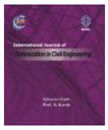
INTERNATIONAL JOURNAL OF OPTIMIZATION IN CIVIL ENGINEERING
Int. J. Optim. Civil Eng., 2020; 10(4):715-732



DESIGNING A FUZZY INFERENCE SYSTEM FOR CONTRACTOR SELECTION UNDER UNCERTAINTY

S. M. Hatefi[*, †], H. Asadi and G. Shams
Department of Civil Engineering, Faculty of Engineering, Shahrekord University, Rahbar Boulevard, P.O. Box 115, Shahrekord, Iran

ABSTRACT

The increase in the number of construction projects and the involvement of a large amount of resources show that one of the most important actions of any construction project is to select the right contractor for the project. Delays in most construction projects and increased costs compared to initial estimates are often due to inadequacies by contractors, indicating that the contractor has not been properly selected. The complexities of the construction industry and the existing uncertainties have led experts to point out that choosing a contractor is a sensitive and difficult task. The purpose of this paper is to design a fuzzy inference system (FIS) to select the best contractor in conditions of uncertainty. The fuzzy inference system is a powerful tool for handling the uncertainties and subjectivities arising in the evaluation process of contractors. The proposed FIS has a two-step computational process in which 28 criteria are determined to evaluate the contractors. The proposed FIS is applied to evaluate and select the best contractor among 5 contractors considered by the general department of roads and urban development in Shahrekord. The studied criteria for evaluating contractors are categorized in six groups, including good history and credibility, equipment, management and specialized staff, economic-financial, skills-ability, and technical criteria. The results show that technical criteria are determined as the most important criteria for evaluating contractors. Furthermore, the results of applying the proposed FIS reveal that contractor C is the best contractor with the final score of 31.40.

Keywords: fuzzy inference system; contractor selection; benchmark weight; membership function; uncertainty.

Received: 10 September 2020; Accepted: 18 November 2020

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[*]Corresponding author: Department of Civil Engineering, Faculty of Engineering, Shahrekord University, Rahbar Boulevard, P.O. Box 115, Shahrekord, Iran
[†]E-mail address: smhatefi@alumni.ut.ac.ir (S. M. Hatefi)

1. INTRODUCTION

Whether a project succeeds in terms of sustainability, cost, completion time, maintenance cost, etc., depends on the choice of contractor. In order to create business capability and increase the efficiency of activities, managers are handing over part of their activities to contractors. Therefore, managers should pay attention to the fact that they choose contractors, which prevent the waste of resources and cause the conservation of resources (Jamshidi and Hatefi, 2016; Gurgun and Koc, 2020). The existing method in selecting a contractor based on the lowest bid price has not only been able to solve the problems of employers and investors, but also has caused failures. There are different qualitative and quantitative indicators with different degrees of importance that must be reflected in evaluation process of contractors (Taylan et al., 2018). One of the most important problems in selecting inefficient contractors can be safety problems and accidents that are imposed on the project, which puts a lot of costs on the management and implementation of the project (El-Sayegh et al., 2019). Hiring a suitable contractor should be related to actual performance, both empirically and normatively, which is a very important step in implementing an investment project (Morkūnaitė et al., 2017). The selection of the contractor requires proper management of the evaluation, including identifying the criteria influencing the selection of project contractors, determining the importance of the criteria, and ranking contractors. The contractor is the main factor in converting resources into the final product (Khalafallah et al., 2019).

Multi criteria decision making methods are widely used tools which are applied to solve the contractor selection problems. In the following, we will review the articles that have evaluated and selected contractors using multi-criteria decision making methods. Mani et al. (2014) identified the indicators affecting the performance of contractors and determined the importance of these indicators using fuzzy analytical hierarchy process (AHP) in a group decision making structure. The authors described the use of fuzzy AHP model to select the most suitable contractor in the automotive industry. Puri and Tiwari (2014) suggested some appropriate criteria for evaluating contractors. The criteria used for evaluating contractors are financial transparency, technology capability, management capabilities, safety and reputation. Bluobid and Al-Amoudi (2015) studied the effective criteria in selecting the best contractor, and used a fuzzy AHP to compare and rank the contractors. Taheri and Iranban (2015) proposed integrated model of DEMATEL and analytic network process (ANP) for selecting the best contractor in the Parsian Gas Refinery Company. They considered five indicators including: equipment, technology, planning, work experience, experience and performance guarantee for contractors participating in the tender.

Borujeni and Gitinavard (2017) proposed a hesitant fuzzy priority selection method based on a new soft computing approach with risk settings of DMs for handling the sustainable mining contractor selection problems. Hasnain et al. (2018) introduced a novel decision support system, which was developed based on the ANP method, for solving the contractor selection problem. The proposed method is applied for the best value contractor election in road construction projects. Cheaitou et al. (2019) intended to create a decision framework to assist public organizations in selecting the most appropriate construction contractors. The proposed method used a combination of multi-criterion decision tool and the fuzzy logic theory and data envelopment analysis.

Hashemi et al. (2018) introduced a new decision model with multi-criteria analysis by a group of decision makers with intuitive fuzzy sets. Their proposed model consisted of three methods including ELECTRE and VIKOR theory along with gray relationship analysis. To illustrate the uncertainties of real life and to consider the complex decision problem, the authors presented a multi-criteria group decision model. To illustrate the application of the proposed new decision model, an industrial application presented for evaluating contractors in the construction industry. Tomczak et al. (2018) developed a method for group decision making in the contractor qualification process. In the proposed method, aggregation of judgments is performed by using type 2 fuzzy sets that allow for inaccurate decision-makers' assessments. The use of a neutral standard deviation estimator to determine the compromise assessment takes into account the small size of the expert group and the deviation in their assessment. The use of the proposed method produced better results than the other two methods discussed for this sample of contractors. The method presented here may also be used to solve decision problems in other areas.

Afolayan et al. (2020) introduced an integrated multi-criteria group decision support model for contractor selection. The proposed model consists of two modules including the technical evaluation module and financial evaluation module. The technical evaluation module is used to display contractors to a smaller set of acceptable contractors, and the performance module is based on the Fuzzy AHP. The outputs of the technical evaluation module are imported in the financial evaluation module by considering the bid price criterion, the difference between the project owner's cost estimate and the bid prices. The contractor with the least amount of this difference will be awarded the contract.

As the literature shows, various decision-making methods have been used to evaluate and select the best contractor. The evaluation methods used have been developed both in terms of certainty and uncertainty. Many contractor evaluation tools developed under uncertainty are based on fuzzy theory. Research has not yet found a study that evaluates and selects the best contractor using a fuzzy inference system. Fuzzy set theory provides a systematic computational method for discussing linguistic information. This theory is based on numerical calculations on the values generated by the fuzzy membership function for qualitative criteria. In addition, the selection of fuzzy if-then rules is a key component in the fuzzy inference system. With the help of these rules, a person's expertise in a particular field can be effectively modeled. Fuzzy rules and fuzzy reasoning form the backbone of the fuzzy inference system. Fuzzy inference systems are the most important modeling tools based on fuzzy set theory. These systems have successful performance in a wide range of applications such as automated control, expert systems, pattern recognition, time series prediction and data classification (Pourjavad and Shahin., 2018). Therefore, in this research, a fuzzy inference system is designed to evaluate and select the best contractor and it is used to evaluate the contractors of the General Directorate of Roads and Urban Development in Shahrekord. The fuzzy inference system is a powerful tool for evaluating contractors based on experts' subjective judgments about evaluation criteria (Pourjavad and Shahin., 2018).

The remaining of the paper is organized as follows. The basic concept of fuzzy inference system is presented in section 2. The proposed fuzzy inference system is introduced in section 3. In section 4, the proposed fuzzy inference system is applied on a case study to evaluate five contractors of General Department of Roads and Urban Development of Shahrekord. The results of the proposed fuzzy inference system are discussed and compared with those obtained by the fuzzy simple additive weighting method in section 5. Finally, the concluding remarks are reported in section 6.

2. BASIC EXPLANATIONS

2.1 Fuzzy inference system

Fuzzy inference systems provide a systematic process for transforming a knowledge base into a nonlinear mapping. For this reason, knowledge-based systems (fuzzy systems) are used in engineering and decision-making applications (Pourjavad and Shahin., 2018). As it is sown in Fig. 1, a fuzzy inference system has at least four components:

a) Fuzzifier: The inputs of the fuzzy set are shown with the membership function so that the final inputs become fuzzy, defined, and done. Types of membership functions are: 1- Triangular membership function, 2- Trapezoidal membership function, 3- Linguistic items function, 4- Gaussian membership function, 5- Bell membership function 6- Simgoidal membership function. In this paper, the triangular membership function is used.

b) Rule Base: The set of rules of a fuzzy system is called the rule base. This set of rules is created in a way that expresses a human description or a human inference of the system. Rules are usually created to include all possible combinations of different input modes and to specify what the output should be in each mode. Fuzzy rules should not contradict each other. Fuzzy rules are created based on human experience, self-organizing methods, evolutionary methods, or mathematical conditions. Fuzzy rules are used in the fuzzy inference engine to generate the appropriate response. Fuzzy rules are used in the fuzzy inference engine to generate the appropriate response. Usually in a system, the number of fuzzy sets of inputs multiplied by each other, there is a fuzzy rule that is expressed as: "if - then" (Amindoust et al., 2012).

   For example, if a_1 is b_1 and a_2 is b_2 then a_3 is c_3, like formula number 1

$$if\ a_1\ is\ b_1\ and\ a_2\ is\ b_2\ then\ a_3 = c_3 \tag{1}$$

c) Inference Engine: This means that the degree of compliance of the system input with each of the rules is determined. The degree of conformity of a number is between zero and one, and the number one means the complete conformity of the input with a rule, and zero means the complete conformity (Amindoust et al., 2012).

d) Defuzzifier: The process of converting fuzzy numbers to definite numbers is called defuzzing. In this paper, the Mamdani model used in the Mamdani model, different methods for dispensing are presented, but the method of calculating the center of gravity (COA) is the most common and accurate dispensing method for the Mamdani model (Amindoust et al., 2012).

$$X_{COA} = \frac{\sum_{i=1}^{n} x_i \mu_i(x)}{\sum_{i=1}^{n} \mu_i(x)} \tag{2}$$

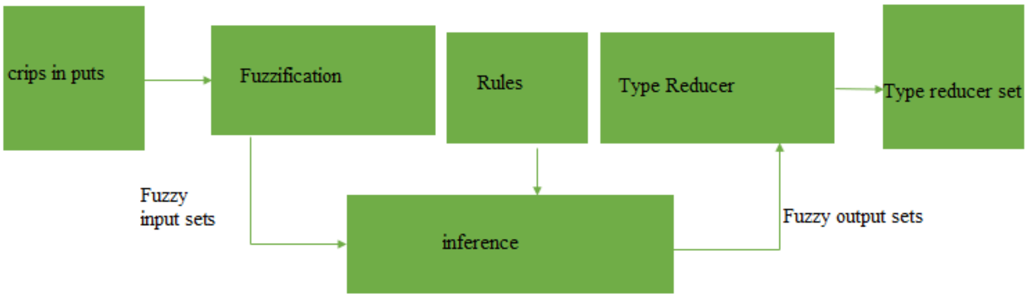

Figure 1. General structure of a fuzzy inference system

3. THE PROPOSED FUZZY INFERENCE SYSTEM (FIS) FOR CONTRACTOR SELECTION

The fuzzy inference system is a computational framework based on the concept of fuzzy sets of if-then rules of fuzzy reasoning. Fuzzy rules and fuzzy reasoning form the backbone of the fuzzy inference system, which effectively gathers human knowledge in the face of inaccurate and uncertain issues and environments. In this way, it provides the possibility of learning and adapting to the unknown and changing environment with higher efficiency.

As shown in Fig. 2, the proposed fuzzy inference system has two stages. The first stage consists of four parts including FIS1, FIS2, FIS3 and FIS4, according to the membership function of the inputs and outputs. In the first part of the first stage (FIS1), the value of each sub-criterion is given in pairs to Mamdani fuzzy inference system and one output is taken, and in this part, fourteen outputs are taken (Amindoust and saghafinia, 2017).

In part 1, the values of two sub-criteria (for example C_{11} and C_{12}) are given to the fuzzy inference system (FIS1), and after implementation, an output like *a* is given. We can formulate it as a=FIS1(C_{11},C_{12}). The output of this part and another output are considered as the inputs of the second part. Suppose b= FIS1(C_{13},C_{14}). Therefore, we have c=FIS2(a, b). This computational process is continued for all criteria values.

There are 28 sub-criteria in part 1. They enter the first stage fuzzy inference system in pairs. After implementing the fuzzy inference system (FIS1) on two inputs, one output is extracted. As the number of inputs in part 1 is 28, the number of outputs of this part is equal to 14. These outputs are considered as the inputs of the second part (FIS2). In addition, the outputs of the second part are equal to 7 items, which are considered as the inputs of part 3 (FIS3). At this stage, 6 inputs out of seven inputs enter the third part (FIS3). The output of this part becomes 3 items. These three outputs, with the input already left, are considered as inputs of part 4 (FIS4). The number of outputs in part 4 is equal to 2 items. These two outputs are considered as the inputs of the second stage of the proposed fuzzy inference system. The only difference between the first and second stage fuzzy inference systems is how they fuzzy their inputs and outputs.

In order to implement the proposed fuzzy inference system the following steps must be performed.

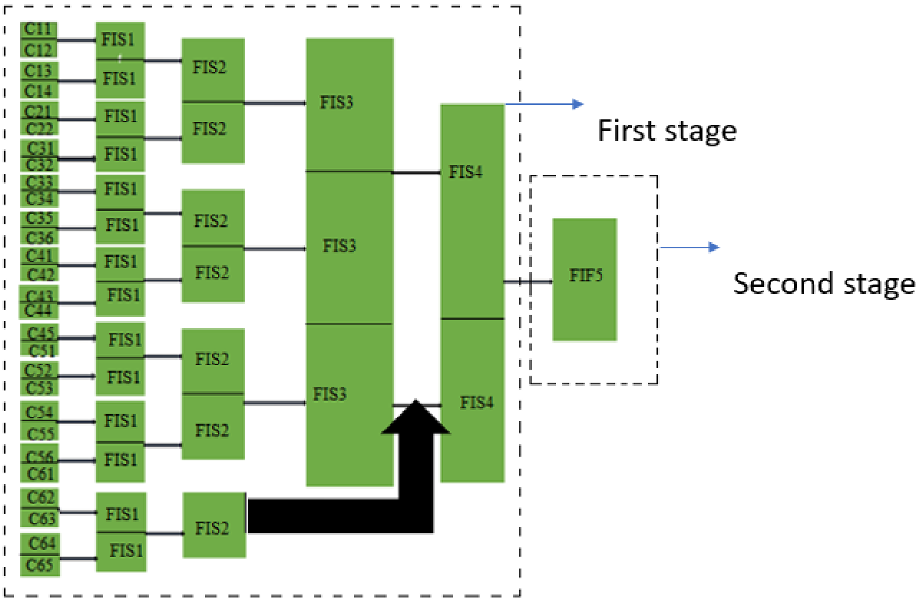

Figure 2. The structure of the proposed two-stage fuzzy inference system

Step 1: Determine the shape and form of the membership function

The fuzzy triangular numbers are used for fuzzification of inputs and outputs in the proposed fuzzy inference system. A fuzzy triangular number is formulated as follows and depicted in Fig. 3 (Amindoust and saghafinia, 2017).

$$\mu_{\omega}(x)=\begin{cases} 0 & if \;\; x<a^{l} \\ \dfrac{(x-a^{l})}{(a^{m}-a^{l})} & if \; a^{l}<x<a^{m} \\ \dfrac{(x-a^{u})}{(a^{m}-a^{u})} & if \; a^{m}<x<a^{u} \\ 0 & if \;\; x>a^{u} \end{cases} \tag{3}$$

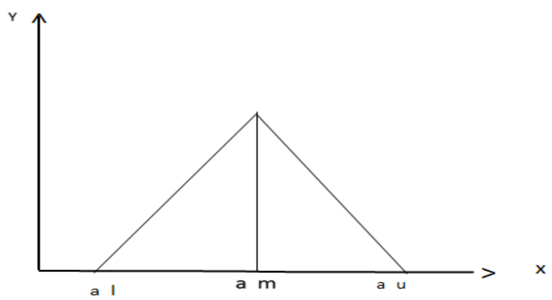

Figure 3. Triangular membership function

Step 2: Fuzzification of inputs and outputs in the first stage of the proposed FIS

Five triangular membership functions are considered for fuzzification of inputs and outputs in the first stage of the proposed fuzzy inference system. The respected fuzzy membership functions are obtained according to the linguistic judgments of experts including weakly preferred (WP), low moderately preferred (LMP), moderately preferred (MP), strongly preferred (SP) and extremely preferred (EP). The used fuzzy numbers, and their corresponding intervals, and the linguistic expressions are presented in Table 1 and depicted in Fig. 4 (Amindoust and saghafinia, 2017).

Table 1: linguistic terms in the first stage

Corresponding values	Linguistic judgment	Importance	Score range
1	Weakly preferred	WP	(0,10/6,10/3)
2	Low moderately preferred	LMP	(10/6,10/3,5)
3	Moderately preferred	MP	(10/5,5,20/3)
4	Strongly preferred	SP	(5,20/3,50/6)
5	Extremely preferred	EP	(20/3,50/6,10)

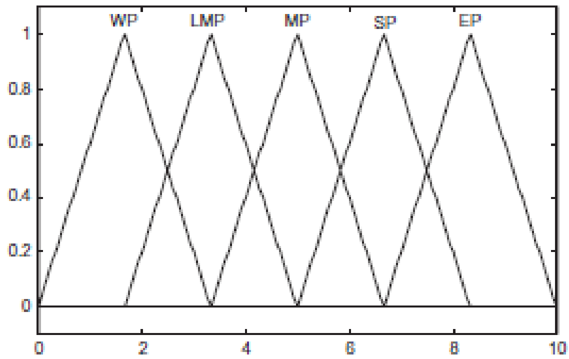

Figure 4. Input and output membership function of the first stage

Step 3: Determine the rule matrix in first stage of the proposed FIS

The rule matrix (if-then) use in the first stage of the proposed fuzzy inference system is defined in Table 2 (Amindoust and saghafinia, 2017).

Table 2: Matrix of rules of the first stage

	The first input				
The second input	WP	LMP	MP	SP	EP
WP	WP	WP	LMP	LMP	MP
LMP	WP	LMP	LMP	MP	MP
MP	LMP	LMP	MP	MP	SP
SP	LMP	MP	MP	SP	SP
EP	MP	MP	SP	SP	EP

Step 4: Determine the weight of the criteria

The weight of the criteria of inputs and outputs are determined by the linguistic terms in both stages of the proposed FIS. Linguistic expressions and corresponding fuzzy intervals for evaluating the weight of criteria are given in Table 3 and graphically depicted in Fig. 5. The linguistic experessions and their respected fuzzy numbers are as WI in the sense of very weak importance and in the range (0, 1/6, 2/6), LMI in the sense of low moderance importance and in the range (1/6, 2/6, 3/6), MI in the sense of moderate importance and in the range (2/6, 3/6, 4/6), SI in the sense of relatively strong importance and in the range ((3/6 , 4/6 , 5/6), EI means extreme importance and in the range (4/6 , 5/6 , 1) (Amindoust and saghafinia, 2017).

Table 3: Intervals of linguistic terms Weight of criteria

Corresponding values	Linguistic judgment	Importance	Score range
1	Weak importance	WI	(0 , 1/6 , 2/6)
2	Low moderate importance	LMI	(1/6 , 2/6 , 3/6)
3	Moderate importance	MI	(2/6 , 3/6, 4/6)
4	Strong importance	SI	(3/6 , 4/6 , 5/6)
5	Extreme importance	EI	(4/6 , 5/6 , 1)

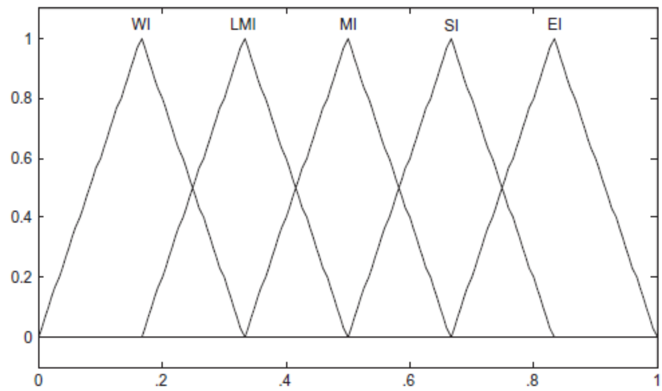

Figure 5. Membership function of the weights

Step 5: Obtain the weighted criteria

To implement the first stage of the proposed FIS, the importance of criteria must be considered in evaluation process. Assume $\tilde{w} = (w_1, w_2, w_3)$ and $\tilde{a} = (\alpha, \beta, \gamma)$ show the weight of a sub criterion and the assessment value of that sub criterion, respectively, which are stated in the form of fuzzy numbers. Formulation (9) shows the weighted sub criterion, which is defuzzified. After weighting and defuzzifying all sub criteria, they are used as inputs in the first stage of the proposed FIS.

$$O = \frac{\alpha.w_1 + \beta.w_2 + \gamma.w_3}{3} \tag{4}$$

Step 6: Define the membership function of the inputs and outputs in the second stage of the proposed FIS

For the second stage, a set of five membership functions for two inputs and seven membership functions for one output is performed in Mamdani fuzzy inference. It is worthy to mention that the input functions are the same as the first stage. But the output membership function has seven values of weakly preferred language (VWP) with fuzzy number (0, 12.5, 25), weak importance (WP) with fuzzy number (12.5, 25, 37.5), low moderately preferred (LMP) with fuzzy number (25, 37.5, 50), moderately preferred (MP) with fuzzy number (37.5,50, 62.5), high moderately The performance (HMP) with fuzzy number (50,62.5,75), strongly preferred (SP) with fuzzy number (62.5,75,87.5) and extremely preferred (EP) with fuzzy number (75, 87.5, 100). The used membership functions and their fuzzy numbers, which have a scale between [0,100] are presented in Table 4 and graphically depicted in Fig. 6 (Amindoust and saghafinia, 2017).

Table 4: Linguistic terms used for outputs of the second stage of the proposed FIS

Corresponding values	Linguistic judgment	Importance	Score range
1	Weakly preferred language	VWP	(0, 12.5, 25)
2	weak importance	WP	(12.5, 25, 37.5)
3	Low moderately preferred	LMP	(25, 37.5, 50)
4	Moderately preferred	MP	(37.5, 50, 62.5)
5	high moderately performance	HMP	(50, 62.5, 75)
6	Strongly preferred	SP	(62.5, 75, 87.5)
7	Extremely preferred	EP	(75, 87.5, 100)

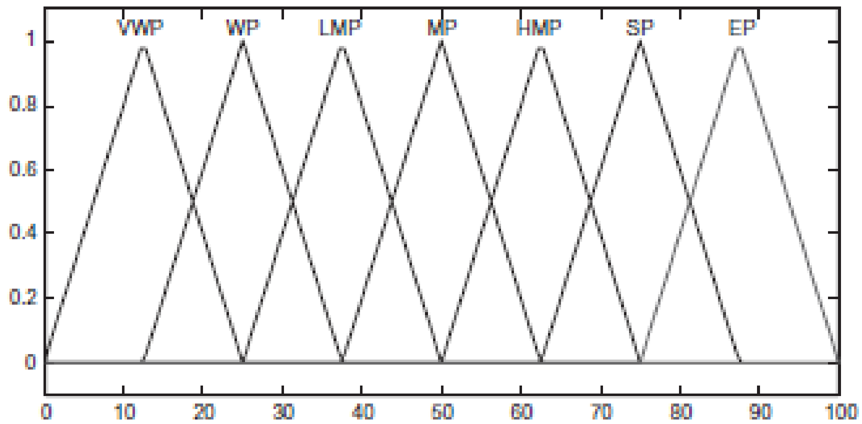

Figure 6. Membership function of the outputs of the second stage of the fuzzy inference system

Step 7: Determine the matrix of rules in the second stage of the proposed FIS

The matrix of rules in the second stage of the proposed FIS is stated in Table 5.

Table 5: Rule matrix of the second stage in the proposed FIS

	The first input				
The second input	WP	LMP	MP	SP	EP
WP	VWP	WP	LMP	LMP	MP
LMP	WP	LMP	LMP	MP	HMP
MP	LMP	LMP	MP	HMP	SP
SP	LMP	MP	HMP	SP	SP
EP	MP	HMP	SP	SP	EP

Step 8: Obtain the performance score of the contractors

The stored data of the fourth part in the first stage according to the membership function introduced in Fig. 6 and the rule matrix of Table 5 are given to the Mamdani inference system in pairs and finally the performance score of each contractor is determined (Amindoust and saghafinia, 2017).

4. CASE STUDY

Evaluation and selection of the best contractor in the road and urban development department of Shahrekord city is one of the strategic decisions of this organization. Among the existing contractors, 5 contractors have more executive experience in this office and have been able to cooperate with this office in more projects. Therefore, the proposed FIS is implemented to evaluate these 5 contractors, which are denoted by A, B, C, D and E. In the matter of evaluating and selecting the best contractor, a set of contractors are evaluated according to several criteria and sub-criteria. The evaluation of contractor is performed according to the proposed FIS as follows:

Step 1: The literature and expert opinions have been used to identify the criteria and sub-criteria for contractor evaluation. Criteria and sub-criteria are extracted from Gholipour et al., (2014) and finalized according to the opinion of experts. In order to gather the performance data, a questionnaire is designed and complement by 3 experts in the department of road and urban development in Shahrekord city. The contractor evaluation criteria and their sub-criteria are shown in Table 6.

Table 6: Criteria and sub-criteria for evaluating contractors

Criteria		Sub - criteria	
C1	Experience and reputation	C11	Credibility and reputation of the company and key personnel
		C12	Good record in previous works
		C13	Receive awards and appreciation of official programs
		C14	Qualification of various official and reputable organizations and bodies
C2	Equipment	C21	Complete and timely equipment of the workshop
		C22	Having equipment and machinery ready or available
C3	Management and specialized staff	C31	Continuous staff training
		C32	Works of scientific and technical writings and researches

		C33	Presenting articles in conferences and specialized journals
		C34	Education level, field of study, executive experience of specialized staff and key elements
		C35	Proof of board members and specialized staff
		C36	Efficient management and proper management system
C4	Economic - financial	C41	Insure all facilities, equipment and personnel against possible accidents
		C42	Timely payment of salaries of employees, workshop agents and component contractors
		C43	How to analyze
		C45	Proposed price
		C46	Financial strength and support
C5	Skills -Ability	C51	Continuous communication and coordination with the employer and the monitoring device
		C52	Classification of workshop documents and classification of previously done works
		C53	Application of appropriate methods and executive organization and order in the affairs of the workshop
		C54	Creativity and innovation in previous projects
		C55	Indigenous contractor with experience in the project site
		C56	Executive background in the desired field and field of work
C6	Technical	C61	Observe the safety and protection instructions of the workshop
		C62	Comply with relevant current laws such as environmental, labor and social security laws
		C63	How to implement previous projects in terms of quality, cost and schedule
		C64	How to comply with standards and technical specifications in previous projects
		C65	Having a comprehensive project planning and control system

Step 2: The linguistic terms and their fuzzy numbers are obtained according to Table 1. During a discussion on the performance of criteria and sub-criteria, the experts of the road and urban development department announced their opinion and performance score (1 to 5) to each contractor. The status of contractors in terms of sub-criteria is reported based on the opinions of experts in Table 7.

Table 7: Status of contractors in each sub-criterion based on expert opinions

Criteria	Sub - criteria	A	B	C	D	E
C1	C11	EP	SP	EP	SP	SP
	C12	SP	SP	SP	SP	SP
	C13	WP	WP	WP	LMP	LMP
	C14	SP	SP	EP	SP	MP
C2	C21	MP	SP	SP	LMP	MP
	C22	SP	SP	SP	MP	SP

C3	C31	LMP	SP	MP	MP	LMP
	C32	WP	WP	WP	WP	WP
	C33	WP	WP	WP	WP	WP
	C34	MP	MP	SP	SP	SP
	C35	SP	SP	SP	SP	SP
	C36	MP	SP	SP	MP	MP
C4	C41	EP	SP	EP	SP	SP
	C42	MP	MP	SP	SP	MP
	C43	SP	SP	EP	MP	LMP
	C44	MP	SP	EP	MP	MP
	C45	SP	MP	EP	MS	MP
C5	C51	SP	SP	EP	SP	MP
	C52	EP	SP	SP	MP	LMP
	C53	SP	SP	SP	MP	MP
	C54	MP	LMP	SP	SP	WP
	C55	WP	WP	EP	E	SP
	C56	SP	EP	EP	SP	SP
C6	C61	SP	MP	SP	MP	LMP
	C62	EP	SP	SP	MP	LMP
	C63	SP	SP	EP	MP	MP
	C64	MP	SP	EP	MP	MP
	C65	LMP	SP	EP	MP	LMP

Step 3: To determine the weight of criteria and sub-criteria, Table 3 is used. Experts have given their opinion on each criterion and sub-criterion, and the average value of each criterion and sub-criterion has been determined and reported in Table 8. As Table 8 shows, criterion C6 which refers to the technical aspects of the contractors has the high importance when comparing to other criteria.

Table 8: Average weight of expert opinions in each of the criteria and sub-criteria

Criteria	E1	E2	E3	Average	Sub - criteria	E1	E2	E3	Average
C1	MI	EI	SI	(0.5, 0.66, 0.83)	C11	EI	SI	SI	(0.55, 0.72, 0.89)
					C12	EI	SI	SI	(0.55, 0.72, 0.89)
					C13	MI	WI	MI	(0.22, 0.39, 0.59)
					C14	SI	EI	MI	(0.5, 0.67, 0.83)
C2	EI	SI	EI	(0.61, 0.77, 0.94)	C21	SI	MI	SI	(0.44, 0.64, 0.78)
					C22	SI	SI	EI	(0.55, 0.72, 0.89)
C3	SI	EI	EI	(0.61, 0.77, 0.94)	C31	MI	SI	SI	(0.44, 0.64, 0.78)
					C32	MI	LMI	LMI	(0.22, 0.39, 0.56)

					C33	MI	LMI	MI	(0.28, 0.45, 0.61)
					C34	SI	SI	SI	(0.5, 0.67, 0.83)
					C35	MI	SI	SI	(0.44, 0.64, 0.78)
					C36	SI	EI	EI	(0.61, 0.77, 0.94)
C4	EI	SI	SI	(0.55, 0.72, 0.89)	C41	SI	EI	SI	(0.55, 0.72, 0.83)
					C42	SI	EI	SI	(0.55, 0.72, 0.89)
					C43	SI	EI	SI	(0.55, 0.72, 0.83)
					C44	EI	EI	EI	(0.67 ,0.83, 1)
					C45	SI	SI	EI	(0.55, 0.72, 0.89)
C5	SI	SI	SI	(0.5, 0.67, 0.83)	C51	EI	SI	EI	(0.61, 0.77, 0.94)
					C52	MI	SI	MI	(0.39, 0.56, 0.72)
					C53	SI	SI	SI	(0.5, 0.67, 0.83)
					C54	SI	SI	EI	(0.55, 0.72, 0.89)
					C55	MI	SI	SI	(0.44, 0.64, 0.78)
					C56	SI	SI	SI	(0.5, 0.67, 0.83)
C6	EI	EI	EI	(0.67,0.83,1)	C61	SI	SI	EI	(0.55, 0.72, 0.89)
					C62	MI	SI	EI	(0.5, 0.66, 0.83)
					C63	EI	SI	EI	(0.61, 0.77, 0.94)
					C64	SI	SI	EI	(0.55, 0.72, 0.89)
					C65	SI	SI	EI	(0.55, 0.72, 0.89)

Step 4: Determine the value of each sub-criterion for the first stage according to formulation (4) in such a way that the average of the product of the weight of each sub-criterion is multiplied by the set of fuzzy numbers of each sub-criterion. The defuzzified weighted data obtained by the mentioned procedure are reported in Table 9. For example, if the opinion of an expert on the performance of contractor A with respect to C11 be EP (20/3, 50/6, 10), and the respected average weight of C11 is (0.55, 0.72, 0.89), then the defuzzified weighted value is calculated as follows:

$$O = \frac{\frac{20}{3}\times 0.55 + \frac{50}{6}\times 0.72 + 10\times 0.89}{3} = 6.19$$

Table 9: The sum of the product of the weight of each sub-criterion in the set of fuzzy numbers

	C11	C12	C13	C14	C21	C22	C31	C32	C33	C34	C35	C36	C41	C42
A	6.19	4.98	0.84	4.6	2.42	4.98	2.25	0.84	0.92	3.5	4.32	4.05	6.19	3.78
B	4.98	4.98	0.84	4.6	4.32	4.98	4.32	0.84	0.92	3.5	4.32	5.34	4.98	3.78
C	6.19	4.98	0.84	5.71	4.32	4.98	2.42	0.84	0.92	4.6	4.32	5.34	6.19	4.98
D	4.98	4.98	1.47	4.6	2.25	3.78	2.42	0.84	0.92	4.6	4.32	4.05	4.98	4.98
E	4.98	4.98	1.47	3.5	2.42	4.98	2.25	0.84	0.92	4.6	4.32	4.05	4.98	3.78
	C43	C44	C45	C51	C52	C53	C54	C55	C56	C61	C62	C63	C64	C65

A	4.98	4.35	4.98	5.34	4.82	4.6	3.78	1.19	4.6	4.98	5.71	5.34	3.78	2.58
B	4.98	5.73	3.78	5.34	3.89	4.6	3.78	1.19	5.71	3.78	4.6	5.34	4.98	4.98
C	6.19	5.73	6.19	6.62	3.89	4.6	4.98	5.35	5.71	4.98	4.6	6.62	6.19	4.98
D	3.78	4.35	3.78	5.34	2.97	4.6	4.98	5.35	4.6	3.78	4.6	4.05	3.78	3.78
E	2.25	4.35	3.78	4.05	2.04	4.6	1.39	4.32	4.6	2.58	2.39	4.05	3.78	2.58

Step 5: obtaining the value of all criteria by implementing the first stage of the proposed FIS. The data reported in Table 9 are considered as input data for the first stage of the proposed FIS. After implementing the first stage of the proposed FIS on the sub criteria in each criterion, the value of each criterion is obtained. The results are obtained and reported in Table 10. For obtaining the results of C1, all its sub criteria are considered as inputs in pairs and the first stage of the proposed FIS is implemented so that the value of C1 is obtained. The value of all criteria is reported for each contractor in Table 10.

Table 10: Contractors score in each criterion

	C1	C2	C3	C4	C5	C6
A	3.29	3.30	3.33	4.26	2.78	2.56
B	3.29	4.29	2.60	3.86	3.33	3.95
C	3.33	4.29	2.61	4.91	4.42	4.41
D	3.29	2.30	1.67	3.87	3.87	3.87
E	3.29	3.33	1.67	2.61	2.59	2.48

Step 6: Determine the input and output membership function of the second stage. The membership functions of inputs in the second stage of the proposed FIS are similar to those of outputs in the first stage. But its membership functions of outputs are considered according to the Table 4 and Fig. 6.

Step 7: The rule matrix presented in Table 5 is utilized to obtain the final score of the contractors in the second stage of the proposed FIS.

Step 8: To obtain the final results according to the second stage, the numbers stored in the fourth part (FIS4) of the first stage are given to the Mamdani fuzzy inference. Finally, the performance score of the contractors are obtained and reported in Table 11 and Fig. 7.

Table 11: Score and rating of each contractor

Contractor	Achieved score	Rank
A	26.20	2
B	26.10	3
C	31.40	1
D	20.00	4
E	18.50	5

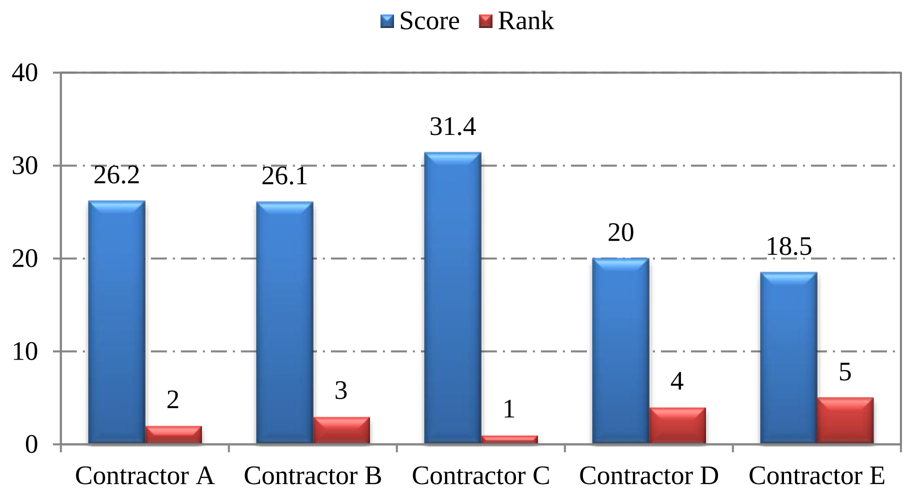

Figure 7. The score and rank of contractors obtained by the proposed FIS

As Table 11 and Fig. 7 show, contractor C has obtained the highest score and determined as the best contractor in department of road and urban Development in Shahrekord. Contractor A is in second place. Contractor B is in third place. Contractors D and E are ranked fourth and fifth, respectively. Fig. 8 shows the computational results of applying the proposed FIS to obtain the performance score of contractor A.

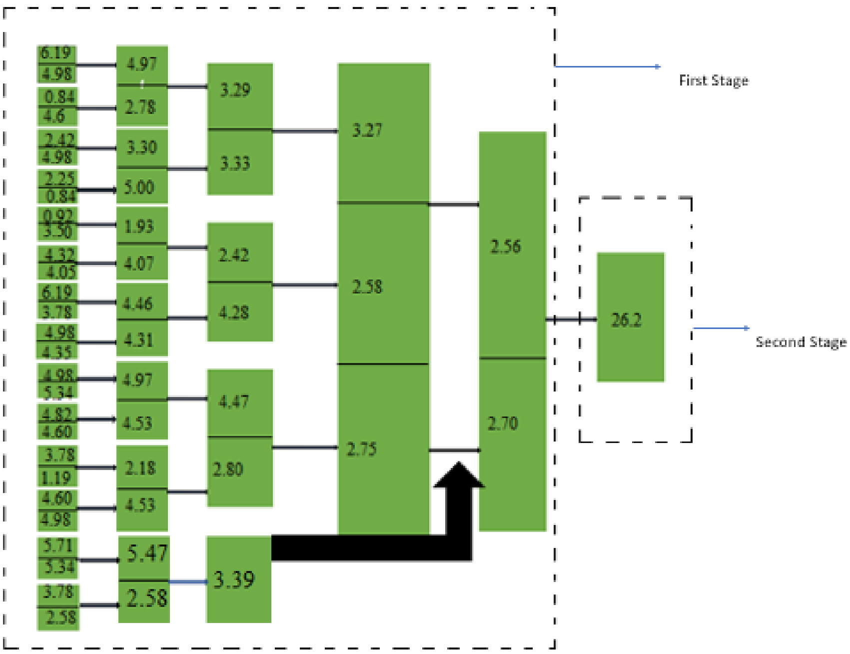

Figure 8. the results of applying the proposed FIS for evaluating contractor A

5. DISCUSSION

In order to validate the results obtained by the proposed FIS, a multi attribute decision making method is considered. In this paper, the simple additive weighting (SAW) method in the fuzzy form is used to prioritize contractors, and the respected results are compared with those obtained by the proposed FIS. In the fuzzy SAW method, the score of alternative *i* ($\tilde{R}_i$) can be obtained by $\tilde{R}_i = \sum_{j=1}^{n} \tilde{w}_j \tilde{a}_{ij}, i = 1,2,...,m$, where $\tilde{w}_j$ denotes the weight of criterion *j* and $\tilde{a}_{ij}$ denotes the assessment value of contractor *i* with respect to criterion *j*, respectively As the final score of alternatives are in the form of the fuzzy triangular numbers, they can be defuzzified by formulation (4). Table 12 reports the final score of contractors and their ranks, which are obtained by the proposed FIS and the fuzzy SAW. The comparison results of the priority of contractors are depicted in Fig. 9. As the results show the priority of contractors C,D, and E obtained by two methods are similar and they are gained the first, fourth and fifth ranks, respectively. Contractors A and B are gained the second and third positions, respectively, by applying the proposed FIS while they are gained the third and second positions by the fuzzy SAW method, respectively.

Contractor C is determined as the best contractor by applying both the proposed FIS and the fuzzy SAW. According to Table 10, contractor C has the best performance in all criteria. Furthermore, contractor E which is considered as the worst contractor by applying our proposed FIS and the fuzzy SAW, has the worst performance in all criteria except C2.

The results obtained in the table below show that the proposed model, which is based on the opinions of experts and their inference, has reasonable results. Therefore, this designed fuzzy inference system can be used to evaluate and select the best contractor in situations where we face uncertainty due to lack or insufficiency of information.

Table 12: Score and rating of each contractor

Contractor	The proposed FIS		The fuzzy SAW	
	Score	Rank	Score	Rank
A	26.20	2	77.05	3
B	26.10	3	80.29	2
C	31.40	1	92.13	1
D	20.00	4	75.29	4
E	18.50	5	65.55	5

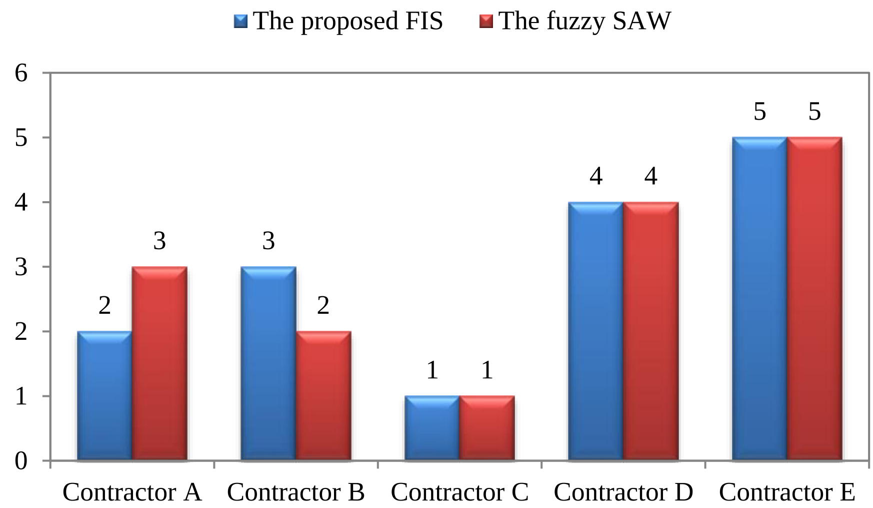

Figure 9. The priority of contractors by the proposed FIS and the fuzzy SAW

6. CONCLUSION

These days, considering the economic, social and cultural conditions, choosing an efficient contractor is an important issue. Given that the project submitted by the contractor must meet the intended objectives (cost, quality and time). In this paper, using the uncertainty of fuzzy inference system due to having accurate theoretical foundations, a useful tool for modeling and analysis on five contractors selected from the Road and Urban Development Department of Shahrekord city was assigned a percentage to each contractor. Contractor A is equal to 26.2, Contractor B is equal to 26.1, Contractor C is equal to 31.40, Contractor D is equal to 20 and Contractor E is equal to 18.5. It can be concluded that Contractor C has been selected as the best contractor with the highest score. Because the proposed FIS method requires specialized knowledge of fuzzy inference system, it may not be an easy to use method in organizations. This limits the application of the proposed method in reality. Therefore, to solve this challenge, designing novel software to implement the proposed fuzzy inference system is proposed for the future research.

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