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Developing an Assessment Model for Factors Affecting the Quality in the Construction Industry

Usama Hamed Issa

Civil Engineering Department, Faculty of Engineering, Minia University, Minia, Egypt

Abstract: Quality is considered as one of the most important elements in the construction industry. The factors affecting quality in the construction industry should be assessed. This paper aims to introduce a new model to assess these factors. The model is namely Fuzzy Assessment Model for Quality (*FAMQ*). Fuzzy set theory provides a useful way to deal with ill-defined and complex problems in a decision-making environment that incorporates vagueness. The proposed model employs the combined effect of both; the factors probability of occurrence and their impacts on the quality of construction. Twenty five logical rules for each factor were implemented in the model. The model was evaluated using data that collected from the infrastructure projects in Egypt. It was applied to many factors that affect the quality of this kind of projects as a case study. The results of the study proved that the proposed model can be used successfully in the assessment of factors affecting quality in the construction industry. In addition, the results provided a platform of useful assessment reference to those infrastructure's firms, who plan to establish their businesses in Egypt.

Key words: Quality in construction, fuzzy, Egypt.

1. Introduction

The most important problem, which faces the project managers of the construction projects in developing countries, is the lack of detailed and documented previous data that concern with the factors affecting quality in their projects.

The Fuzzy set theory is chosen to be used in this research because of its suitability for uncertain or approximate reasoning that involves human intuitive thinking. It can overcome the problem of the shortage in the detailed and documented previous data that concern with the factors affecting quality in construction projects. The history of fuzzy logic is quite interesting, since many researchers looked deeply into the past in order to determine the evolution of this type of logic. Fuzzy logic was first introduced in 1965 by Zadeh [1] with the concept of fuzzy sets as an extension of the classical set theory formed by crisp sets. Later Zadeh defined the whole algebra of fuzzy logic [2], which uses fuzzy sets to compute with words as an extension of the proper operations of the classical logic.

Baloi and Price [3] reported that Zadeh stated that as the complexity of a system increases, human ability to make precise yet significant statements about its behavior diminishes until a threshold is reached beyond which precision and significance become mutually exclusive''. Fuzzy Set Theory is not intended to replace Probability Theory rather than providing solutions to the problems that lack mathematical rigour inherent in the Probability Theory. It is, therefore, suitable for uncertain or approximate reasoning that involves human intuitive thinking. In most cases, the fuzzy logic system is a nonlinear mapping of an input data vector into a scalar output, where this relation is defined by linguistic expressions that are obviously computed in numbers. Thus, the fuzzy logic system is considered unique for its ability to handle numerical data and linguistic knowledge. The richness of this logic lies in the presence of many possibilities that could lead to many different mappings.

Corresponding author: Usama Hamed Issa, PhD, assistance professor, research fields: construction engineering and management, civil engineering. E-mail: usamah77@yahoo.com.

2. Fuzzy Logic Process

The fuzzy logic process can be defined as rule-based systems, in which the input is first fuzzified (i.e., converted from a crisp number to a fuzzy set) and subsequently processed by an inference engine. This engine retrieves the knowledge in the form of fuzzy rules contained in a rule-base. The fuzzy sets computed by the fuzzy inference as the output of each rule are then composed and defuzzified (i.e., converted from a fuzzy set to a crisp number). Fuzzy Logic allows the mapping of the linguistic values in a way that mimics precise numerical analysis by using membership structure that organizes the data [4–7]. The fuzzy logic system usually involves three steps: fuzzification, rule evaluation, and defuzzification. This concept will be used in developing the proposed assessment model. Fig. 1 shows the main steps in the fuzzy logic process [1].

3. Rsearch Aim and Objectives

The main aim of the research discussed in this paper is to develop a new model, which requires a little data to assess the factors affecting quality in the construction industry. Fuzzy logic modeling seems to be best fit in order to achieve the aims of the proposed model. The model is constructed based on the combined effect of the probability of occurrence and the impact of the factor on the quality of the project.

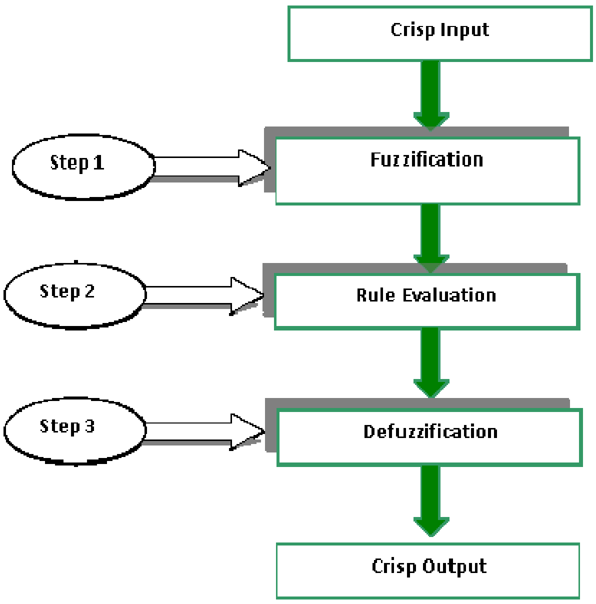

Fig. 1 The main steps in fuzzy logic process

4. Fuzzy Assesment Model for Quality (*FAMQ*)

The aim of the proposed model is to assess the factors affecting quality in the construction industry in an acceptable and easy way. It depends on the relationships between the factor's probability of occurrence and its impact on the quality of the project (if it does occur). It should be noted that this model is general and with slight modifications can be easily adapted and applied to any other types of projects.

The crisp inputs used in this model are two indices: probability index (*PI*), and impact index for quality (*IIQ*).

In order to assess the factors affecting quality, a new quality factor index is represented as the output of this model, namely Fuzzy Index for Quality (*FIQ*). *FIQ* indicates the importance or the magnitude of a certain factor to assess the expected quality. Fig. 2 shows the inputs and output for the proposed model.

5. Membership Funcations

The membership function represents the fuzziness degree of linguistic variables [1]. Membership functions are established to give a numerical meaning for each label. Each membership function identifies the range of input values that corresponds to each label. Unlike Boolean logic, the membership function of each label does not define boundaries, where the label is fully applied to one side of a cutoff and not at all to the other side of the cutoff. Instead, there is a region, where input values gradually change from being fully applicable to completely inapplicable.

The membership function used in the *FAMQ* is the triangle shape for all factors inputs and outputs sources as shown in Fig. 3. This membership function has been used in many models within the field of construction management and has been chosen depending on pervious researches' work. This shape of membership function was used in previous study [8] in their factors' assessment model using the cause and effect diagrams. Moreover, it was used in another study [9] to rate the cost overrun risk in international construction projects. The same shape of the membership function in selecting planning and design alternatives in public office building was used by Hsieh [10].

The linguistic description assigned to a fuzzy set in this model was taken similar to the labels used in the previous field survey study [11]. For example, the probability of occurrence for a certain factor, the fuzzy label could be: very low, low, medium, high, or very high. Each label is associated with a fuzzy set as shown in Fig. 3.

The evaluation of the chosen membership function is checked using the two indices of overlap ratio, and overlap robustness as introduced in previous study [1].

The corresponding fuzzy sets can be defined as follows:

Very low = (1, 0.67, 0.33, 0, 0, 0, 0, 0, 0, 0, 0)
Low = (0, 0, 0.5, 1, 0.5, 0, 0, 0, 0, 0, 0)
Medium = (0, 0, 0, 0, 0.5, 1, 0.5, 0, 0, 0, 0)
High = (0, 0, 0, 0, 0, 0.5, 1, 0.5, 0, 0, 0)
Very high = (0, 0, 0, 0, 0, 0, 0, 0, 0.33, 0.67, 1)

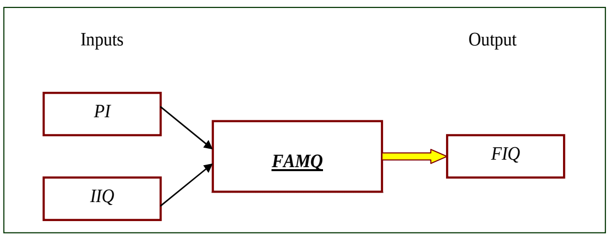

Fig. 2 Inputs and outputs for the *FAMQ*.

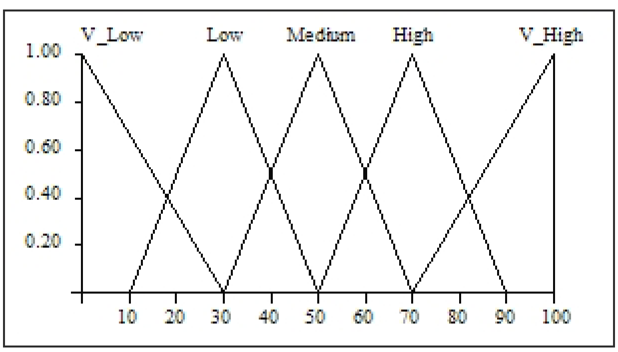

Fig. 3 Membership functions used for proposed model.

6. Aggregation Rules

Fuzzy logic is basically logic with multiple values, including several logical rules by explaining how the linguistic labels are related to the means in constructing fuzzy systems. Each fuzzy contains the antecedent and the consequent that includes fuzzy propositions. These propositions in turn are statements as well that join the linguistic variables with linguistic operators. The fuzzy rule allows values between the conventional evaluations of the precise logic 1 and 0. It also includes operations for "and", "or", "not" and "if-then".

In the majority of fuzzy modeling, only the linguistic operator and is used to join the linguistic labels of the antecedent, whereas the consequent is formed by only one linguistic label (MISO systems). For this reason, this case will be considered.

Aggregation rules in the *FAMQ* follow the common sense behavior of the system and are written in terms of membership function linguistic labels. The risk magnitude can usually be assessed by considering two fundamental factor parameters; likelihood and severity as stated in previous work [13]. Therefore, the relationship in this model (two inputs and one output system) is needed to introduce logical rules for the two inputs (probability of occurrence and impact for each factor) which are considered the only available data.

Assuming there is a relationship between the two inputs probability of occurrence for a certain factor and represented by its probability index (*PI*). Meanwhile, the impact of the same factor on a project quality is represented by its impact index for quality (*IIQ*), and the output of the model (the importance or magnitude of the factor) represented by fuzzy index for quality (*FIQ*). This relation can be represented by a double premise rule such as:

If the probability of occurrence and Impact on quality then factor magnitude

The inputs (probability of occurrence, the Impact on quality) can be represented by (*PI*, and *IIQ*) while the outputs (magnitude) can be represented by (*FIQ*).

Mathematically the double premise rule can be transformed to the following rules:

If (*PI*) and (*IIQ*) then (*FRIQ*)

There are many relationships with varying values of *PI*, *IIQ*, and *FRIQ*. These relationships can be represented using fuzzy associative memories (FAMs), using the method suggested and used by previous studies [8, 14–15]. The interrelationships in the FAMs are taken similar to those introduced by previous work [8]. The rules can be readily represented by the matrix shown in Table 1.

In this proposed method, Zadeh Operators are limited to use of (AND) only. This is referred to as minimum or min. inferencing. The process for determining the result or rule strength of the rule is done by taking the minimum fuzzy input of (antecedent 1 AND antecedent 2, min. inferencing). This minimum result is equal to the consequent rule strength. If there are any consequents that are the same, then the maximum rule strength between similar consequents is taken and is referred to as maximum or max. inferencing, hence min./max. inferencing. This infers that the rule that is most true is taken. These rule strength values are referred to as fuzzy outputs.

$$\mathrm{FIQ} = \mathrm{PI} \wedge \mathrm{IIQ} \tag{1}$$

where $\wedge$ refers to the intersection between the two inputs. Samples of rules extracted from the FAMs matrix are as follows:

If the *PI* is Low and the *IIQ* is High then the *FIQ* is Medium

If the *PI* is High and the *IIQ* is Medium then the *FIQ* is Medium

If the *PI* is Very low and the *IIQ* is High then the *FIQ* is Low

All rules which are used in this model have a weight equal to 1.

Once identified, the probability of occurrence, the impact of an individual factor as well as its importance can be assessed using the fuzzy index for quality, which can be computed using the proposed model.

According to the FAMs used in this model there are twenty five rules will be used.

7. Factors Affecting Quality

Issa [11, 12] identified sixty five factors that affect quality in the Egyptian infrastructure projects grouped into fourteen groups. He used a questionnaire with construction practitioners in the field of infrastructure projects in Egypt. He concluded the identified factors in terms of three indices for each factor: the probability of occurrence; the impact on the quality of the work; and the severity. These indices were judged to be suitable to the application and evaluation of the proposed model.

8. Applications and Evaluation of *FAMQ*

The *FAMQ* is applied for the sixty five factor affecting quality in the Egyptian infrastructure projects as introduced by previous work [11]. There are two available indices will be used as inputs for this model: The *PI*, and *IIQ*. The model output is the *FIQ* which

Table 1 FAMs rules used to calculate the output of the proposed model.

Factor Scale		Impact Index for Quality (*IIQ*)				
		V. Low	Low	Med.*	High	V. High
Probability Index (*PI*)	V. Low	V. Low	V. Low	Low	Low	Med.
	Low	V. Low	Low	Low	Med.	Med.
	Med.	Low	Low	Med.	Med.	High
	High	Low	Med.	Med.	High	V. High
	V. High	Med.	Med.	High	V. High	V. High

can be used for assessing the factors affecting quality. In order to evaluate the results of this model, the factors can be ranked due to their severity, which can be calculated as the magnitude of the probability of occurrence multiplied by the impact of the factor.

The severity index for quality (*SIQ*) can be calculated using the following equation:

$$\mathrm{SIQ} = \mathrm{PI} \times \mathrm{IIQ} \tag{2}$$

Table 2 shows a comparison of the identified factors' rank based on both; their fuzzy index for quality (*FIQ*) and their severity index for quality (*SIQ*). The correlation coefficient was calculated using the Spearman's test for ranking the factors due to *FIQ* and *SIQ*. The value of it was 0.929. This high value is very close to +1 which means that the ranks of both coefficients increase together and the relationship between the ranking due to model and due to severity is almost linear.

Table 2 Ranking factors affecting quality based on their fuzzy index for quality and severity index.

Factor No.	Factors Affecting Quality	*FIQ*	Ranke due to *FIQ*	Ranke due to *SIQ*
34	Changes in the materials prices	42.2	1	1
40	Defective workmanship	42	2	3
19	Lack in project financing	39.5	3	7
65	Fluctuation default of Subcontractor	38.4	4	2
39	Delay in materials delivering	37.2	5	4
38	Long lead items equipment and bulk material	37	6	8
20	Fluctuation of project cash flow such as (Delay in payment by client)	36.8	7	5
52	Client's representative problems	34.1	8	10
41	Contract dispute results from disagreement over some conditions in contracts	33.8	9	12
4	Increase of inflation rates	33.4	10	13
62	Change order control	32.7	11	6
64	Problems resulted in interference among different subcontractor's	32.7	12	16
37	Shortage of required equipment	32.4	13	11
8	Market suitability for advanced technology	30	14	9
36	Poor productivity of manpower or equipments	30	15	14
58	Inadequate site management staffing	29.8	16	20
44	Inadequate project organization structure	29.1	17	21
27	Improper site stores management such as storage and protection of material	28.8	18	15
10	Poor quality of local materials	28.6	19	23
31	Side effects due to project activities	28.1	20	30
46	Poor Communication, coordination and different opinions among team members	28.1	21	27
48	Changes in core team	28.1	22	33
32	Improper design for the usual methods of construction	27.4	23	17
51	Lack of Client's experience	27.3	24	41
60	Poor quality, performance control, and supervision	27.3	25	18
18	Variations of actual quantities of work compared with quantities in bidding documents	27.1	26	29
25	Limited working hours and difficulties in access to the site	27.1	27	31

(to be continued)

(Continued)

Factor No.	Factors Affecting Quality	*FIQ*	Ranke due to *FIQ*	Ranke due to *SIQ*
28	Poor site safety	27.1	28	42
29	Unforeseen site conditions such as soil conditions, groundwater and historical finds	27.1	29	26
47	problems among project team members	27.1	30	39
45	Lacked appropriate skills	26.9	31	28
7	Unfairness in tendering and Method of Contractor choice	26.4	32	19
35	Familiarity of the work and Project complexity	26.3	33	22
42	Breach of contract	26.2	34	24
5	High taxation and Tax rate changes	25.9	35	38
14	Inadequate specifications and shortage of design data	25.9	36	35
43	Contractual failure	25.9	37	45
53	Poor communication and coordination among the project team work and other partners (Client, consultant, ...)	25.9	38	40
57	Inadequate project management budget	25.9	39	25
63	Delay of regulatory reporting	25.9	40	36
59	Inadequate definition of authority and responsibility for any partner	25.4	41	34
2	Political risks in countries of suppliers, owners, and contractors	25.3	42	48
26	Inadequate of Existing facilities	24.8	43	32
49	Inadequate Motivation for workers	23.3	44	55
6	Fluctuations in market demand for product or service	23	45	57
3	Currency exchange difficulties	22.8	46	56
9	Shortage of transportations and communications	22.8	47	37
33	Problems in technology implementation and feasibility of construction methods	22.8	48	46
50	Improper accommodations for workers	22.8	49	52
56	Scheduling, errors and underestimation of cost	22.8	50	43
24	Delay in possession of site due to any reason such as land expropriation.	21.6	51	44
1	Loss or delay due to war, revolution, and riot	21.5	52	47
22	Inadequacy of project insurance (during construction)	21.2	53	61
11	Force majeure such as (Flash Flood, Earthquake, Fire, wind damage, lightning, soil conditions and landslide)	20.7	54	63
30	Environmental protection due to project pollutions (noise, smoke, and wastes caused by project)	19.4	55	59
13	Code changes	19.3	56	64
15	Design errors and omissions	19.1	57	51
21	Bond policy problems in banks	19.1	58	50
12	Severe weather conditions.	18	59	62
23	Non confirmation of site boundaries	18	60	53
55	Delayed dispute resolution	18	61	49
61	Inadequate and slow decision-making mechanism	18	62	54
16	Design changes	14.7	63	60
17	Delay in design and regulatory approval	14.7	64	58
54	Third party delay	11	65	65

9. Discussion of the Results from Applying the *FAMQ*

Based on applying the *FAMQ*, the *FIQ* is calculated for each factor as shown in Table 2. The factors importance for quality can be compared using ranking for all factors. These results can be introduced for professionals in the infrastructure construction industry in Egypt.

Regarding to Table 2, the *Changes in the material prices* factor is ranked first using both *FIQ* and *SIQ*, while the *Defective workmanship* factor comes in second place in ranking using *FIQ* and in third place using *SIQ*. The ranking of many factors are very close using both: the *FIQ* and *SIQ* and ranking some of the factors relatively divergent use the two indices.

As stated in previous work [11, 12] many factors affecting quality had a significant difference in their ranking due to their probability of occurrence and their impact on quality. The proposed model introduces good results to assess the factors based on a combined effect for both the probability and impact.

10. Conclusions

Fuzzy Logic is considered a branch of modern mathematics to model vagueness intrinsic to human cognitive processes. Since then, it has been used to tackle ill-defined and complex problems due to incomplete and imprecise information that characterize the real-world systems.

The results of this paper presented a new model (*FAMQ*) which can be used in the assessment of factors affecting quality in the construction projects. The developed model introduced a new approach and reference for assessing the factors affecting quality, based on the combination between the factor probability of occurrence and its impact. The new reference represented the magnitude as well as importance of the factors affecting quality. The model was evaluated using previous data of sixty five factor affecting quality of the infrastructure projects in Egypt. The model can be easily adapted and applied to any other types of projects or countries. The results showed that there is a high agreement between the ranking for the factors using the severity index for quality and by using the model.

The results of applying this model provided a clear comprehensive image to the Egyptian government and local partners that helps them in having in-depth understanding of the factors affecting quality in the Egyptian construction industry.

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