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Applying "Fuzzy Techniques" in Construction Project Management

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ABSTRACT: The application of "fuzzy techniques" has been growing to the research studies of construction project management for risk management, decision making, and improving the performance of the construction projects. Fuzzy techniques include fuzzy set, fuzzy logic, and hybrid fuzzy techniques which combines fuzzy set/fuzzy logic with other techniques such as fuzzy neural network, neuro fuzzy, fuzzy reasoning etc. These techniques are found very effective management techniques to achieve the objectives of the construction project under uncertainties and imprecision. This paper focuses on the basic concept of fuzzy logic theory and its application in construction project management. A comprehensive literature review (from 1984 to 2018) has been employed and it is found that until the late 1990's fuzzy set theory was not very popular. It became the most researched topic with the advanced computational techniques. These methods based on fuzzy theory have capability to handle the similarity which is found in the complex construction projects. The application of fuzzy theory for construction projects has been illustrated for evaluating the project performance.

Keywords: Fuzzy techniques, Construction projects, Fuzzy model, Project performance, Decision making.

I. INTRODUCTION

Fuzzy set theory was introduced by Zadeh, 1965 to model vagueness, ambiguity and imprecision inherent in human cognitive processes [1]. Since then it has been widely used to handle poorly defined and complex issues owing to, incomplete, ambiguous, imprecise and conflicting information [2]. The concept of fuzzy logic has been applied to many fields of science, management and engineering application. In the area construction project management also such as risk management, decision making, and improving the performance of the construction projects, the application of "fuzzy techniques" has been growing rapidly. It is very hard to deal with the uncertainties associated with construction activities. The traditional techniques used for uncertain and biased data are based on numerical estimation requiring tedious calculations, special mathematical knowledge and high quality of data, which is very difficult to acquire for construction project. Fuzzy logic theory is either knowledge based or rule based. The variables in fuzzy set theory are depicted in linguistic expressions similar to human reasoning. Rules are constructed in the form of If-then using human knowledge. These rules describe the relation and dependence among the input and output variables. A systematic process called fuzzy inference is applied for transforming a knowledge base into a non-linear mapping using fuzzy sets. The input variables are first fuzzified in which variables are transformed from a crisp number to a fuzzy set. Inference engine then reprocesses the knowledge in the form of fuzzy rules contained in a rule-base. The fuzzy sets which are calculated by the fuzzy inference as the output of each rule are then collected and defuzzified to get the crisp number from fuzzy set. Fuzzy techniques include fuzzy set, fuzzy logic, and hybrid fuzzy techniques which combines fuzzy set/fuzzy logic with other techniques such as fuzzy neural network, neuro fuzzy, fuzzy reasoning etc. These all techniques are based on fuzzy concept. This paper focuses on the basic concept of fuzzy logic theory and its application in construction project management. For this purpose a extensive literature review has been done from 1985 to 2018 from different part of the globe.

II. LITRETURE REVIEW

The fuzzy techniques have been extensively applied for developing decision support tool, predicting risks and improving the performance of the construction projects.

1980'S

Ayyub and Haldar (1984) [3] applied fuzzy set theory for determining construction project scheduling. Koehn (1984) proposed the basic outline for the deployment of the fuzzy theory in risk evaluation of construction projects after investigation of the application of FST on the complex issues of building and productivity on a construction site [4]. Nguyen (1985) employed the fuzzy set theory to develop a decision model for deciding bid contracts [5]. Kangari and Riggs (1989) demonstrated the application of fuzzy theory as a risk assessment tool for construction projects. Linguistic variables were used for the risk assessment [6].

1990'S

Chun and Ahn (1992) recommended the application of fuzzy concepts to quantify the vagueness and judgmental uncertainties of accident progression event trees [7]. Diekmann (1992) applied fuzzy set theory with Monte Carlo Simulations and Influence diagramming to represent the risky situations [8]. Paek *et al.* (1993) adopted the application FST for risk-pricing algorithm for contractors to decide on the bid price of a construction project. First, various risk factors were identified and then risk related to these factors was quantified in monetary terms [9].

Tah *et al* (1993) proposed FST to evaluate probability and impact of risk during the tender stage for contingency allocation. Linguistic descriptions of risk probability and severity were utilized for risk assessment and analysis. Weighted mean method was applied to aggregate risk assessments [10]. Wirba *et al.* (1996) presented a risk management method by using fuzzy set theory. The risks associated with the project were identified first and then dependence amongst them was verified. The probability of occurrence of each risk was then calculated by using linguistic variables. By using the fuzzy weighted mean method, the interdependence coefficients were calculated [11]. Wang *et al.* (1996) examined the likelihood of developing a knowledge-based system to select an appropriate contract strategy for a specific project. Concept of Fuzzy sets has been applied for knowledge representation and manipulation and dBASE has been used for managing the database [12]. Fayek (1998) presented a model based on FST for competitive bidding strategy for assisting a company to achieve its goal in bidding. It was further concluded that the quality of the decision making process for setting a margin can be enhanced by using this model. Contractors can be benefited to obtain a competitive edge in bidding [13]. Okoroh and Torrance (1999) applied the concept of FST for development of a model for subcontractor selection and appointment. This model was developed for the purpose of analysing the subcontractor's risk elements in construction refurbishment projects [14].

Boussabaine and Elhag (1999) proposed fuzzy theory for evaluating the cash flow curve of construction projects at any progress stage. He assumed that cash flow is fuzzy at particular valuation phases [15].

Post (2000)

Tah and Carr (2000) proposed a model using FST for assessing risk likelihood and impact and also to calculate the interdependencies between risk factors and risk and consequence. The hierarchical risk breakdown structure (HRBS) was used to organize the risks [16]. Wong *et al.* (2000) applied fuzzy theory for project selection problem by including fuzzy analysis into multiattribute utility theory. For this purpose the aggregate utility function for an individual project was derived as a fuzzy number which, consecutively, yielded probabilistic information for stochastic dominance tests [17]. Tah and Carr (2001) developed a model based on FST to assess the risk rating of a construction project. Heairchial risk break down structure ((HRBS) was utilised to structure various risk factors and their fuzzy aggregation tool to combine the assessments [18].

Knight and Fayek (2002) employed the concept of fuzzy logic to predict the probable cost overruns for engineering design projects. It was found useful to assess the quantity of probable risk and the likelihood of earning a profit on the project [19]. Seo *et al.* (2004) presented a technique based on fuzzy set theory for assessing a sustainable residential building on the basis of acceptable level of environmental impact and socioeconomic characteristics. It was useful for the decision makers, building planners or industrial practitioners [20]. Choi *et al.* (2004) developed fuzzy-based risk assessment model and software for evaluating and managing the risks for underground construction projects. The risk analysis software was designed to consider the degree of uncertainty in both probabilistic estimates and subjective judgments based on the available amount of information [21]. Wang and Liang (2004) developed a multiple fuzzy goals programming model by using the concept of fuzzy theory. This model was helpful for the project managers for reducing the total costs, total completion time, and total crashing costs of the projects [22]. Lin and Chen (2004) used the concepts of fuzzy logic for examining bid/no-bid decision making as they were related with uncertainty and complexity. Linguistic terms were used to explain the evaluation while screening criteria were weighted by their corresponding level of significance using fuzzy values [23]. Zhang *et al.* (2004) developed a discrete-event simulation. For the estimation of activity duration, fuzzy set theory was used to manage ambiguous, imprecise, uncertain and subjective data. A fuzzy distance ranking measure was applied in fuzzy simulation time advancement and event selection for simulation experimentation on the basis of an enhanced activity scanning simulation algorithm [24]. Singh and Tong (2005) assessed the potential of a contractor for delivering the project according to the client's requirements by using fuzzy set theory [25]. Oliveros and Fayek (2005) proposed a model to support the analysis of the effects of delays on a project's completion time using fuzzy theory. The model combines the progress of activity and delays, with a schedule updating and forecasting system to monitor and control the construction project [26]. Thomas *et al*. (2006) presented a fuzzy Delphi methodology for assessing Risk probability and impact using fuzzy-fault tree and the Delphi method [27]. Dikmen and Birgonul (2006) developed a methodology for fuzzy risk assessment for international construction projects. The recommended methodology used effect diagrams to develop the risk model and a fuzzy risk assessment approach to estimate the risks in terms of extra costs over the budget [28]. Zeng *et al.* (2007) used AHP and FST for risk modeling. The subjective uncertainties and risk assessments were handled using FST while AHP was used to rank the risks. A risk parameter known as factor index (FI) was suggested to reflect the relationships and the influences between the risk factors in the hierarchy [29]. Zhang and Zou (2007) suggested a generic quantitative model for construction joint venture projects in China to measure the levels of risks and to assess whether a JV was feasible for project delivery. In this model Fuzzy evaluation matrixes of risk factors were established through FST [30]. Lee and Lin (2008) presented a new methodology for fuzzy risk assessment. In this model in place of linguistic variables fuzzy numbers were directly used [31]. Nieto-Morote and Ruz-Vila (2011) modeled the risk using Probability, Impact and Discrimination. These parameters were assessed using linguistic variables. The fuzzy arithmetic average was applied to aggregate the various assessments given by the experts [32]. Yeung *et al.* (2012) adopted FST to assess the performance of relationship-based construction projects in Australia [33]. San Cristobal (2013) proposed the use of the PROMETHEE method under fuzzy environments in order to determine the critical path of a network, considering not only time but also cost, quality, and safety criteria [34]. Gunduz *et al.* (2015) proposed a fuzzy assessment model to estimate the probability of delay in Turkish construction projects [35]. Shaktawat and Vadhera (2016) proposed a fuzzy methodology for determining the cost overrun of a river type hydro power plant [36]. Khalek *et al.* (2016) presented a model for the global construction market. Analytic hierarchy process (AHP) was used to assess the risk factors weights (likelihood) and fuzzy logic approach was used to evaluate risk factors impact (Risk consequences) [37]. Manoliadis (2018) applied fuzzy theory to identify relationships between risks and the consequences on projects performance measures [38].

III. BASIC CONCEPTS OF FUZZY LOGIC

A. Fuzzy Sets

Fuzzy set theory is extension of classical or 'crisp' set theory. In contrast to classical sets where only full membership or no membership at all is permitted, fuzzy sets allow partial membership. The elements of fuzzy set have degrees of membership, which determines "how much" the element belongs to the set. This is the basic principle of fuzzy set. A fuzzy set A of a universe of discourse X is characterized by a membership function $\mu_A(x)$: $X \rightarrow [0, 1]$ that takes values in the interval [0 1], can be defined as

$$A = \{(X, \mu_A(X) / X \in A, \mu_A(X) \in [0,1])\}$$

Where $\mu_A(x)$ is a membership function, which states the degree to which any element x in A is a member of the fuzzy set A. This definition unites each element x in A with μ_A (x) in the interval [0, 1] which is assigned to x. With the following case, we can explain the distinction between a crisp set and a fuzzy set:

Consider the example of the "height of a student". One might state that "a student's height is shorter than 150 centimeter." This statement can be represented in the form of classical set as short = {x|x ≤ 150} and the membership function characterizing this set in classical set theory can be represented as shown in Fig.1.

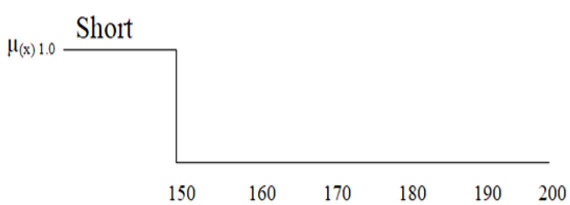


Fig. 1. Crisp set for height of student.

Where $\mu_A(x)$ is a membership function, which states the degree to which any element x in A is a member of the fuzzy set A. This definition unites each element x in A with $\mu_A(x)$ in the interval [0, 1] which is assigned to x. In contrast to classical set where only sharp boundaries are allowed, the idea of membership degree in fuzzy sets permits fuzzy or blurred boundaries to be defined.

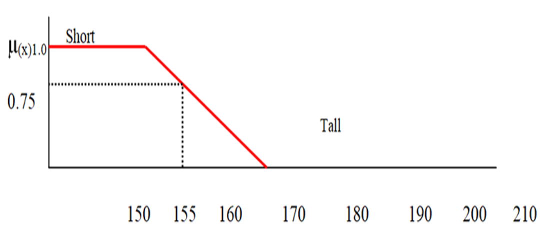


Fig. 2. Fuzzy set for height of student.

In a classical set the degree of membership is zero for a height of 155cm.It does not belong to the set of short at all, Whereas a height of 155cm can be considered as short in fuzzy set but with a lesser degree of membership than for 150cm (i.e μ short (x = 155) = 0.75).Fuzzy set for the height of students is shown in Fig. 2.

B. Membership function linguistic variable

A membership function in fuzzy set theory can be defined as a curve that describes how each point in the input space is mapped to degree of membership between 0 and 1. A membership function $\mu_A(x)$ determines the degree that input value x belongs to fuzzy set A. The membership value of zero shows that the element is entirely outside the set, whereas value one indicates that the element lies entirely inside a given set. Any value between the two extremes indicates that the element has partial degree of membership. Triangular, trapezoidal, gauussian, generalized bell are the most frequently used for membership function. The triangular and trapezoidal membership functions are the easiest membership functions that are produced using straight lines. Both of these memberships are commonly used to describe risks in safety assessment.

The input space is also sometimes referred to as the universe of discourse. The degree of the fuzzy membership function μ (x) can be define as possibility function not probability function. Membership function gives a numerical meaning for each label. There are different shapes of membership functions, viz, triangular, trapezoidal, gaussian, bell-shaped, piecewise-linear etc. A triangular fuzzy number x (see Fig. 3) with membership function can be expressed by the Eq. (1) given below

$$\mu_{(x)} = \begin{cases} \dfrac{X - a_1}{(a_m - a_1)} & a_1 \leq X \leq a_m \\ \dfrac{(a_2 - X)}{(a_2 - a_m)} & a_m \leq X \leq a_2 \\ 0 & Otherwise \end{cases}$$

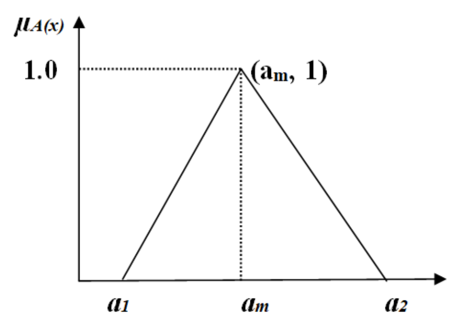


Fig. 3. Triangular fuzzy number.

C. Linguistic variable

The term 'linguistic variable' or fuzzy variable refers to a variable whose values represent "linguistic expressions" rather than numerical values in natural or artificial language. Linguistic variables associate a linguistic condition with a crisp variable. A crisp variable is the kind of variable that is used in most computer programs, an absolute value. A linguistic variable, on the other side, has a proportional nature, being represented by fractional values in the range of 0 to 1 in all software applications of linguistic variables. They are used to discuss a fuzzy concept such as temperature, risk, age, or height. The class fuzzy variable is used to create examples of a fuzzy variable, providing a name (for example, height), the units of the variable if required (for example, centimeters), the universe of discourse for the variable (for example a range from 0 to 200), and a set of primary fuzzy terms (like very short, short, tall and very tall) which is used to describe the particular fuzzy concepts associated with the fuzzy variable. Each linguistic value is represented by a membership function, where the characteristic of each fuzzy set is dependent on the conditions of the particular problem.

D. Fuzzy operators

The fuzzy operators "AND", "OR" and "NOT" are employed to create fuzzy rules. These "fuzzy combination" operators are being explained as follows:

The intersection operation (corresponds to the logical 'AND') for the two fuzzy sets A and B with membership functions $\mu_A(x)$ and $\mu_B(x)$ respectively, can be described as:

$\mu A \cap B(x) = \min [\mu_A(x), \mu_B(x)]$

Union operation (which corresponds to the logical 'OR') for the two fuzzy sets A and B with membership functions $\mu_A(x)$ and $\mu_B(x)$ respectively, can be described as:

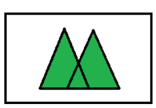
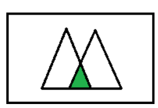
$\mu A U B(x) = \max [\mu_A(x), \mu_B(x)]$

Complement operator (which corresponds to the logical 'NOT') can be described as:

$\mu_{A}^{-}(x) = 1 - \mu_A(x)$

The various types of logical operators are presented in table1.

Table 1: Fuzzy Logical operators.

Logical operators		
Union	***Intersection***	***Negation***
AUB	**A∩B**	
OR	**AND**	**NOT**
		

IV. FUZZY INFERENCE PROCESS

Fuzzy inference can be defined as the process of mapping from a given input to an output by using fuzzy logic. This process of fuzzy inference is a rule-based system, in which the fuzzification (i.e., conversion of a crisp number to a fuzzy set) of input takes place first and then subsequently processed by an inference engine.

This engine repossesses the knowledge in the form of fuzzy rules which is contained in a knowledge base (combination of rule base and data base). The fuzzy sets calculated by the fuzzy inference in the form of the output of each rule are then combined and defuzzified (i.e., conversion of a fuzzy set to a crisp number).

The steps for the fuzzy inference process are as follows:

Step 1. Define input and output

The Independent variables are defined first in the form of input and output members.

Step 2. Fuzzification of input and output

In this step, the crisp quantities are converted into fuzzy quantities. Fuzzy sets are formed for input and output variables. In place of the numerical value, fuzzy sets are used to describe a variable, in terms of human language. The membership function specifies the degree of certainty that each variable belongs to a certain fuzzy set.

Step 3. Inference system

Inference rules are formed in the system. To perform inference, rules, which connect input variables to output variables in the form of 'IF... THEN ...' are used to explain the desired system response in terms of linguistic variables rather than numerical value. The 'IF' part of the rule is referred to as the 'antecedent', the 'THEN' part is referred to as the 'consequent'. The number of rules formation depends on the total number of inputs and outputs, and the preferred behaviour of the system. Once the rules have been established, the system can be viewed as a non-linear mapping from inputs to outputs.

Step 4. Defuzzification

Defuzzification process is used to convert the fuzzy value of the inference engine to a crisp value. On the basis of the independent variables and the inference rules the output fuzzy set of the dependent variable is created. A numerical value may be used after defuzzification to depict the output fuzzy set. The fuzzy inference process is shown in fig.4

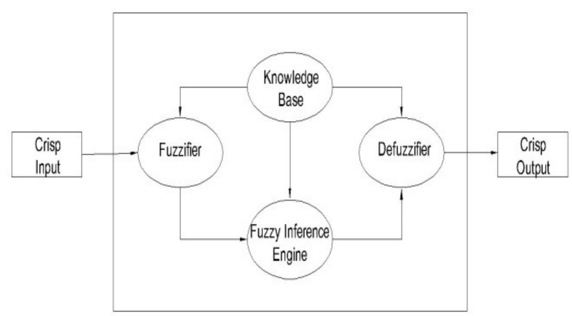


Fig. 4. Fuzzy inference process.

V. APPLICATION OF FUZZY THEORY IN EVALUATING THE PROJECT PERFORMANCE

The application of fuzzy theory for construction projects has been illustrated for evaluating the project performance. The fuzzy toolbox of MATLAB software [39] has been used to evaluate the fuzzy performance of the project. FIS editor, Membership function editor, rule editor, rule viewer and surface viewer, as shown in fig.5, are used for building, editing, and observing in the fuzzy inference systems toolbox.

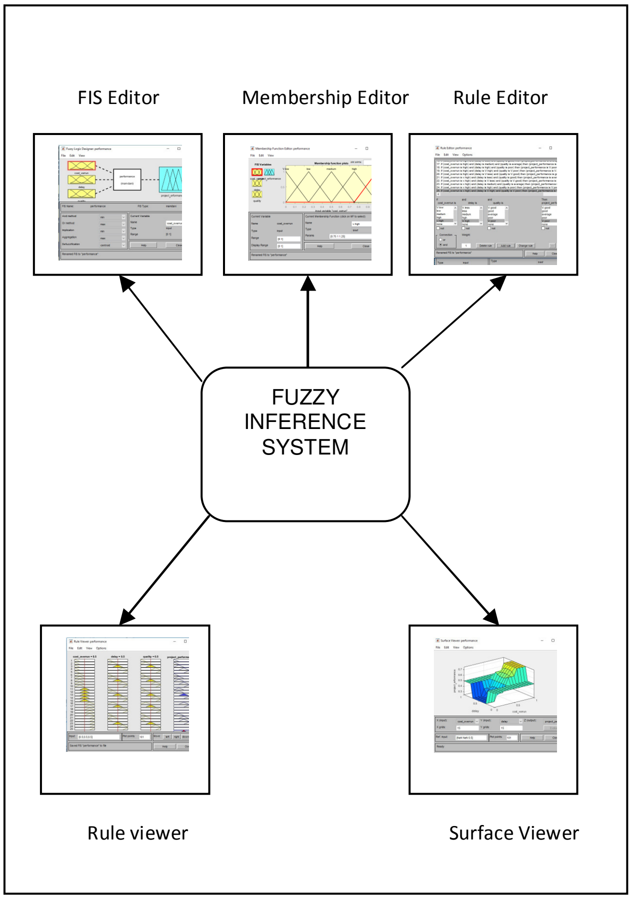


Fig. 5. Fuzzy inference process using fuzzy tool box MATLAB.

Cost, time and quality are considered the major parameter for the success of any project. Cost overrun, delay and quality should be considered for evaluating the project performance. Therefore for fuzzy evaluation of the project performance these parameters are taken as input members and output member is taken as "project performance".

The process of evaluating the project performance using fuzzy inference system has been described in the following steps:

1. FIS Editor: With the help of FIS Editor of fuzzy tool box the input and output variables are defined.

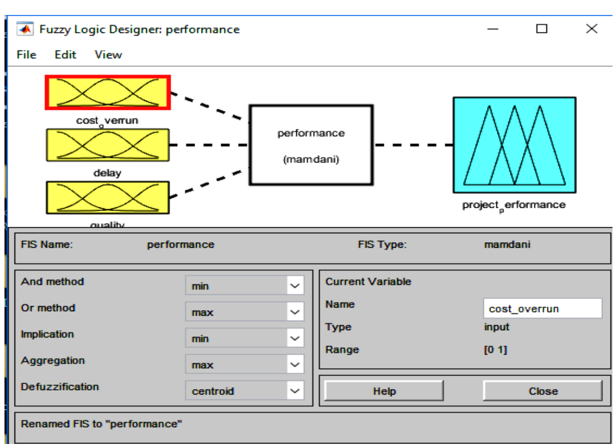


Fig. 6. FIS editor.

As shown in fig. 6 Cost overrun, delay and quality are taken as input members and output member is taken as "project performance" for evaluating the project performance.

2. Membership function editor: It defines the shapes of all the membership functions associated with each variable. Trimf type membership functions are used for this study. In Table 2 the various linguistic variables which are used to describe the input variables are described. Numbers of the membership function are taken five for each variable.

Table 2: Membership function.

Variables	Range	MFs	No of MFs	Linguistic variables
Input parameter				
Cost overrun	[0 -1]	trimf	5	1.V. low 2.low 3.medium 4.high 5.V. high
Delay	[0 -1]	trimf	5	1.V. less 2.less 3.medium 4.high 5.V. high
Quality	[0 -1]	trimf	5	1.V.good 2.good 3.Average 4.poor5 5.V.poor
Output parameter				
Project Performance	[0 -1]	trimf	5	1.V.good 2.good 3.Average 4.poor5 5.V.poor

Membership function editor of fuzzy toolbox of MATLAB software is shown in fig. 7.

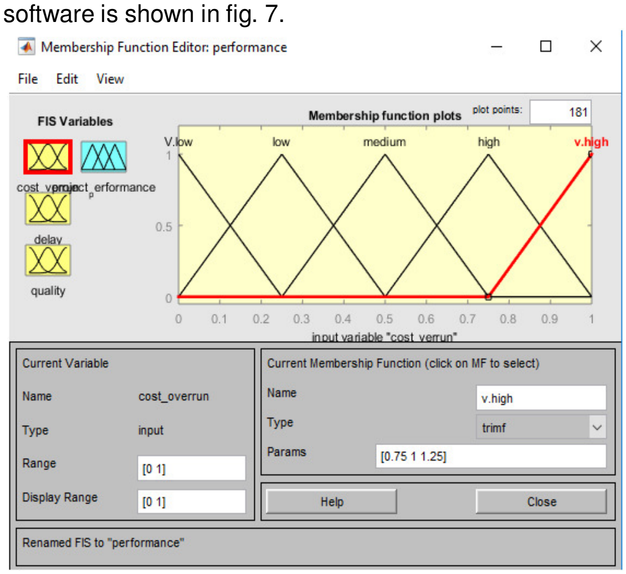


Fig. 7. Membership editor.

3. Rule Editor: Rule Editor edits as shown in fig.8, list of rules that defines the behaviour of the system. For this study rules are constructed with the help experts of construction industry.

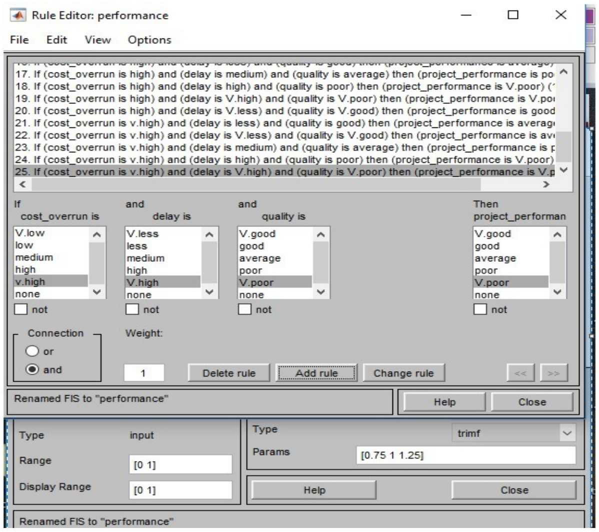


Fig. 8. Rule editor.

4. Rule Viewer: The function of rule view as shown in Fig. 9 is to view the fuzzy inference diagram. It is used to analyse to find out which rules are active, or how individual membership function shapes control the results.

Fig. 9. Rule viewer.

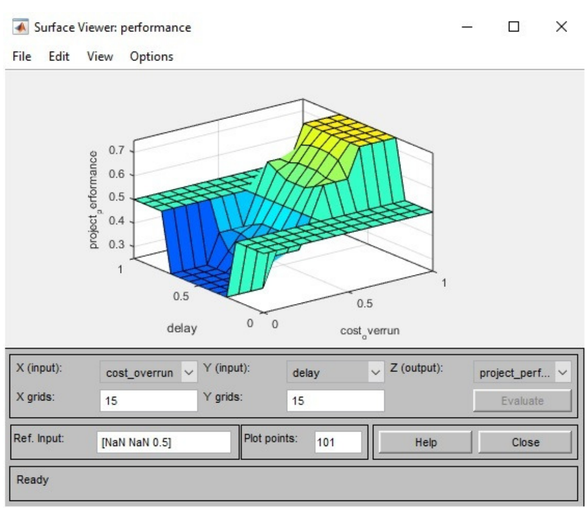


Fig. 10. Surface viewer.

5. Surface Viewer: It is used to view the dependency of one of the outputs on any one or two of the inputs; that is, it generates and plots an output surface map for the system. The Surface Viewer is shown in Fig.10.

VI. EVALUATION OF A PROJECT PERFORMANCE OF A GIVEN PROJECT

After development of the model, It is used for estimating the performance of a given project. The data for the cost overrun, delay and quality was collected by conducting an interview with the experts of the project. The projects experts were asked to indicate the cost overrun in the range of 0-1. The collected data are shown in table 3.The Project performance is evaluated as 0.667 as shown in Fig.11, which is corresponding to "good".

Fig. 11. Defuzzification.

VI. CONCLUSION

The concept of fuzzy logic has been applied to many areas of implementation in science, management and engineering. Through the comprehensive review of litreture (from 1984 to 2018) it is found that although the concept of fuzzy theory was introduced in 1965, until the late 1990's the theory was not common. It became the subject of investigation and research study at the beginning of new millennium, with the progress of advanced computation techniques. The implementation of "fuzzy methods" is also growing in the area construction project management such as risk management, decision making, and performance enhancement of the construction projects. It is also observed through the literature review that fuzzy set, fuzzy logic, and hybrid fuzzy techniques such as fuzzy neural network, neuro fuzzy, fuzzy reasoning has the capability to address the vagueness, uncertainty and subjective nature of any problems. These methods can deal with the similarity which is found in the complex construction projects. The techniques enable the translation of a subjective judgment given in linguistic expressions (i.e., "low," "high," etc.) into mathematical measures. Defining input and output, fuzzification of input and output, and defuzzification are the basic steps for fuzzy inference process. An application of fuzzy theory for construction projects have been illustrated for evaluating the project performance. Cost overrun, delay and quality are considered as input variables for evaluating the project performance. Output member is taken as "project performance". Project performance is evaluated as 0.667 which is corresponding to "good".

VII. FUTURE SCOPE

The scope of probable applications of fuzzy logic theories in the area of construction management is very broad. Fuzzy techniques can be applied to solve the various complex issues which are ill defined and ambiguous. Models could also be developed using hybrid fuzzy techniques such as fuzzy neural network neuro fuzzy for determining the probabilities of delay and cost overrun considering the area specific issues.

CONFLICT OF INTEREST: No

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