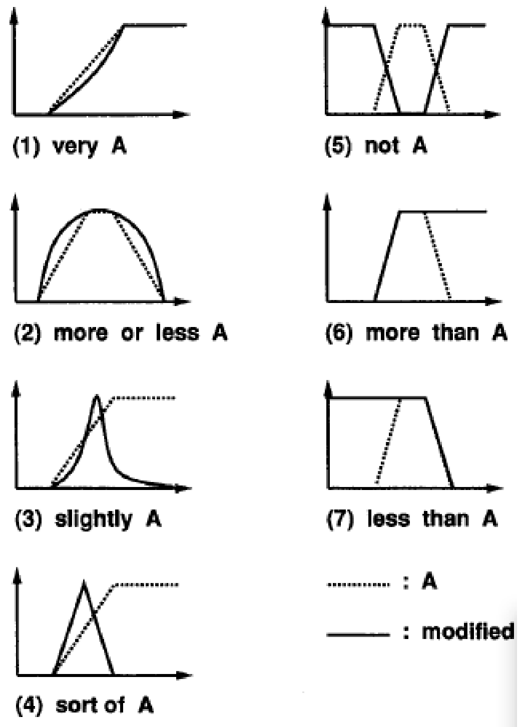


Figure-3: Different Membership functions for different Linguistic terms [**18**]

Table-7 shows the membership functions chosen for each term:

Table- 6: Membership functions		
Linguistic term	**Membership function**	**Range %**
Very	shape 1	75-100
Sort of	shape 4	50-80
Slightly	Shape 3	50-70
Less than Slightly	shape 7	20-55
Not	shape 5	10-40
Not at all	shape 5	0-20

Both triangular and trapezoidal membership functions have been used, especially in real-time implementations as a result to their efficiency and simplicity[19][20]. As for the risk magnitude and the seventh input variable (Risk type), the membership function is the triangular MF, as it is frequently used in construction project risk[4], the risk liability, on the other hand, will be based on Hartman's et al. (1996) that is described in Figure-4:

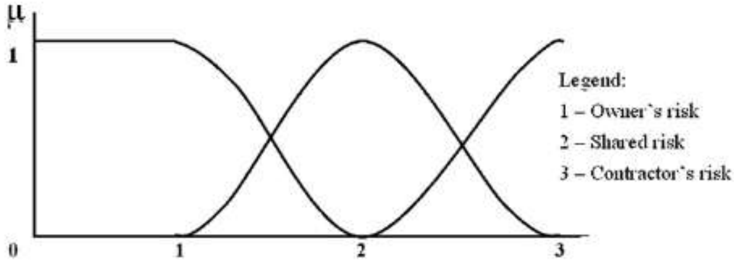


Figure-4: Fuzzification Membership for Risk Liability[**20**]

To define the rules, expert knowledge was gathered through semi-structured interviews along with a questionnaire to define the general weights of the six inputs as well as their individual weights. General weight is calculated using the formula:

$$Fi = \frac{n - ri + 1}{\sum_{i=1}^{6} ri}$$

Where:

- **Fi** is general weight for the input variable i.
- **n** is the number of input variables = 6.
- **ri** is the ranking of input variable i according to the five experts.

The second factor (**Fij**) is individual weight of each input variable for risk j and is defined according to the experts and calculated as follows:

$$Fij = \frac{n - Mij + 1}{\sum_{\substack{i=1 \\ j=1}}^{\substack{i=6 \\ j=10}} Mij}$$

Where:

- **Fij** is individual weight for the input variable i.
- **n** is the number of input variables = 6.
- **Mij** is the final ranking of input i for risk j according to the five experts.

The final general weight and individual weights are explained in Table-8. These weights were then used as a way to help the experts form the rules based on the relative and general importance of each of the six criterions against each of the ten risks.

Table- 8: General and Individual Weights for input variables

	C1	C2	C3	C4	C5	C6
General Weight	28.57%	23.81%	19.05%	9.52%	14.29%	4.76%
Individual Weight for R1	28.57%	14.29%	23.81%	9.52%	19.05%	4.76%
Individual Weight for R2	28.57%	23.81%	19.05%	9.52%	14.29%	4.76%
Individual Weight for R3	14.29%	28.57%	4.76%	9.52%	19.05%	23.81%
Individual Weight for R4	28.57%	9.52%	19.05%	23.81%	4.76%	14.29%
Individual Weight for R5	9.52%	14.29%	28.57%	19.05%	23.81%	4.76%
Individual Weight for R6	28.57%	4.76%	23.81%	19.05%	9.52%	14.29%
Individual Weight for R7	19.05%	28.57%	23.81%	14.29%	4.76%	9.52%
Individual Weight for R8	28.57%	23.81%	19.05%	4.76%	9.52%	14.29%
Individual Weight for R9	19.05%	28.57%	23.81%	14.29%	4.76%	9.52%
Individual Weight for R10	28.57%	14.29%	23.81%	19.05%	9.52%	4.76%

3.3.2. Creating the rule base:

Each of the six input variables has six linguistic terms that would be typically used to create the rule base by using the IF-THEN Rules. This means that the number of rules is $6^6 = 46656$ rule. This is a huge number and it would be impossible to form a base rule with such number. Instead, the experts previously weighted opinions will be used to form a more realistic rule base. The first step is calculating the final weights for each of the ten risks as the average of the generalized and the individual weights which will be shown in Table-9. The weights are then ranked from the least important criteria with the smallest weight up to the most important criteria with the largest weight for each of the ten suggested risks. This is shown in Table-10 which would result in 720 rules. The next step is to rank each criteria for each of the ten suggested risks from the risk that is the least Affected by this criteria up until the risk with the largest weight for this specific criteria. This is shown in Table-11 and would result in 720 more rules. This means that a total of 1440 rule is expected which is a reasonable number and can be formed.

Table- 7: Final weights for each Risk against each Criteria/Input Variable

Average weight	C1	C2	C3	C4	C5	C6
R1	**28.57%**	**19.05%**	**21.43%**	**9.52%**	**16.67%**	**4.76%**
R2	**28.57%**	**23.81%**	**19.05%**	**9.52%**	**14.29%**	**4.76%**
R3	**21.43%**	**26.19%**	**11.91%**	**9.52%**	**16.67%**	**14.29%**
R4	**28.57%**	**16.67%**	**19.05%**	**16.67%**	**9.53%**	**9.53%**
R5	**19.05%**	**19.05%**	**23.81%**	**14.29%**	**19.05%**	**4.76%**
R6	**28.57%**	**14.29%**	**21.43%**	**14.29%**	**11.91%**	**9.53%**
R7	**23.81%**	**26.19%**	**21.43%**	**11.91%**	**9.53%**	**7.14%**
R8	**28.57%**	**23.81%**	**19.05%**	**7.14%**	**11.91%**	**9.53%**
R9	**23.81%**	**26.19%**	**21.43%**	**11.91%**	**9.53%**	**7.14%**
R10	**28.57%**	**19.05%**	**21.43%**	**14.29%**	**11.91%**	**4.76%**

Table- 8: Risks, Criterion weighted and their corresponding impacts according to risks

Risk	Criteria	Weight	Accumulated Weights	Impact
R1	C6	4.76%	4.76%	Minimum
	C4	9.52%	14.28%	
	C5	16.67%	30.95%	Moderate
	C2	19.05%	50.00%	
	C3	21.43%	71.43%	High
	C1	28.57%	100.00%	
R2	C6	4.76%	4.76%	Minimum
	C4	9.52%	14.28%	
	C5	14.29%	28.57%	Moderate
	C3	19.05%	47.62%	
	C2	23.81%	71.43%	High
	C1	28.57%	100.00%	
R3	C4	9.52%	9.52%	Minimum
	C3	11.91%	21.43%	
	C6	14.29%	35.71%	Moderate
	C5	16.67%	52.38%	
	C1	21.43%	73.81%	High

Table- 8: Risks, Criterion weighted and their corresponding impacts according to risks

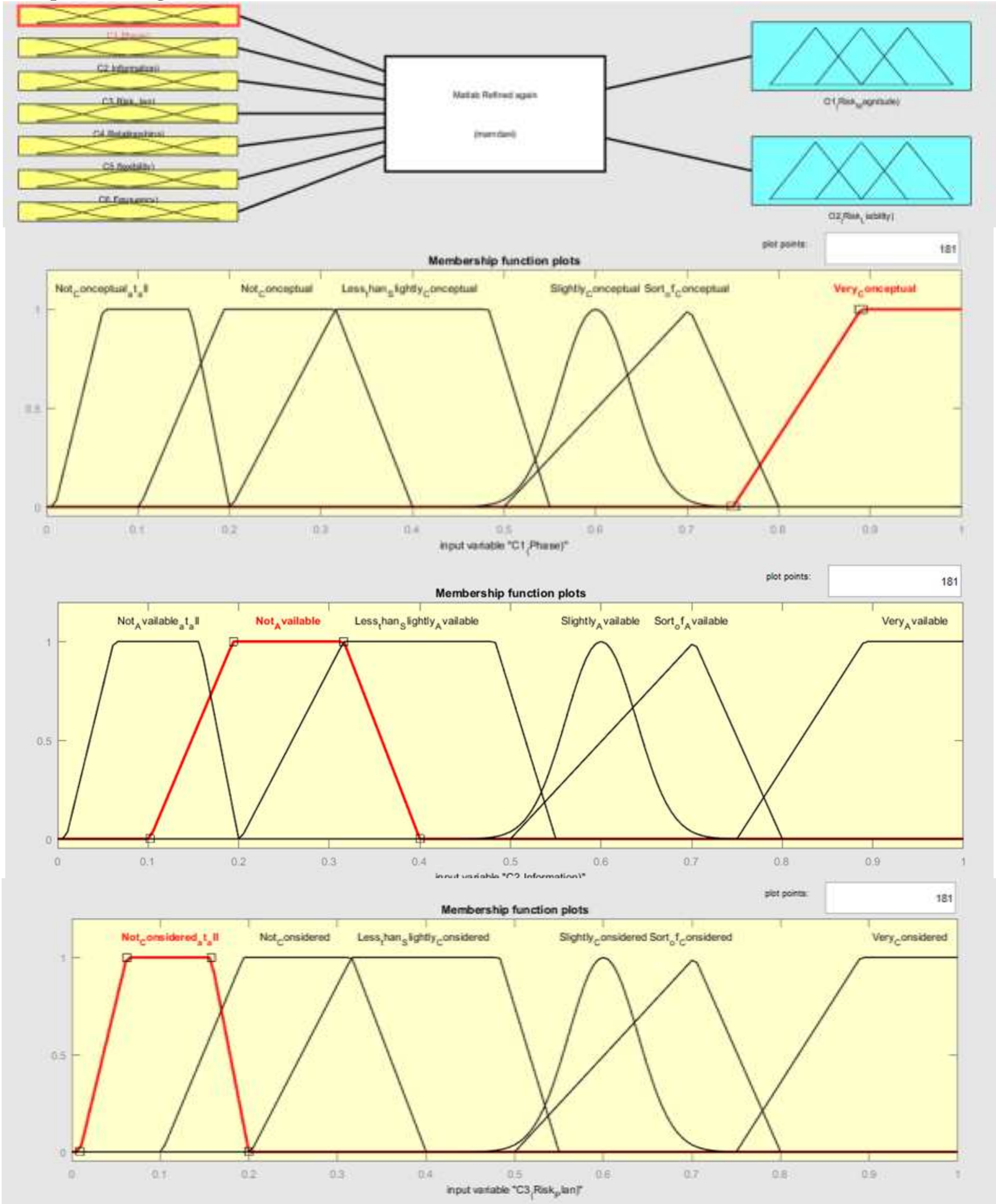
Risk	Criteria	Weight	Accumulated Weights	Impact
	C2	26.19%	100.00%	
R4	C5	9.53%	9.53%	Minimum
	C6	9.53%	19.05%	
	C2	16.67%	35.72%	Moderate
	C4	16.67%	52.38%	
	C3	19.05%	71.43%	High
	C1	28.57%	100.00%	
R5	C6	4.76%	4.76%	Minimum
	C4	14.29%	19.05%	
	C1	19.05%	38.09%	Moderate
	C2	19.05%	57.14%	
	C5	19.05%	76.19%	High
	C3	23.81%	100.00%	
R6	C6	9.53%	9.53%	Minimum
	C5	11.91%	21.43%	
	C2	14.29%	35.72%	Moderate
	C4	14.29%	50.00%	
	C3	21.43%	71.43%	High
	C1	28.57%	100.00%	
R7	C6	7.14%	7.14%	Minimum
	C5	9.53%	16.67%	
	C4	11.91%	28.57%	Moderate
	C3	21.43%	50.00%	
	C1	23.81%	73.81%	High
	C2	26.19%	100.00%	
R8	C4	7.14%	7.14%	Minimum
	C6	9.53%	16.67%	
	C5	11.91%	28.57%	Moderate
	C3	19.05%	47.62%	
	C2	23.81%	71.43%	High
	C1	28.57%	100.00%	
R9	C6	7.14%	7.14%	Minimum
	C5	9.53%	16.67%	
	C4	11.91%	28.57%	Moderate
	C3	21.43%	50.00%	
	C1	23.81%	73.81%	High
	C2	26.19%	100.00%	
R10	C6	4.76%	4.76%	Minimum
	C5	11.91%	16.67%	
	C4	14.29%	30.95%	Moderate

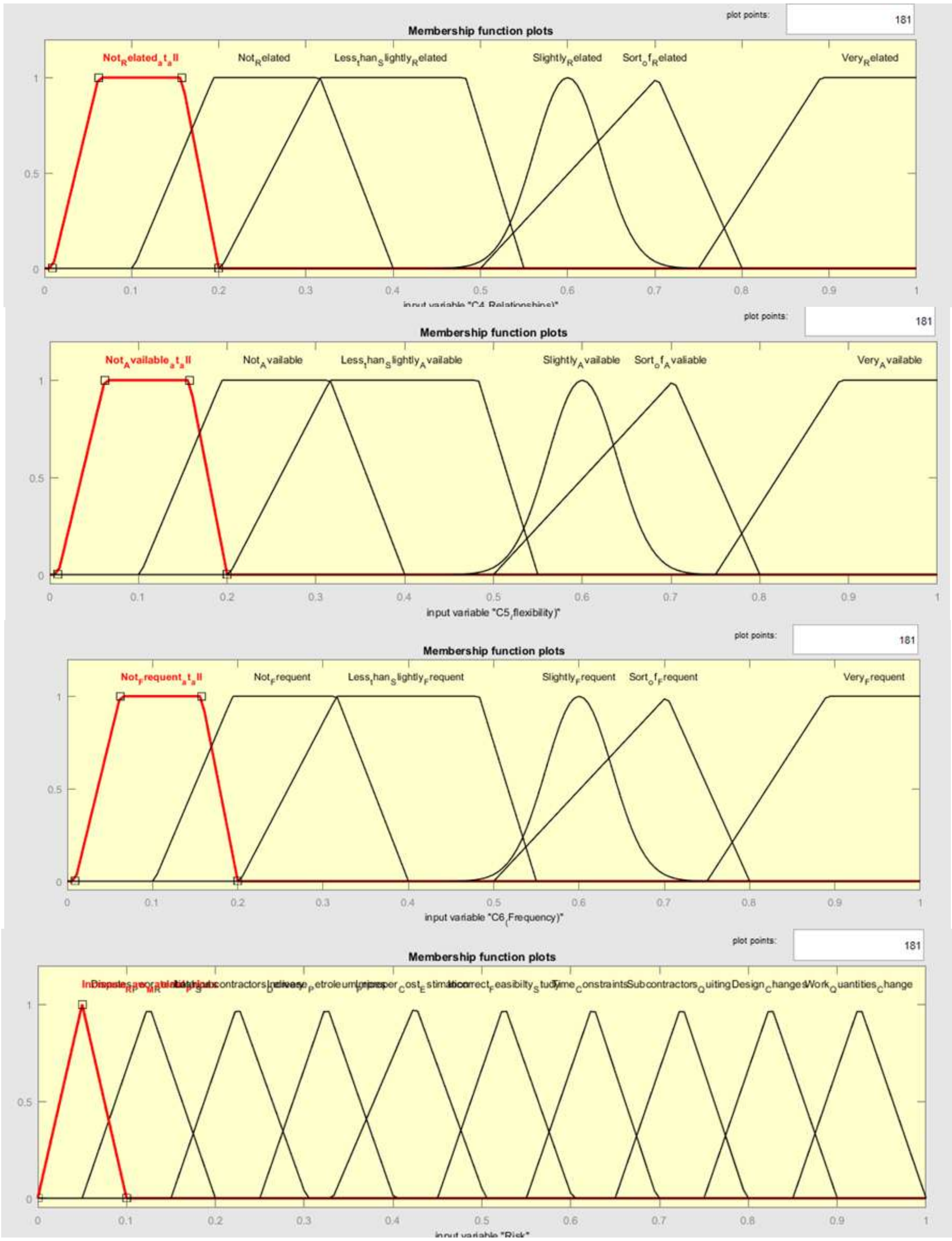
Table- 8: Risks, Criterion weighted and their corresponding impacts according to risks				
Risk	**Criteria**	**Weight**	**Accumulated Weights**	**Impact**
	C2	19.05%	50.00%	
	C3	21.43%	71.43%	High
	C1	28.57%	100.00%	

Table- 9: Risk, Criterion Weights and their corresponding impacts according to the criteria			
Risk	**Weight**	**Accumulated Weights**	**Impact**
C1			
R1	28.57%	28.57%	Minimum
R2	28.57%	57.14%	
R3	21.43%	78.57%	
R4	28.57%	107.14%	Moderate
R5	19.05%	126.19%	
R6	28.57%	154.76%	
R7	23.81%	178.57%	High
R8	28.57%	207.14%	
R9	23.81%	230.95%	
R10	28.57%	259.52%	
C2			
R1	19.05%	19.05%	Minimum
R2	23.81%	42.86%	
R3	26.19%	69.05%	
R4	16.67%	85.72%	Moderate
R5	19.05%	104.77%	
R6	14.29%	119.05%	
R7	26.19%	145.24%	High
R8	23.81%	169.05%	
R9	26.19%	195.24%	
R10	19.05%	214.29%	
C3			
R1	21.43%	21.43%	Minimum
R2	19.05%	40.48%	
R3	11.91%	52.39%	
R4	19.05%	71.44%	Moderate
R5	23.81%	95.25%	
R6	21.43%	116.68%	
R7	21.43%	138.11%	High
R8	19.05%	157.16%	
R9	21.43%	178.59%	
R10	21.43%	200.02%	
C4			
R1	9.52%	9.52%	Minimum

Table- 9: Risk, Criterion Weights and their corresponding impacts according to the criteria			
Risk	**Weight**	**Accumulated Weights**	**Impact**
R2	9.52%	19.04%	
R3	9.52%	28.56%	
R4	16.67%	45.23%	Moderate
R5	14.29%	59.51%	
R6	14.29%	73.80%	
R7	11.91%	85.70%	High
R8	7.14%	92.84%	
R9	11.91%	104.75%	
R10	14.29%	119.03%	
C5			
R1	16.67%	16.67%	Minimum
R2	14.29%	30.96%	
R3	16.67%	47.63%	
R4	9.53%	57.16%	Moderate
R5	19.05%	76.21%	
R6	11.91%	88.11%	
R7	9.53%	97.64%	High
R8	11.91%	109.54%	
R9	9.53%	119.07%	
R10	11.91%	130.97%	
C6			
R1	4.76%	4.76%	Minimum
R2	4.76%	9.52%	
R3	14.29%	23.81%	
R4	9.53%	33.33%	Moderate
R5	4.76%	38.09%	
R6	9.53%	47.62%	
R7	7.14%	54.76%	High
R8	9.53%	64.28%	
R9	7.14%	71.42%	
R10	4.76%	76.18%	

The rule base was then developed and tested out on a real life ongoing as well as previously executed projects later on. After choosing the membership function and creating the appropriate rule base, outputs of the desired model need to be transformed again into linguistic terms according to their fuzzy set [6]. This is called the "Defuzzification" Which is basically converting the fuzzy inferences into linguistic terms similar to the ones the human users actually use[9]. As for the Defuzzification method, Center of sum will be used as it is quite simple, representative and widely known for being used for these types of applications[14]. The final input and output variables are shown in Figure- 5 after implementing them into Matlab Works.




plot points:
181
Membership function plots
Not_Related_at_all
Not_Related
Less_than_Slightly_Related
Slightly_Related
Sort_of_Related
Very_Related
Membership function plots
Not_Available_at_all
Not_Available
Less_than_Slightly_Available
Slightly_Available
Sort_of_Available
Very_Available
input variable "C5_flexibility)"
Membership function plots
Not_Frequent_at_all
Not_Frequent
Less_than_Slightly_Frequent
Slightly_Frequent
Sort_of_Frequent
Very_Frequent
input variable "C6_Frequency)"
Membership function plots
Subcontractors_Quiting
Design_Changes
Work_Quantities_Change
input variable "Risk"

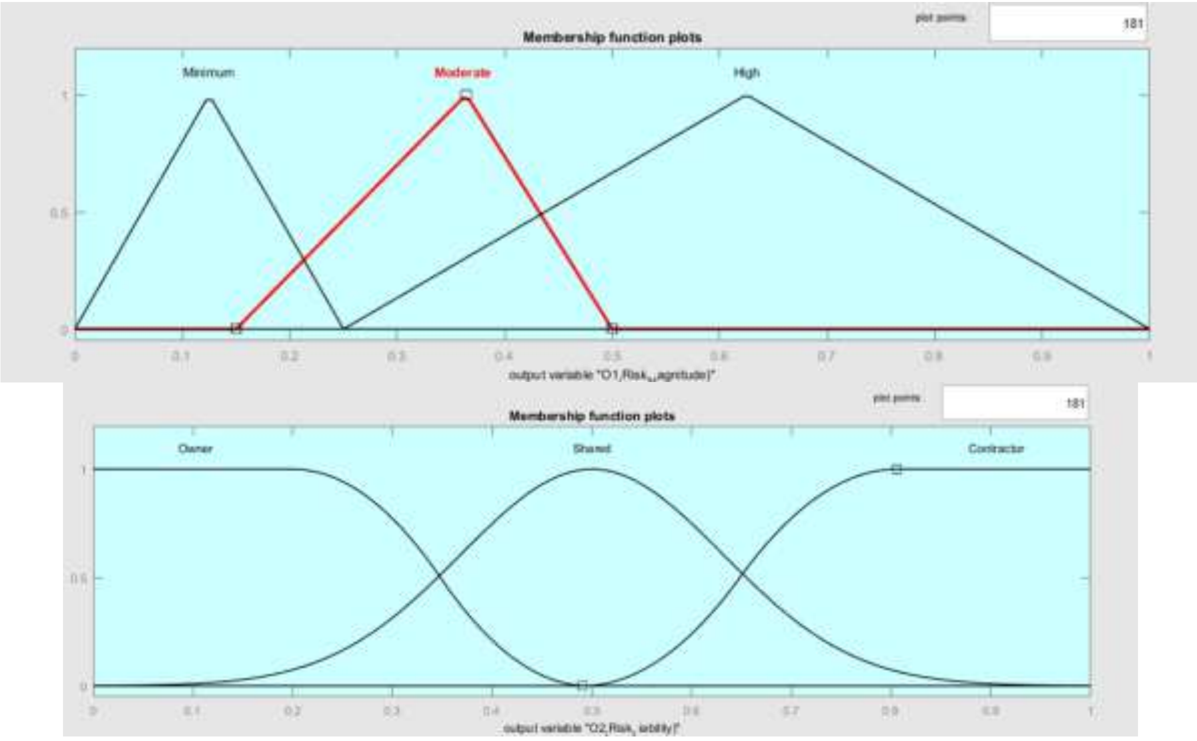


Figure- 5: Input and output variables Final Membership Functions

3.4. Testing the prototype model

In order to test out the validity and the applicability of the model, case studies of actual projects have been examined. Risks predicted by the model were compared to the risks documented in the project's records throughout its lifecycle. Engineers and managers who supervised and/or designed those projects were also consulted and interviewed for possible undocumented risks. Three already done projects were used. Information about the projects is introduced in the Table-12. Major risks were determined by investigating available documents and by Interviewing People who actually worked in these projects. Table- 13 depicts a comparison between the top three risks according to the model risks and risks according to the available historical data.

Table 10: Information about projects

Project	Scope	Estimated Cost (Syrian Pounds)	Estimated Time (Actual work Days)
1	Finishing works for two 10-story buildings	825792044	360
2	General site works	780833456	360
3	Constructing Tower buildings	975860000	400

Table- 11: Comparison between risks in the developed model and in the historical data		
	Model	**Records**
Project 1	1. Contractual Breaches 2. Improper and inadequate designs 3. Improper specifications	1. Unavailability of workshop drawings 2. Improper specifications 3. Delays due to complicated bureaucratic procedures
Project 2	1. Incorrect cost estimation 2. Incorrect feasibility study 3. Unavailability of resources	1. Losing critical work teams 2. An unprecedented increase in raw material prices 3. Subcontractors late work delivery and/or quitting
Project 3	1. An unprecedented increase in raw material prices 2. Improper cost estimation 3. Incorrect feasibility study	1. Design changes ordered by the client 2. A spike in material cost 3. Unexpected surprises due to the lack of a through site investigation

For ongoing projects, two 14-story tower buildings are chosen. Managers and Engineers entered the input terms into the model and the top five risks were predicted in addition to the risk liability. Table-14 is used to demonstrate the results:

Table- 12: Ongoing projects major risks according to the model			
Project	**Phase**	**Top Five risks**	**Risk liability**
Tower building 1	**Preliminary**	1. An unprecedented increase in raw material prices 2. Improper cost estimation 3. Incorrect feasibility study 4. Improper and inadequate designs 5. Loss due to an increase in petroleum prices	1. Shared 2. Contractor 3. Contractor 4. Shared 5. Shared
Tower Building 2	**Construction**	1. An unprecedented increase in raw material prices 2. Contractual breaches 3. Incorrect feasibility study 4. Improper specification 5. Unavailability of resources	1. Shared 2. Shared 3. Contractor 4. Contractor 5. Shared

Results and Discussion:

The top three risks described in the studied projects in Table-13 were the documented risks as well as the risks that the engineers and managers remembered occurring during the projects' lifecycle. These risks are only used for comparison. In real time projects, it is necessary to evaluate at least the top eight risks according to Porter as it is more representative and can include up to 90% of the total risks. Interviews with mangers showed that risks predicted by the model are somewhat more representative and consistent with what actually went on and how it affected the project's final time and cost. For instance, the increase in raw materials' prices in project 3 in table-13 was not documented but rather deducted from interviews with managers and engineers who actually worked in these projects. The model predicts them in a way similar to the human brain system without actually having to interview experts that may or may not be still working in the industry. It can predict risks that may be hard to document during the lifecycle of the project based on the intuition and reasoning human experts use unconsciously. Incorrect feasibility study is also a major risk that did not show up in regular documentation but experts can remember quiet vividly why things went wrong and when it can go wrong again if the same circumstance were to present themselves in similar future projects. The use of the model could be extremely beneficial for early life project decisions which can affect the project's success rate. In tower building number one, the improper cost estimation is anticipated. So, managers and contractual parties are expected to pay extra attention to cost estimation as it is one of the major risks affecting the project's success rate.

Conclusions and Recommendations:

Eventually, the proposed model can be used as a supportive tool to help make more reliable decisions and to analyze risks in residential projects using more natural, more meaningful linguistic terms to executives and managers in such industry. Risk consultants and managers can use the software to quantify different risk scenarios and choose an adequate risk response in advance. In conclusion, the prototype had shown an ability to predict some the most impactful risks that residential projects in Lattakia are mostly prone to. According to the experts, it is somewhat easy to deal with. It can be a useful tool towards an integrated system for risk management in Syrian residential projects. The model's results could be used for making a contingency plan to control and minimize risks in every phase of the project that can be updated as the project goes through its normal life cycle as the project's phase is one of the input variables that can be interpreted according to the decision makers.

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