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RESEARCH ARTICLE - ENGINEERING

Developing a Fuzzy Inference Model for Construction Project Risk Management in Iraq

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Abstract

The construction industry is considered a high-risk business. Risk management is one of the most influential methods used in construction project management to increase the chances of delivering the project successfully, Risk Assessment (RA) is necessary to help organizations identify and mitigate risks; therefore, this paper suggests a framework for developing an intelligent RA. There are many Risk Factors (RF) that affect construction projects, and they vary from one country to another. In this paper, a questionnaire of forty-one questions about RF was performed; its evaluation criteria are risk probability and its impact on cost, time, and quality, this questionnaire relied on several experts' opinions to identify the most common RF affecting Iraqi construction projects. The collected linguistic data were converted into a triangular fuzzy number. Qualitative Risk Analysis was performed to assess the priority of the identified risks; while the Adaptive Neuro-Fuzzy Inference System (ANFIS) was proposed as the intelligent model. The training outcome produced three Fuzzy Inference Systems (FISs) models evaluated using the fuzzy designer application and tested using the fuzzy designer app and MATLAB Simulink to evaluate their accuracy and reliability. Finally, a set of corrective actions were suggested to facilitate the task for users.

Publisher : Middle Technical University

Keywords: Risk Management; Risk Assessment; Probability; Fuzzy; Adaptive Neuro-Fuzzy Inference System (ANFIS).

1. Introduction

Engineering projects are rarely completed without any foreseeable difficulties or risks, necessitating the researchers to identify, analyse and assess them. For a closer look at what the term risk means, we will refer to the definition of [1] for risk as the exposure for losing/gaining or the possibility of the losing/gaining event multiplied by the connected importance. Project risk management aims to optimize the likelihood of project success by rising the probability and/or impact of positive risks and reducing the probability and/or impact of negative risks [2].

From a construction perspective, risks are generally considered as incidences that influence the principal objectives of a particular project (time, cost, quality) [3]. Project risk management has gained significant recognition as a critical procedure and capability area within project management, its focus on identifying, analyzing, and responding to risks helps organizations improve project outcomes and increase the possibility of success [4]. Despite the truth that risks are an adjoining element of construction projects due to the lengthy implementation duration, these risks can be managed to reduce their negative impact on project objectives [5].

There are many of the Construction Projects' Risk Assessment Methods (CPRAM) were proposed by researchers such as; the TOPSIS approach [6, 7], Risk Matrix [8], Monte Carlo Simulation [9], Bayesian network [10], Fault tree method [11], Fuzzy approach [12]. To improve the accurateness and efficiency of the results, some researchers have introduced hybrid methods for RA, such as: Fuzzy- Bayesian network approach [13], Fuzzy-TOPSIS [14], risk matrix-based Monte Carlo Simulation approach [15], FMCS [16], ANFIS [17]. There are many qualitative and quantitative risk assessment analysing tools in various sources. According to [18] the existing CPRAM was categorized into four types: indexing, matrix, probabilistic, and fuzzy methods.

Fuzzy methods are very efficient in modelling the uncertainties encountered in expert judgments and have therefore been frequently and widely used as independent or hybridized methods of construction RA for the last two decades [19]. A fuzzy System (FIS) is robust in reasoning, inference, and clear representation of knowledge, while ineffective in learning capabilities [20]. On the other hand, artificial neural networks have powerful learning abilities while poor reasoning and inference [21]. As a result, the research on the applications of artificial intelligence techniques indicated a transition from the use of these traditional stand-alone artificial intelligence methods towards employing hybrid systems by integrating two or more different artificial intelligence techniques such as ANFIS [22]. The researchers of [23] employed a fuzzy neural network risk analysis technique for construction projects utilizing prefabricated buildings, by leveraging the advantages of both neural and fuzzy networks, the method incorporated both qualitative and quantitative analyses to create fault tolerance and enhance adaptive capabilities.

Nomenclature & Symbols

ANFIS	Adaptive Neuro-Fuzzy Inference System	P	Probability of Risk Factor
CI	Cost Impact of risk factor	PMI	Project Management Institute
CPRAM	Construction Projects' Risk Assessment Methods	QI	Quality Impact of risk factor
CRTFN	Cost Risk Triangular Fuzzy Number	QRTFN	Quality Risk Triangular Fuzzy Number
CRV	Cost Risk Value	QRV	Quality Risk Values
FIS	Fuzzy Inference System	RA	Risk Assessment
FL	Fuzzy Logic	RF	Risk Factor
LVs	Linguistic Variables	RV	Risk Value
MFs	Membership Functions	TI	Time Impact of risk factor
NFS	Neuro-Fuzzy System	TFN	Triangular Fuzzy Number
VH	Very High	TRTFN	Time Risk Triangular Fuzzy Number
VL	Very Low	TRV	Time Risk Values

The input factors of the neural network were the vector of membership of the qualitative and quantitative indicators of the fuzzy comprehensive evaluation of the risk in the sample projects, while the output was the assessment result. After training, programming, and debugging the samples, the results showed good agreement with the expected outputs, which confirmed the applicability of the fuzzy neural network in the RA process of prefabricated buildings and its feasibility.

An ANFIS has been built based on collected data of identified risks that affected the construction projects and organized in a systematic hierarchical structure to prioritize and assess risks. Then a regression model was built to compare and analyse the results, the results showed that the fuzzy systems are more reliable [24]. This research objective is to assess the key RFs that can transpire in construction projects and create a highly effective intelligent model for assessing them.

2. Methodology

The workflow path applied in this research included two phases:

2.1. Practical phase

- At this phase, the RF affecting construction projects, especially projects inside Iraq, are determined by relying on articles approved in international journals, as well as personal interviews with several experts.
- Then, after identifying these factors, they are organized into a questionnaire to conduct a field survey among specialized experts and collect their opinions on the extent of the probability for each of the factors individually and the impact of each of them on the triangle of project management or what is called the iron triangle (time, cost, and quality).
- Finally, the data collected from the questionnaire feedback is analysed using statistical methods to conclude the information that will be used toward the third stage of the study.

2.2. Simulation phase

- In the last phase of this study, a model will be created using Fuzzy Logic (FL) and the ANFIS to analyse the Linguistic Variables (LVs) used in the questionnaire to assess risks and convert them into a mathematical model to assess their impact on construction projects in Iraq, based on expert opinions.

3. Practical Phase

This phase included a field survey relied on personal interviews with a number of experts specialized in the construction industry for projects executed in Iraq, some of whom have a certificate of professional project management (PMP), to organise a questionnaire form consisting of forty-one questions about RF categorized into five sections according to the Risk Breakdown Structure (RBS) recommended by the PMI, as shown in Fig. 1, the respondents had to select a linguistic variable from a five-scale range to specify the impact criterion's weight, hence assigning a score to each risk factor. In qualitative risk assessment the answers of the seventy participants to forty-one questions are reviewed regarding the probability of the RF inquired about and the impact of each of them on the project as Cost Impact of risk factor (CI), Time Impact of risk factor (TI), and Quality Impact of risk factor (QI). Hence, the denotation of these factors (as risk categorization in RBS displayed in Fig. 1 are as follows: F1: The unavailability of the documents required to start designing, as well as the unavailability of design maps for the service networks passing through the site, F2: The work description is unclear, and so on up to F41: Events and sudden holidays. While risk assessment denotation is as follows R01 for risk factor F1, R02 for risk factor F2, and so on up to R41 for risk factor F41. Fig. 2 shows the risk assessment for R01.

4. Simulation Phase

The presented paper introduces a RA model that employs fuzzy concepts to address epistemic uncertainty. The RA approach comprises three stages, which together form the algorithm of the risk model: the preparatory stage, data collection stage, and risk measurement stage. The risk owner has to go via these stages to execute the proposed construction projects' risk assessment model by heeding the following procedures:

- #1: The review of risk data, the description of fuzzy LVs, and the selection of their related fuzzy MFs. In this paper, Triangular Fuzzy Number (TFN) maps the membership values to maximize clarity.
- #2: This stage involves using an expert opinion questionnaire to identify potential sources of risk and gather information related to risks, including their probability and potential impact on project cost, time, and quality.

- #3: The process entails utilizing fuzzy operations to aggregate data gathered from the questionnaire and calculate the risk value through a FIS.

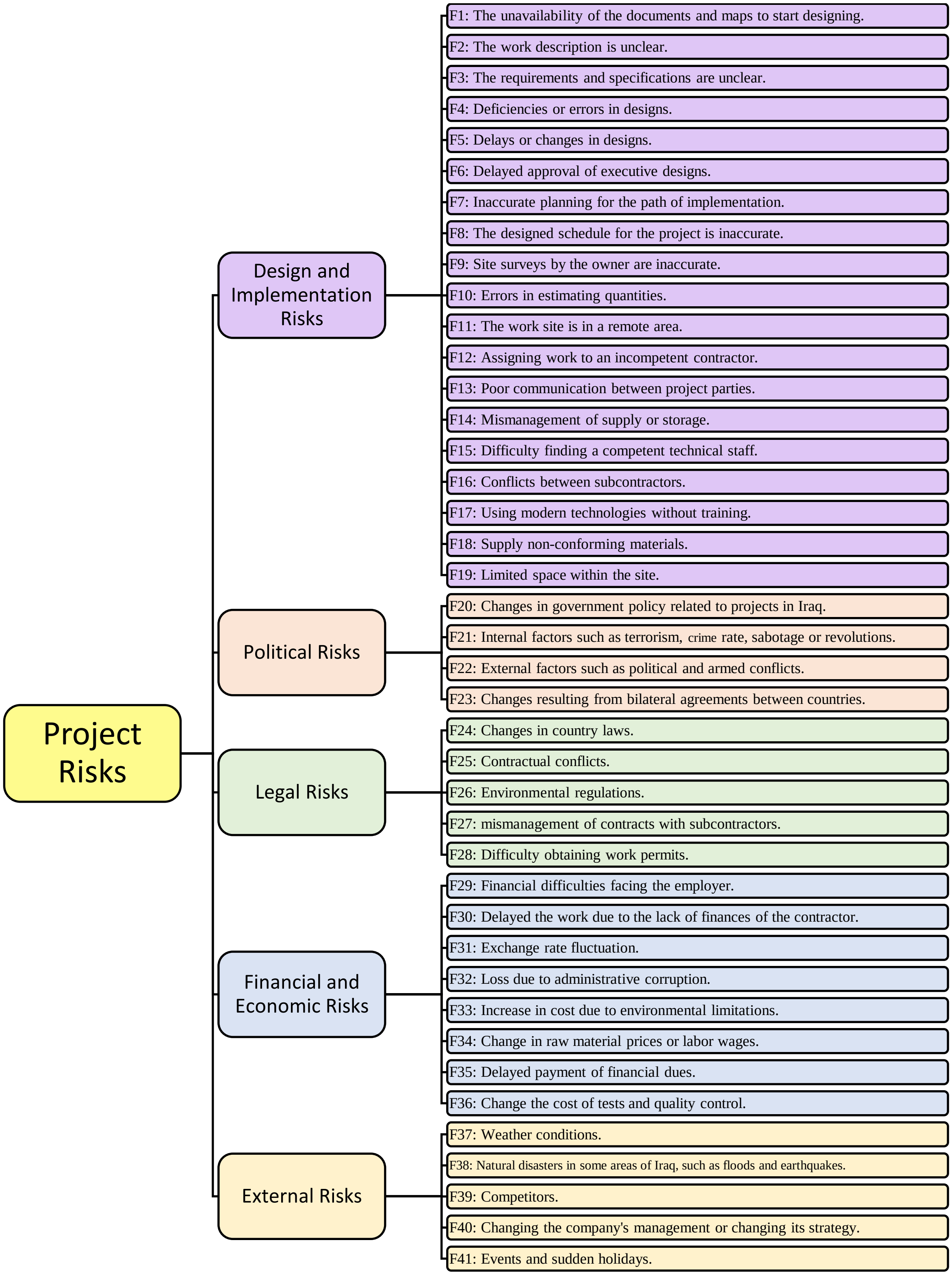


Fig. 1. Risk Breakdown Structure (RBS)

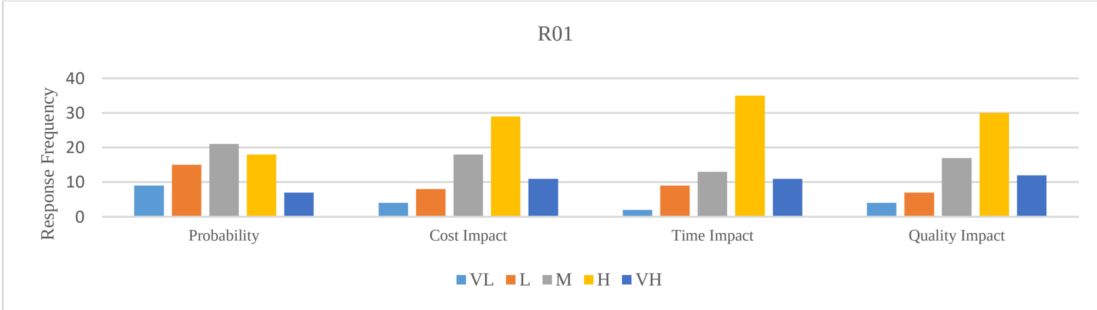


Fig. 2. Risk assessment

4.1. Preparatory stage

In the initial stage of the RA process, it is necessary to examine the risk data and determine the LVs. This approach helps quantify the RF when exact numerical values are difficult to determine. A linguistic variable is a variable whose values are expressed in natural language words. For instance, the probability of a risk incident can be represented using basic expressions which are, "Very Low", "Low", " Medium ", "High", and "Very High,". To measure risks, the LVs must be transformed into a corresponding fuzzy number using an appropriate conversion scale. LVs are characterized by Fuzzy MFs, which are described within the functional universe of discourse for the variable. Several fuzzy MFs are available, such as triangular, trapezoidal, Gaussian, and S-shaped MFs. Nevertheless, triangular and trapezoidal MFs are the most common MFs employed in analysing the risks of construction projects. Table 1 displays the TFN for LVs associated with the risk parameters.

Table 1. TFN of Linguistic Variables

Linguistic variables	Fuzzy numbers
Very Low	(0,0,0.25)
Low	(0,0.25,0.5)
Medium	(0.25,0.5,0.75)
High	(0.5,0.75,1)
Very High	(0.75,1,1)

To clarify what these LVs and fuzzy numbers mean, a description of them in terms of probability and impact is composed in Table 2.

Table 2. Descriptions of Linguistic Variables of Risk Probability and Impact

Linguistic Variables	Fuzzy numbers	Descriptions of Risk Probability	Descriptions of Risk Impact
Very Low	(0,0,0.25)	Very rarely occur	The impact is quite negligible
Low	(0,0.25,0.5)	Unlikely to occur	Little impact
Medium	(0.25,0.5,0.75)	Occurrence is usual	Moderate impact
High	(0.5,0.75,1)	Very likely to occur	High impact
Very High	(0.75,1,1)	Occurrence is almost inevitable	Very high impact

4.2. Data collection stage

Acquiring adequate recorded or statistical data for conducting risk analysis in construction projects can be challenging. As a result, many existing models rely solely on expert opinions, given the complex nature of construction projects and the unique features of each project. While each project is a distinct, one-time undertaking, some risks are common to all projects, while others are specific to a particular project. To determine the factors affecting construction projects in Iraq, the research relied on internationally approved articles and expert interviews. These factors were then organized into a questionnaire for a field survey among specialized experts.

4.2.1. Allocating weights

Experience is a crucial factor in assessing risk criteria regarding probability and impact. Therefore, a weight was placed according to the years of experience by repeating the number of answers for each experience category, thus, as listed in Table 3, the answers of experts with more than twenty years of experience were repeated three times, answers from whom experience between 16-20 years were repeated twice, and those with experience between 10-15 were repeated once, while the same number of answers received from those with experience less than ten years was sufficient.

Table 3. Allocated Weights

Experience Years	Frequency (FR)	Experience Factor (EF)	Added Frequency (AF)	New Frequency (NF)
Less than 10 years	7	0	0	7
Between 10-15 years	22	1	22	44
Between 16-20 years	19	2	38	57
More than 20 years	22	3	66	88
			New Frequency Total (NFT)	196

4.2.2. Aggregating TFN of P, CI, TI, and QI into set TFN

This step involves consolidating the risk data collected from various sources, about the individual risk factor probability and its impact on time, cost, and quality, into a set TFN. To compute the aggregated data, a fuzzy weighted triangular averaging operator is utilized, which is described in equations (1) and (2). The resulting aggregated TFN scores are then utilized as inputs in the subsequent fuzzy inferences phase to assess the Cost Risk Value (CRV), Time Risk Value (TRV), and Quality Risk Value (QRV) outputs. Table 4 lists the aggregated TFNs of RV.

$$NFT = \sum_{i=1}^{4} NF_i = \sum_{i=1}^{4} FR_i\,(EF_i + 1) \quad (1)$$

$$Agg(R_{nm}) = \left(\sum_{j=1}^{4} (1 + EF_j) \sum_{i=1}^{F_j} ETFN_i \right) / NFT \quad (2)$$

Where:
NFT is the new frequency total.
NF_i is the new frequency based on experience years classification.
FR_i is the frequency based on experience years classification.
EF_i is an experience factor based on experience years classification.
$Agg(R_{nm})$ is the aggregated value of R_{nm}, where R refers to risk, n refers to the number of risk factors (1-41), and m refers to risk factor parameters (P, CI, TI, and QI).
$ETFN_i$ is the TFN of experts' opinion.

4.3. Risk measurement stage

The utilization of FL in converting a given input mapping into an output mapping is known as FIS. In the fuzzy inference stage, the aggregated TFNs of "Probability of occurrence", "Impact on Cost", "Impact on Time", and "Impact on Quality" are transformed into corresponding fuzzy sets of Risk Value (RV). FIS can provide a more nuanced understanding of the potential risks associated with different courses of action by creating FL rules that incorporate probability and impact. This can be especially useful in situations where there are multiple risks to consider or where there is a high degree of uncertainty surrounding the potential impact of a particular risk. Ultimately, by using a FIS to apply logical relations between risk probability and impact using the "AND" rule, decision-makers can make more informed and effective decisions that can help mitigate potential risks and protect the interests of their organization. To define the junction between two fuzzy sets, A and B, a binary mapping T is used that combines the two MFs using Eq. (3):

$$\mu_{A\cap B} = T(\mu_A(x), \mu_B(x)) \quad (3)$$

Cost Risk Triangular Fuzzy Number (CRTFN), Time Risk Triangular Fuzzy Number (TRTFN), and Quality Risk Triangular Fuzzy Number (QRTFN), thus, the range for the value of risk become three classes, (L: the lowest value, AV: the average value, and H: the highest value) as listed in Table 5. When working with fuzzy numbers, it is necessary to convert them into non-fuzzy numbers through a process called defuzzification. There are several defuzzification methods available, and the choice of method will depend on the specific requirements of the decision-maker and the situation at hand. Some popular methods include centroid, middle of maximum, maximum of maximum, smallest of maximum, bisector, and α-cut. For this particular phase, the centroid method has been selected due to its ease of application relatively and it is the most used method in the construction sector. This method can be mathematically described using Eq. (4). These risk values are also listed in Table 5Table 5 for each risk factor.

$$RV = \frac{\int_0^1 x f(x)\, dx}{\int_0^1 f(\mathrm{x})\, dx} \quad (4)$$

Where f(x) indicates the RV membership function

Table 4. The Aggregated Data

Risk Factor	P (min, mid, max)	CI (min, mid, max)	TI (min, mid, max)	QI (min, mid, max)
F1	(0.230, 0.408, 0.633)	(0.347, 0.544, 0.753)	(0.327, 0.518, 0.727)	(0.349, 0.541, 0.748)
F2	(0.199, 0.372, 0.604)	(0.296, 0.485, 0.712)	(0.313, 0.502, 0.724)	(0.303, 0.495, 0.709)
F3	(0.215, 0.393, 0.625)	(0.291, 0.484, 0.717)	(0.311, 0.500, 0.729)	(0.327, 0.520, 0.743)
F4	(0.271, 0.461, 0.696)	(0.339, 0.539, 0.770)	(0.360, 0.559, 0.781)	(0.345, 0.543, 0.768)
F5	(0.296, 0.493, 0.724)	(0.332, 0.530, 0.768)	(0.309, 0.507, 0.747)	(0.285, 0.479, 0.725)
F6	(0.273, 0.467, 0.704)	(0.354, 0.544, 0.770)	(0.253, 0.433, 0.678)	(0.238, 0.408, 0.648)
F7	(0.253, 0.444, 0.678)	(0.301, 0.498, 0.720)	(0.304, 0.503, 0.732)	(0.276, 0.472, 0.706)
F8	(0.276, 0.462, 0.691)	(0.331, 0.526, 0.742)	(0.273, 0.461, 0.688)	(0.250, 0.434, 0.669)
F9	(0.219, 0.398, 0.638)	(0.291, 0.482, 0.712)	(0.268, 0.456, 0.684)	(0.247, 0.421, 0.655)
F10	(0.250, 0.442, 0.679)	(0.258, 0.439, 0.676)	(0.347, 0.536, 0.743)	(0.260, 0.442, 0.674)
F11	(0.271, 0.451, 0.681)	(0.245, 0.429, 0.673)	(0.286, 0.467, 0.701)	(0.204, 0.378, 0.620)
F12	(0.316, 0.516, 0.742)	(0.421, 0.622, 0.814)	(0.395, 0.590, 0.788)	(0.433, 0.633, 0.817)
F13	(0.265, 0.456, 0.692)	(0.331, 0.530, 0.758)	(0.303, 0.498, 0.732)	(0.311, 0.507, 0.735)
F14	(0.199, 0.378, 0.620)	(0.247, 0.426, 0.656)	(0.255, 0.442, 0.669)	(0.257, 0.439, 0.673)
F15	(0.232, 0.410, 0.638)	(0.276, 0.470, 0.706)	(0.275, 0.465, 0.691)	(0.347, 0.544, 0.752)
F16	(0.257, 0.456, 0.692)	(0.313, 0.507, 0.734)	(0.278, 0.465, 0.697)	(0.311, 0.503, 0.729)
F17	(0.209, 0.388, 0.627)	(0.257, 0.439, 0.676)	(0.281, 0.470, 0.702)	(0.285, 0.474, 0.707)
F18	(0.247, 0.418, 0.651)	(0.313, 0.495, 0.717)	(0.336, 0.518, 0.737)	(0.391, 0.579, 0.776)
F19	(0.186, 0.357, 0.595)	(0.232, 0.413, 0.650)	(0.229, 0.410, 0.651)	(0.207, 0.382, 0.625)
F20	(0.324, 0.523, 0.735)	(0.357, 0.556, 0.760)	(0.345, 0.533, 0.737)	(0.308, 0.493, 0.701)
F21	(0.317, 0.510, 0.727)	(0.388, 0.586, 0.778)	(0.390, 0.586, 0.783)	(0.342, 0.531, 0.738)
F22	(0.388, 0.586, 0.778)	(0.390, 0.586, 0.783)	(0.342, 0.531, 0.738)	(0.276, 0.467, 0.686)
F23	(0.390, 0.586, 0.783)	(0.342, 0.531, 0.738)	(0.276, 0.467, 0.686)	(0.327, 0.520, 0.740)
F24	(0.342, 0.531, 0.738)	(0.276, 0.467, 0.686)	(0.327, 0.520, 0.740)	(0.322, 0.513, 0.724)

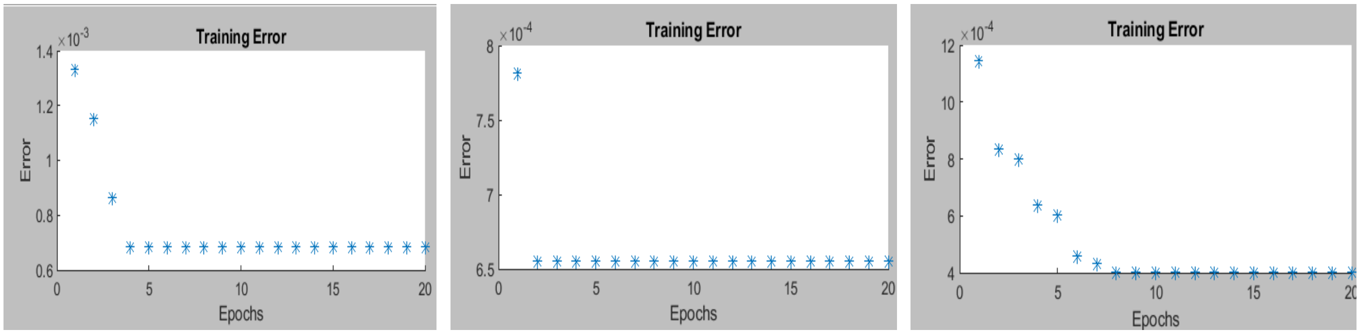
F25	(0.276, 0.467, 0.686)	(0.327, 0.520, 0.740)	(0.322, 0.513, 0.724)	(0.298, 0.485, 0.704)
F26	(0.327, 0.520, 0.740)	(0.322, 0.513, 0.724)	(0.298, 0.485, 0.704)	(0.176, 0.331, 0.569)
F27	(0.322, 0.513, 0.724)	(0.298, 0.485, 0.704)	(0.176, 0.331, 0.569)	(0.196, 0.365, 0.600)
F28	(0.298, 0.485, 0.704)	(0.176, 0.331, 0.569)	(0.196, 0.365, 0.600)	(0.214, 0.382, 0.613)
F29	(0.176, 0.331, 0.569)	(0.196, 0.365, 0.600)	(0.214, 0.382, 0.613)	(0.204, 0.372, 0.609)
F30	(0.196, 0.365, 0.600)	(0.214, 0.382, 0.613)	(0.204, 0.372, 0.609)	(0.191, 0.355, 0.590)
F31	(0.214, 0.382, 0.613)	(0.204, 0.372, 0.609)	(0.191, 0.355, 0.590)	(0.237, 0.419, 0.658)
F32	(0.204, 0.372, 0.609)	(0.191, 0.355, 0.590)	(0.237, 0.419, 0.658)	(0.219, 0.398, 0.632)
F33	(0.191, 0.355, 0.590)	(0.237, 0.419, 0.658)	(0.219, 0.398, 0.632)	(0.196, 0.362, 0.597)
F34	(0.237, 0.419, 0.658)	(0.219, 0.398, 0.632)	(0.196, 0.362, 0.597)	(0.227, 0.416, 0.656)
F35	(0.219, 0.398, 0.632)	(0.196, 0.362, 0.597)	(0.227, 0.416, 0.656)	(0.273, 0.469, 0.707)
F36	(0.196, 0.362, 0.597)	(0.227, 0.416, 0.656)	(0.273, 0.469, 0.707)	(0.243, 0.418, 0.656)
F37	(0.227, 0.416, 0.656)	(0.273, 0.469, 0.707)	(0.243, 0.418, 0.656)	(0.234, 0.405, 0.645)
F38	(0.273, 0.469, 0.707)	(0.243, 0.418, 0.656)	(0.234, 0.405, 0.645)	(0.150, 0.314, 0.561)
F39	(0.243, 0.418, 0.656)	(0.234, 0.405, 0.645)	(0.150, 0.314, 0.561)	(0.169, 0.334, 0.579)
F40	(0.234, 0.405, 0.645)	(0.150, 0.314, 0.561)	(0.169, 0.334, 0.579)	(0.169, 0.332, 0.576)
F41	(0.150, 0.314, 0.561)	(0.169, 0.334, 0.579)	(0.169, 0.332, 0.576)	(0.160, 0.317, 0.563)

Table 5. Defuzzification to Evaluate RV

Risk Factors	CRTFN			CRV	TRTFN			TRV	QRTFN			QRV
	L	AV	H		L	AV	H		L	AV	H	
F1	0.080	0.222	0.477	0.260	0.075	0.211	0.460	0.249	0.080	0.221	0.474	0.258
F2	0.059	0.180	0.430	0.223	0.062	0.186	0.437	0.228	0.060	0.184	0.428	0.224
F3	0.063	0.190	0.448	0.234	0.067	0.197	0.455	0.240	0.071	0.204	0.465	0.246
F4	0.092	0.248	0.536	0.292	0.098	0.258	0.544	0.300	0.094	0.250	0.534	0.293
F5	0.098	0.261	0.556	0.305	0.092	0.250	0.540	0.294	0.084	0.236	0.525	0.282
F6	0.097	0.254	0.542	0.298	0.069	0.202	0.477	0.249	0.065	0.191	0.456	0.237
F7	0.076	0.221	0.488	0.262	0.077	0.224	0.496	0.266	0.070	0.210	0.478	0.253
F8	0.091	0.243	0.512	0.282	0.075	0.213	0.475	0.254	0.069	0.201	0.462	0.244
F9	0.064	0.192	0.454	0.237	0.059	0.181	0.437	0.226	0.054	0.168	0.418	0.213
F10	0.065	0.194	0.459	0.239	0.087	0.237	0.505	0.276	0.065	0.196	0.458	0.240
F11	0.067	0.193	0.458	0.239	0.078	0.211	0.477	0.255	0.055	0.170	0.422	0.216
F12	0.133	0.321	0.604	0.353	0.125	0.305	0.584	0.338	0.137	0.327	0.606	0.357
F13	0.088	0.241	0.525	0.285	0.080	0.227	0.507	0.271	0.082	0.231	0.509	0.274
F14	0.049	0.161	0.407	0.206	0.051	0.167	0.415	0.211	0.051	0.166	0.417	0.211
F15	0.064	0.193	0.450	0.236	0.064	0.191	0.441	0.232	0.080	0.223	0.480	0.261
F16	0.080	0.231	0.508	0.273	0.071	0.212	0.483	0.255	0.080	0.229	0.505	0.271
F17	0.054	0.170	0.424	0.216	0.059	0.183	0.440	0.227	0.059	0.184	0.443	0.229
F18	0.077	0.207	0.467	0.250	0.083	0.216	0.480	0.260	0.097	0.242	0.506	0.281
F19	0.043	0.147	0.387	0.192	0.042	0.146	0.388	0.192	0.039	0.136	0.372	0.182
F20	0.116	0.291	0.559	0.322	0.112	0.279	0.542	0.311	0.100	0.258	0.515	0.291
F21	0.123	0.299	0.566	0.329	0.124	0.299	0.569	0.330	0.109	0.271	0.537	0.305
F22	0.090	0.243	0.508	0.280	0.089	0.240	0.496	0.275	0.082	0.227	0.483	0.264
F23	0.034	0.121	0.342	0.166	0.038	0.126	0.349	0.171	0.036	0.123	0.346	0.168
F24	0.045	0.149	0.388	0.194	0.042	0.141	0.373	0.185	0.037	0.129	0.353	0.173
F25	0.062	0.195	0.464	0.240	0.055	0.174	0.431	0.220	0.053	0.168	0.423	0.215
F26	0.025	0.105	0.325	0.152	0.025	0.104	0.323	0.151	0.024	0.100	0.315	0.146
F27	0.082	0.230	0.492	0.268	0.072	0.210	0.463	0.249	0.072	0.214	0.469	0.252
F28	0.091	0.251	0.534	0.292	0.075	0.219	0.489	0.261	0.070	0.207	0.473	0.250
F29	0.138	0.325	0.624	0.362	0.115	0.287	0.575	0.326	0.108	0.273	0.556	0.312
F30	0.142	0.329	0.615	0.362	0.124	0.302	0.585	0.337	0.116	0.286	0.564	0.322
F31	0.100	0.257	0.535	0.297	0.130	0.307	0.597	0.345	0.103	0.260	0.541	0.301
F32	0.123	0.299	0.576	0.333	0.139	0.324	0.605	0.356	0.135	0.321	0.603	0.353
F33	0.039	0.139	0.376	0.185	0.038	0.138	0.373	0.183	0.034	0.126	0.355	0.172
F34	0.050	0.169	0.418	0.212	0.062	0.199	0.456	0.239	0.051	0.172	0.420	0.214
F35	0.146	0.332	0.612	0.363	0.118	0.282	0.553	0.317	0.104	0.260	0.535	0.300
F36	0.025	0.105	0.320	0.150	0.027	0.111	0.331	0.156	0.029	0.114	0.335	0.159
F37	0.038	0.139	0.374	0.184	0.031	0.125	0.357	0.171	0.030	0.120	0.344	0.165
F38	0.015	0.066	0.245	0.109	0.017	0.070	0.252	0.113	0.015	0.066	0.248	0.110
F39	0.044	0.152	0.394	0.196	0.049	0.162	0.406	0.206	0.044	0.148	0.387	0.193
F40	0.040	0.154	0.404	0.200	0.040	0.153	0.398	0.197	0.038	0.141	0.382	0.187
F41	0.056	0.188	0.445	0.230	0.048	0.167	0.417	0.211	0.036	0.140	0.378	0.185

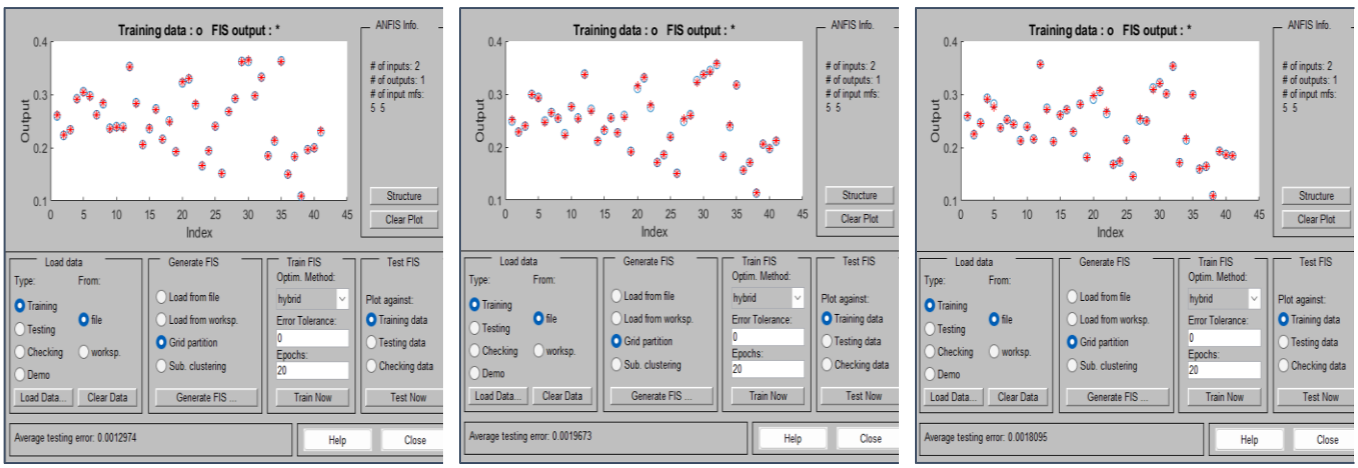
5. The Neuro-Fuzzy App

The two input data were the probability of risk for all risk factors and the risk impact on cost or time, or quality all alone. And the output is the value of risk in terms of cost, time, and quality of each. All data are trained many times using the Neuro-Fuzzy App until the training error is acceptable. Twenty epochs were enough to let the error go to the study state as shown in Fig. 3, which presents the Neuro-Fuzzy training error for cost-risk impact, time-risk impact, and quality-risk impact. The Neuro-Fuzzy app offers the ability to test the trained data by applying the input and comparing them with FIS output.Fig. 4 Fig. 4 presents testing data where the blue circles are referring to the training input data, and the red stars represent the FIS output. This figure illustrates that the average testing error for CRV was 0.0012794, TRV was 0.0019673, and QRV was 0.0018095, by conducting several tests each time with a different number of epochs to train the data until reaching a nearly stable error rate, where it was found that twenty epochs were appropriate, these values of the average testing errors are within tolerated range, hence this is obvious from the resemblance between the blue circles and the red stars, as displayed in the figure, most of the stars are located in the centre of the circles correlated with each.



(a) (b) (c)

Fig. 3. Neuro-Fuzzy Training Error for (a) Cost Risk, (b) Time Risk, and (c) Quality Risk



(a) (b) (c)

Fig. 4. ANFIS Testing Data, (a) Cost, (b) Time, and (c) Quality

5.1. ANFIS model structure

The ANFIS structure depicted in Fig. 5 consists of two inputs, one output, and ten MFs, with five allocated to each input corresponding to the five LVs. Additionally, the figure displays twenty-five fuzzy rules that utilize AND logical operations. The ANFIS output, which denotes the risk value, is generated by compiling the outputs of all individual MFs.

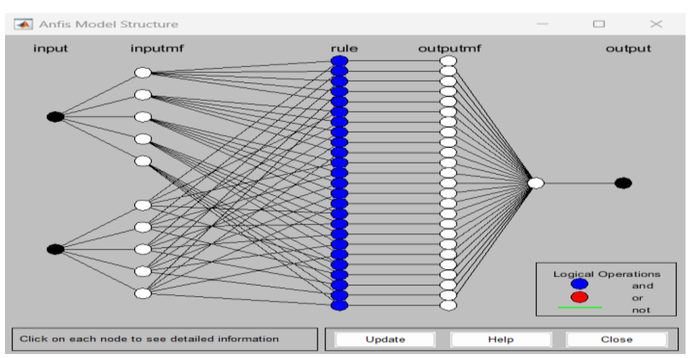


Fig. 5. ANFIS Structure

5.2. Inputs membership function

Input MFs refer to the representation of input variables in FL system. They are used to define the degree of membership of a given input to a particular fuzzy set, which in turn determines the degree to which the input will activate the corresponding rule in the system. Fig. 6 illustrates the presence of five MFs assigned to each input, namely, very low, low, medium, high, and very high.

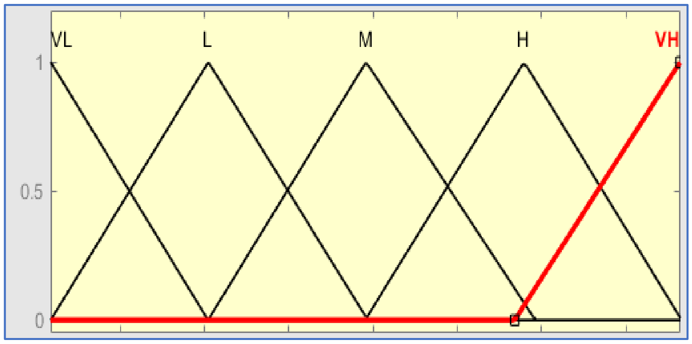


Fig. 6. Membership Functions

5.3. The model rules

Given that the model has five membership functions (MFs), a total of 5^2 rules have been taken into account for each of the three models: cost, time, and quality. The twenty-five (if-then) rules that are applied for CRM are listed in Table 6. The same rules are applied for TRM and QRM TRM

Table **7**. All these rules presented twenty-five output MFs, which will be illustrated in the next section.

Table 6. CRV ANFIS Rules

IF	(	P	is	VL	)	AND	(	CI	is	VL	)	THEN	(	Output	is	Out1MF1	) (1)
IF	(	P	is	VL	)	AND	(	CI	is	L	)	THEN	(	Output	is	Out1MF2	) (1)
IF	(	P	is	VL	)	AND	(	CI	is	M	)	THEN	(	Output	is	Out1MF3	) (1)
IF	(	P	is	VL	)	AND	(	CI	is	H	)	THEN	(	Output	is	Out1MF4	) (1)
IF	(	P	is	VL	)	AND	(	CI	is	VH	)	THEN	(	Output	is	Out1MF5	) (1)
IF	(	P	is	L	)	AND	(	CI	is	VL	)	THEN	(	Output	is	Out1MF6	) (1)
IF	(	P	is	L	)	AND	(	CI	is	L	)	THEN	(	Output	is	Out1MF7	) (1)
IF	(	P	is	L	)	AND	(	CI	is	M	)	THEN	(	Output	is	Out1MF8	) (1)
IF	(	P	is	L	)	AND	(	CI	is	H	)	THEN	(	Output	is	Out1MF9	) (1)
IF	(	P	is	L	)	AND	(	CI	is	VH	)	THEN	(	Output	is	Out1MF10	) (1)
IF	(	P	is	M	)	AND	(	CI	is	VL	)	THEN	(	Output	is	Out1MF11	) (1)
IF	(	P	is	M	)	AND	(	CI	is	L	)	THEN	(	Output	is	Out1MF12	) (1)
IF	(	P	is	M	)	AND	(	CI	is	M	)	THEN	(	Output	is	Out1MF13	) (1)
IF	(	P	is	M	)	AND	(	CI	is	H	)	THEN	(	Output	is	Out1MF14	) (1)
IF	(	P	is	M	)	AND	(	CI	is	VH	)	THEN	(	Output	is	Out1MF15	) (1)
IF	(	P	is	H	)	AND	(	CI	is	VL	)	THEN	(	Output	is	Out1MF16	) (1)
IF	(	P	is	H	)	AND	(	CI	is	L	)	THEN	(	Output	is	Out1MF17	) (1)
IF	(	P	is	H	)	AND	(	CI	is	M	)	THEN	(	Output	is	Out1MF18	) (1)
IF	(	P	is	H	)	AND	(	CI	is	H	)	THEN	(	Output	is	Out1MF19	) (1)
IF	(	P	is	H	)	AND	(	CI	is	VH	)	THEN	(	Output	is	Out1MF20	) (1)
IF	(	P	is	VH	)	AND	(	CI	is	VL	)	THEN	(	Output	is	Out1MF21	) (1)
IF	(	P	is	VH	)	AND	(	CI	is	L	)	THEN	(	Output	is	Out1MF22	) (1)
IF	(	P	is	VH	)	AND	(	CI	is	M	)	THEN	(	Output	is	Out1MF23	) (1)
IF	(	P	is	VH	)	AND	(	CI	is	H	)	THEN	(	Output	is	Out1MF24	) (1)
IF	(	P	is	VH	)	AND	(	CI	is	VH	)	THEN	(	Output	is	Out1MF25	) (1)

5.4. The ANFIS model output

In an ANFIS, the output of a Sugeno-type fuzzy inference system is a crisp value. The Sugeno FIS uses if-then rules with crisp antecedents and linear consequents to model the input-output relationship. The ANFIS model takes input values and applies FL to them to generate a set of fuzzy outputs. The fuzzy outputs are then defuzzified using the weighted average method to generate a single crisp output value.

Thus, the output of an ANFIS model using a Sugeno-type FIS is a single numerical value that represents the system's prediction or estimation based on the input data.

Table **7** listed the output MFs for the coefficients of the linear models for CRM, TRN, and QRM. There is a total of twenty-five MFs presented for these outputs.

6. Model Evaluation

This research aims to build a highly efficient intelligent engineering model, thus to ensure its accuracy it was evaluated and checked using the Fuzzy Logic Designer app and MATLAB Simulink.

6.1. Fuzzy logic designer

The "Fuzzy Logic Designer" app in MATLAB is a graphical user interface that provides tools for designing, training, and testing FL systems. The app allows users to easily create FL systems by defining the input and output variables, MFs, and rule bases. The app also provides tools for visualizing the FIS, such as membership function plots and response surface plots, which can be helpful for understanding and verifying the system's behaviour.

It provides several training algorithms, including the Hybrid Learning Algorithm and the Hybrid Generalized Learning Algorithm, which combine fuzzy clustering and gradient descent optimization, respectively. The app also provides several evaluation and visualization tools, such as ROC (Receiver Operating Characteristic) curves and confusion matrices, that can be used to assess the performance of the FL system.

Overall, the Fuzzy Logic Designer app in MATLAB provides a convenient and user-friendly environment for designing, training, and testing FL systems. It is a valuable tool for engineers, researchers, and students interested in working with FL and provides a platform for experimentation and learning.

Table 7. Coefficients of The Linear Combination

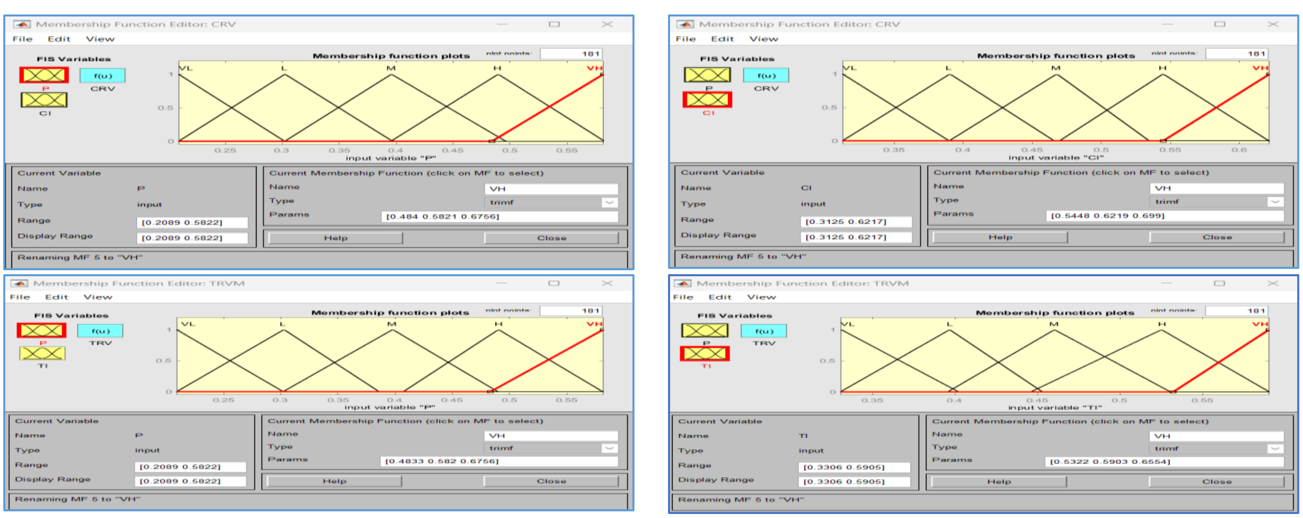
Coefficients	Weight Coeff.	CRM	TRM	QRM
Out1MF1	W1	0.1114	0.1244	0.1107
Out1MF2	W2	0.002852	0.01406	0.000993
Out1MF3	W3	0	0	0
Out1MF4	W4	0	0	0
Out1MF5	W5	0	0	0
Out1MF6	W6	0.1419	0.1462	0.1418
Out1MF7	W7	0.1645	0.1644	0.1662
Out1MF8	W8	0.1847	0.1824	0.1683
Out1MF9	W9	0.1898	0.1938	0.189
Out1MF10	W10	0	0	0
Out1MF11	W11	0.1643	0.1759	0.1704
Out1MF12	W12	0.1982	0.2009	0.2022
Out1MF13	W13	0.2326	0.2258	0.2368
Out1MF14	W14	0.2545	0.2482	0.2568
Out1MF15	W15	0	0.3151	0.3189
Out1MF16	W16	0.2007	0.197	0.1991
Out1MF17	W17	0.2386	0.2427	0.2398
Out1MF18	W18	0.2671	0.2689	0.2674
Out1MF19	W19	0.3097	0.2955	0.3119
Out1MF20	W20	0.3228	0.3204	0.269
Out1MF21	W21	0	0	0
Out1MF22	W22	0	0	0.2647
Out1MF23	W23	0.3206	0.3013	0.3198
Out1MF24	W24	0.3433	0.3437	0.3392
Out1MF25	W25	0.4186	0.3758	0.5446

6.1.1. Fuzzy membership functions

The MFs for cost, time, and quality impact and their probability are shown in Fig. 7. The input variables are classified into five MFs, and they are given as very low, low, medium, high, and very high. The P range is from 0.2089 to 0.5822, the CI range is from 0.3125 to 0.6217, the TI range is from 0.3306 to 0.5905, and the QI range is from 0.3174 to 0.6332.

(a)

(b)



(c)

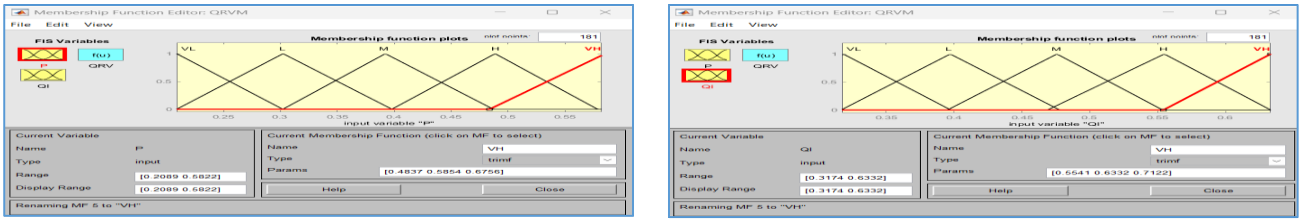


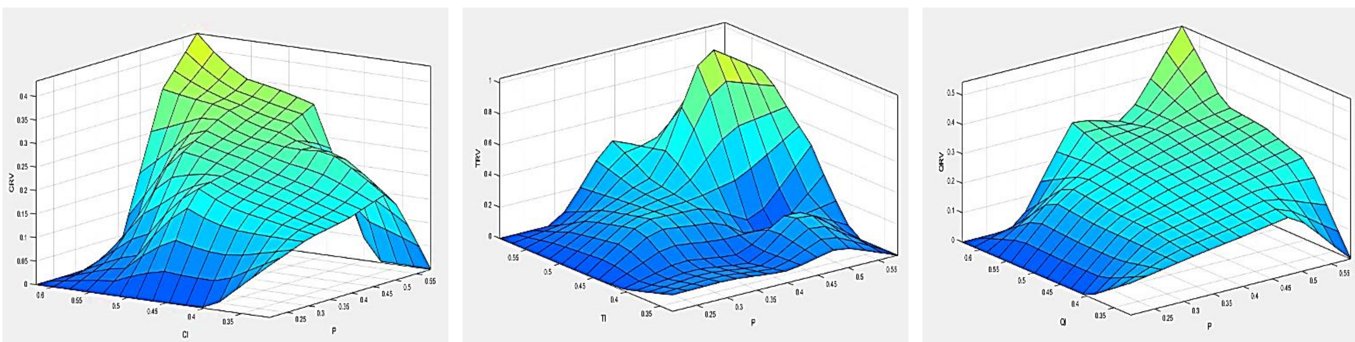
Fig. 7. Membership functions, (a) Cost, (b) Time, and (c) Quality

6.1.2. Fuzzy rules

Since each FIS has two inputs with five levels (VL, L, M, H, and VH), twenty-five rules are presented. The twenty-five fuzzy rules for CI, TI, and QI, and the test results are displayed in the FIS rule viewer. At this stage, the values of P with CI, TI, and QI were tested, and the results were compared with the values of CRV, TRV, and QRV, respectively.

6.1.3. Fuzzy surface presentation

The FIS provides the basis for the conceptualization of a fuzzy risk matrix, to present this matrix, here is the surface plot of the three-dimensional surface (3D) in Fig. 8 presents the evaluation risk values (CRV, TRV, QRV) based on their P, CI, TI, and QI, respectively.



(a) (b) (c)

Fig. 8. Fuzzy surface (a) Cost impact, (b) Time impact, and (c) Quality Impact

6.2. Simulation results using MATLAB Simulink

MATLAB Simulink is a graphical programming environment for modelling, simulating, and analysing dynamic systems. It provides a graphical user interface for building models as block diagrams, which allows for a straightforward representation of complex systems and their interactions. MATLAB Simulink is used in this study to validate our fuzzy three models as shown in Fig. 9. Four constant blocks are used to represent the probability of risk and its impact on the project in terms of cost, time, and quality. Then three fuzzy controllers are used to simulate these three models. Since the fuzzy controller in MATLAB Simulink has a single entity, it is mandatory using a multiplexer to be able to input probability data with each of the impacts. Three signals' multiplexers were needed to be used to multiplex the inputs {(P, CI), (P, TI), (P, QI)}.

The fuzzy outputs are shown in the Simulink three displays; each screen was placed to display the outputs of each effect separately, the first to display CRV, the second to display TRV, and the third to display QRV.

The Simulink is a simulated set of data as an example for ten seconds and the results were as follow:

The inputs are the probability and its three impacts of the first risk factor F1: {(0.408,0.544), (0.408,0.518), (0.408,0.541)} from Table 4, and the outputs: {0.2611, 0.2515, 0.2597}, as CRV, TRV, and QRV respectively.

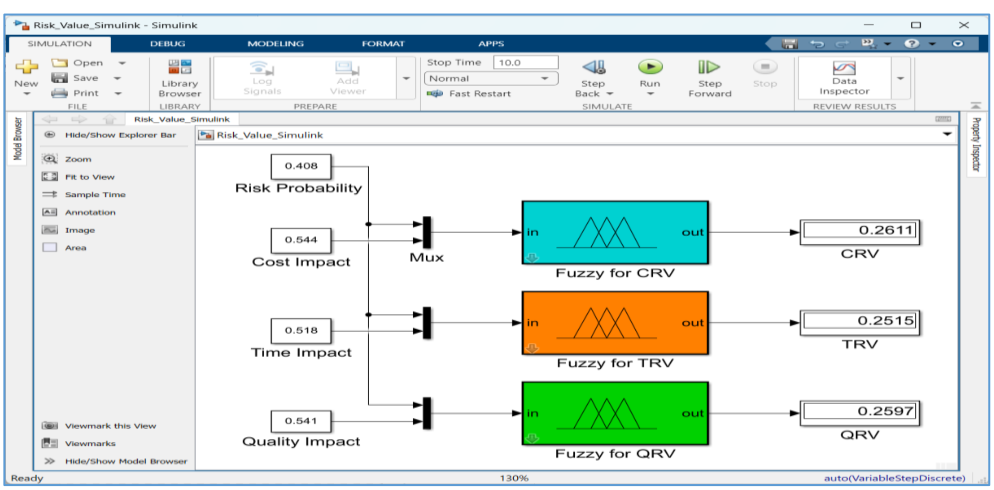


Fig. 9. MATLAB Simulink results

6.3. The priority of risks

Prioritizing risks based on qualitative analysis implicates identifying and evaluating potential risks to define the most critical ones. This process involves assessing the probability and impact of each risk, once risks are identified and assessed, they can be ranked based on their potential impact on the project's objectives. Risks with high probability and high impact should be given the highest priority, while risks with lower probability and impact may be considered a lower priority. the prioritization of RF considered in this study is displayed in Fig. 10. Prioritizing risks in this way allows project managers to focus their resources on the most critical risks and develop effective risk management response strategies.

Rank Numbe	Risk Factor	CRV	CRV(%)	Risk Factor	TRV	TRV(%)	Risk Factor	QRV	QRV(%)
1	F35	0.363	3.52%	F32	0.356	3.51%	F12	0.357	3.64%
2	F29	0.362	3.51%	F31	0.345	3.40%	F32	0.353	3.60%
3	F30	0.362	3.51%	F12	0.338	3.34%	F30	0.322	3.28%
4	F12	0.353	3.42%	F30	0.337	3.33%	F29	0.312	3.18%
5	F32	0.333	3.23%	F21	0.33	3.26%	F21	0.305	3.11%
6	F21	0.329	3.19%	F29	0.326	3.22%	F31	0.301	3.07%
7	F20	0.322	3.12%	F35	0.317	3.13%	F35	0.3	3.06%
8	F5	0.305	2.96%	F20	0.311	3.07%	F4	0.293	2.99%
9	F6	0.298	2.89%	F4	0.3	2.96%	F20	0.291	2.97%
10	F31	0.297	2.88%	F5	0.294	2.90%	F5	0.282	2.87%
11	F4	0.292	2.83%	F10	0.276	2.72%	F18	0.281	2.86%
12	F28	0.292	2.83%	F22	0.275	2.71%	F13	0.274	2.79%
13	F13	0.285	2.76%	F13	0.271	2.67%	F16	0.271	2.76%
14	F8	0.282	2.74%	F7	0.266	2.63%	F22	0.264	2.69%
15	F22	0.28	2.72%	F28	0.261	2.58%	F15	0.261	2.66%
16	F16	0.273	2.65%	F18	0.26	2.57%	F1	0.258	2.63%
17	F27	0.268	2.60%	F11	0.255	2.52%	F7	0.253	2.58%
18	F7	0.262	2.54%	F16	0.255	2.52%	F27	0.252	2.57%
19	F1	0.26	2.52%	F8	0.254	2.51%	F28	0.25	2.55%
20	F18	0.25	2.43%	F1	0.249	2.46%	F3	0.246	2.51%
21	F25	0.24	2.33%	F6	0.249	2.46%	F8	0.244	2.49%
22	F10	0.239	2.32%	F27	0.249	2.46%	F10	0.24	2.45%
23	F11	0.239	2.32%	F3	0.24	2.37%	F6	0.237	2.42%
24	F9	0.237	2.30%	F34	0.239	2.36%	F17	0.229	2.33%
25	F15	0.236	2.29%	F15	0.232	2.29%	F2	0.224	2.28%
26	F3	0.234	2.27%	F2	0.228	2.25%	F11	0.216	2.20%
27	F41	0.23	2.23%	F17	0.227	2.24%	F25	0.215	2.19%
28	F2	0.223	2.16%	F9	0.226	2.23%	F34	0.214	2.18%
29	F17	0.216	2.10%	F25	0.22	2.17%	F9	0.213	2.17%
30	F34	0.212	2.06%	F14	0.211	2.08%	F14	0.211	2.15%
31	F14	0.206	2.00%	F41	0.211	2.08%	F39	0.193	1.97%
32	F40	0.2	1.94%	F39	0.206	2.03%	F40	0.187	1.91%
33	F39	0.196	1.90%	F40	0.197	1.94%	F41	0.185	1.89%
34	F24	0.194	1.88%	F19	0.192	1.89%	F19	0.182	1.86%
35	F19	0.192	1.86%	F24	0.185	1.83%	F24	0.173	1.76%
36	F33	0.185	1.79%	F33	0.183	1.81%	F33	0.172	1.75%
37	F37	0.184	1.79%	F23	0.171	1.69%	F23	0.168	1.71%
38	F23	0.166	1.61%	F37	0.171	1.69%	F37	0.165	1.68%
39	F26	0.152	1.47%	F36	0.156	1.54%	F36	0.159	1.62%
40	F36	0.15	1.46%	F26	0.151	1.49%	F26	0.146	1.49%
41	F38	0.109	1.06%	F38	0.113	1.12%	F38	0.11	1.12%

Fig. 10. The priority of risks

6.4. Corrective actions

After conducting a qualitative risk analysis that assessed the priority of risks according to the parameters P, CI, TI, and QI, several corrective actions were proposed based on this priority; these actions were formed in a raw state to be the starting point on which the project manager relies on the risk response process.

The value of minimum and maximum risk values are listed in Table 8, for each cost, time, and quality then they have been divided into nine levels, based on which the corrective action is chosen; as stated by [25] that, a consensus was reached that a set of nine LVs namely (very low, very low-low, low, low-medium, medium, medium-high, high, high-very high, and very high) would adequately encompass the full as a spectrum of risk values. Each of these nine LVs was framed by a range of categories to submit the risk values, hence proposing a corrective action.

Table 8. Risk Value Range

Risk Value-Type	Min Risk Value	Max Risk Value	Risk Range
CRV	0.109	0.363	0.255
TRV	0.113	0.356	0.24276
QRV	0.11	0.357	0.24692

Table 9 elaborates on the categories numbers and the corrective action for each one based on the level of RV. In Table 10Table 10, The corrective category number is listed according to their respective corresponding risk value ranges.

Table 9. Risk Corrective Action Categories

Category#	Corrective Action Categories	RV Level
1	No corrective steps are necessary.	VL
2	No need to execute any corrective step(s)/accept.	VL-L

3	Low urgency to implement any corrective step(s)/accept.	L
4	Implementing corrective step(s) is slightly moderately important / taking mitigation.	L-M
5	Implementing corrective step(s) is moderately important / taking mitigation or transfer into consideration.	M
6	Implementing corrective step(s) has relatively high importance/ taking mitigation or transfer into consideration.	M-H
7	Implementing corrective step(s) has high importance/ take avoidance or transfer into consideration.	H
8	The urgency to implement corrective step(s)/ take avoidance or transfer into consideration.	H-VH
9	Taking corrective step(s) is essential/taking avoidance.	VH

The common probability and impact matrix was used to classify the risks according to priority so that the appropriate corrective action is taken. It appears from Fig. 11 that the area shaded in red is the area with the highest priority and requires effective corrective actions, the area shaded in yellow is considered to be of medium priority, and the area shaded in green represents the lowest priority; it may not require any corrective action, but it must be noted the importance of continuing to monitor it, as its priority may change with the progress of the project's life.

Table 10. Category Ranges of Risk Values

	Corrective Action Categories	CRV	TRV	QRV
1	Category#1	$x < 0.115$	$x < 0.119$	$x < 0.116$
2	Category#2	$0.115 \leq x < 0.131$	$0.119 \leq x < 0.134$	$0.116 \leq x < 0.132$
3	Category#3	$0.131 \leq x < 0.150$	$0.134 \leq x < 0.152$	$0.132 \leq x < 0.150$
4	Category#4	$0.150 \leq x < 0.173$	$0.152 \leq x < 0.174$	$0.150 \leq x < 0.172$
5	Category#5	$0.173 \leq x < 0.198$	$0.174 \leq x < 0.198$	$0.172 \leq x < 0.196$
6	Category#6	$0.198 \leq x < 0.227$	$0.198 \leq x < 0.225$	$0.196 \leq x < 0.224$
7	Category#7	$0.227 \leq x < 0.259$	$0.225 \leq x < 0.256$	$0.224 \leq x < 0.255$
8	Category#8	$0.259 \leq x < 0.294$	$0.256 \leq x < 0.289$	$0.255 \leq x < 0.289$
9	Category#9	$x \geq 0.294$	$x \geq 0.289$	$x \geq 0.289$

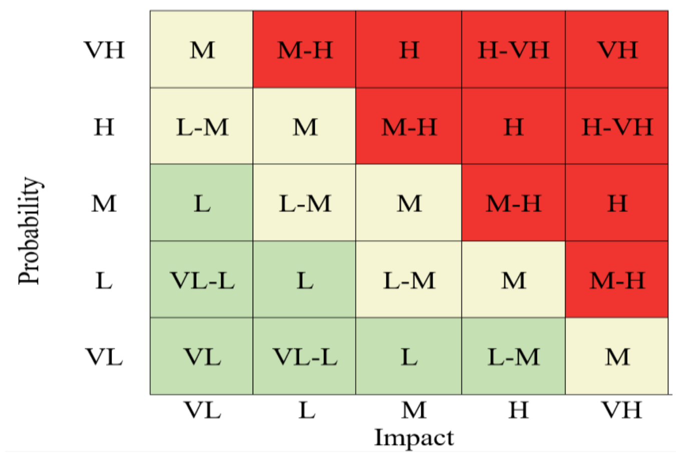
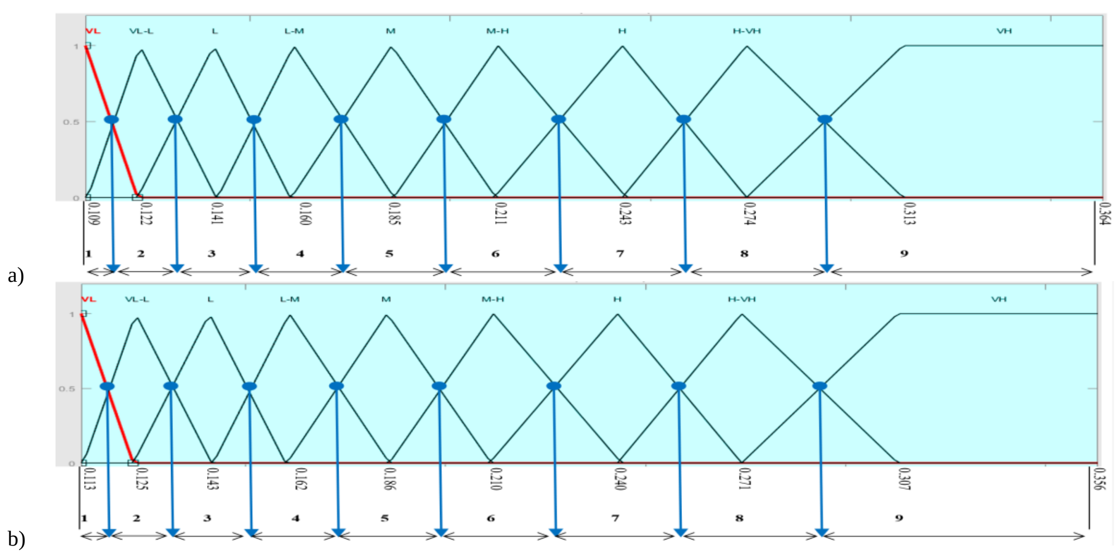


Fig. 11. Probability and impact matrix

The RV membership functions and levels, as well as the range of the corrective action categories, are displayed inFig. **12** Fig. 12, that CRV as cost risk value in Fig. 12 (a), TRV as time risk value in Fig. 12 (b), and QRV as quality risk value in Fig. 12 (c).



c)

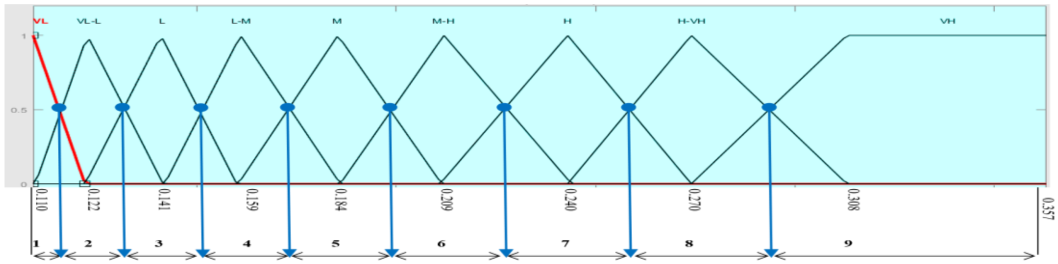


Fig. 12. Risk corrective action categories, (a) Cost, (b) Time, and (c) Quality

7. Conclusions and Future Works

This study introduces new fuzzy models for assessing risk values in construction projects based on their probability and impact. The models include three distinct risk assessments for cost, time, and quality, which are disclosed by feedback from industry experts. Notably, this study examines a comprehensive set of forty-one RFs commonly specific to construction projects in Iraq. To collect data, a questionnaire was designed and distributed to experts across the country, resulting in the participation of seventy individuals.

The project manager bears the primary responsibility for completing the project within budget, on schedule, and with the required level of quality. This creates a significant burden of responsibility and pressure. As such, the fuzzy model's proposed to get implications highly accurate in risk value estimation. Adopting this model can assist organizations and project managers in various ways, such as estimating the precise construction project duration, accurately pricing tender items, and avoiding RF that may negatively impact project quality. Ultimately, this can lead to improved quality and successful project completion. It is noteworthy to mention that the scope of this model is limited, as the study was centred around a questionnaire focused on potential risks associated with construction projects in Iraq and how they impact projects within the country's specific working conditions. Since each country has its distinct risks and the magnitude of its influence on projects, considering factors such as political, geographical, and economic circumstances, the fuzzy model proposed in this study may not be applicable or beneficial in other countries.

As forward-looking, the author recommends the following:

- Utilizing this methodology in diverse projects across different industrial sectors.
- Attempting to apply the proposed fuzzy model approach to construction projects in different countries while considering necessary adjustments to align with the conditions of implementing construction projects in each respective country. More risk factors may be added according to the project types and country.
- Comparing different methodologies or procedures with the results of the proposed approach.

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