PAPER • OPEN ACCESS

Application of Fuzzy Logic on Selection of Contractors for Construction of High Rise Buildings

IOP ebooks™

Bringing you innovative digital publishing with leading voices to create your essential collection of books in STEM research.

Start exploring the collection - download the first chapter of every title for free.

Application of Fuzzy Logic on Selection of Contractors for Construction of High Rise Buildings

Z Beljkas[1], Z Prascevic[2], N Ivanisevic[2], M Knezevic[1] and M Cvetkovska[3]

[1] Faculty of Civil Engineering in Podgorica, University of Montenegro
[2] Faculty of Civil Engineering, University of Belgrade
[3] Civil Engineering Faculty, Ss. Cyril and Methodius University-Skopje

zeljkab@ac.me

Abstract. Selection process of a construction contractor is highly important and successful implementation of a project and realization of sustainability are largely dependent on it. Computer programs - expert systems - may be used to help the employer or his consultants in the process of best tenderer selection. This paper presents a new expert system based on the implementation of fuzzy logic as an aid in selecting a contractor for construction of high rise buildings.

1. Introduction

Selection of a contractor is an important stage in the construction process. It is a complex task and depends on many factors. Three main goals: quality of works, price and time of completion and realization of sustainability largely depend on the selected contractor.

The above mentioned aspects are essential for success of a construction project, thus the choice of contractors should be approached with great care.

As the first step in this selection process, it is necessary to clearly define the elements that determine the selection of the best candidate contractor. Depending on the type of structure to be constructed, the selection criteria may vary. The most common, and often the only criterion for selecting a contractor is the offered price. However, practice has shown that, apart from the price, it is very important to consider other criteria such as the financial situation of the contractor, the contractor's experience in the construction of similar structures, the number of employees, etc. Each of the adopted criteria should be carefully considered and the decision on the selected contractor should be made as a result of a detailed analysis.

Support in the process of reaching this very important decision may be provided by computer programs called expert systems. These systems are systems that simulate the inference process of a human expert. These systems also act in areas where there are no human experts, in an expertly way. Expert systems are also called "advisory systems" because, usually the final decision on making a certain action is made by an authorized manager, as she/he is the one considered responsible for the decision. Expert systems that use fuzzy logic are called fuzzy expert systems.

There are many items of research that have dealt with this topic and with the application of various methods. Sik-Wah Fong and Kit-Yung Choi dealt with selection of contractors using the analytical hierarchy process. Their selection was based on criteria that were not

based on the lowest bid price [1]. Bendaña et al. created contractors selection system based on fuzzy logic and with the aim to support private sector client [2]. Kolekar and Kanade also used analytical hierarchy process for selection contractors. They concluded that suitability of these methods depends on the input regarding various attributes of contractors and attributes of selection criteria obtained from the decision makers [3]. Rajaie, Hazrati and Rashidi dealt with evaluation of construction contractors in developing countries using fuzzy SAW method [4]. Singh and Robert defined systematic procedure based on fuzzy set theory to evaluate the capability of a contractor to deliver the project according to the owner's requirements [5].

The aim of this paper is to define fuzzy expert system that would support those responsible for decision-making in the selection of a contractor.

2. Fuzzy logic

The language we use in everyday communication is often imprecise and indeterminate. Nevertheless, language represents the strongest way for information exchange between humans. Despite the imprecision and the indetermination of the language, people do not have great problems in understanding the terms that are used in mutual communication. However, communication with computers produces a different situation. In the process of issuing commands to a computer, a great level of precision is needed. This may be explained by using a very simple example.

In the communication between humans, when we say that someone is a "young man", despite the ambiguity of the term "young", there is a great deal of coincidence in understanding this notion between the people who participate in the exchange of information. On the other hand, in communication with computers it is necessary to accurately specify the man's age, and to express it in years (e.g. 25 years). Here we come upon the question of whether a 25-year-old belongs to the group of young people or not. For a 20-year-old, we can say with certainty that he or she belongs to this category. On the other hand, a 60-year-old certainly does not.

The fuzzy set theory has been developed in order to mathematically describe the inference-making process about the phenomena for which there is imprecise linguistic information. Zadeh was the first to develop the idea about the possibility of decision-making based on imprecise, qualitative data, by combining descriptive linguistic rules using fuzzy logic [6–7]. After that, application of fuzzy logic has become widespread and a great number of authors are involved [8–13].

3. Fuzzy expert system

In the process of making conclusions and displaying results, fuzzy logic is used by fuzzy expert systems [12].

This paper presents a fuzzy expert system for the selection of contractors for construction of high rise buildings. Such an expert system could be helpful in selecting a contractor for a specific project. Through series of questions that it asks the user, i.e. through the replies it receives, it collects all the necessary information in order to finally give a recommendation.

The expert system consists of a knowledge base, a global memory and an inference mechanism.

The knowledge base is created from the information provided by experts. Questionnaire was conducted for purpose of this research and it contained a lot of carefully premeditated questions, to which experts provided the answers. As part of the question, there are different characteristics of the contractor. Experts according to their experience give an answer whether to choose such a contractor or not. Based on the answers provided in the questionnaire, knowledge base was built. All questions, with relevant expert answers, were processed with a support of a specific computer program.

The system user supplies the system with the necessary information about a particular project for which advice is sought and this data is then stored in the global memory space. Required information is the input variables of the fuzzy expert system.

The inference mechanism provides an expert solution to the problem by using data from the knowledge base, together with the information provided by users. A set of fuzzy rules describing the decision-making strategy forms a fuzzy algorithm, while linguistic concepts and expressions are represented and quantified by fuzzy sets and fuzzy relationships.

The fuzzy algorithm consists of fuzzification, the inference engine and defuzzification.

Fuzzification is a process by which raw data from everyday life is transformed into functions of membership to particular subgroups. Fuzzification is performed through the selection of input variables, representation of input variables in fuzzy sets, and choice of output variables.

The first step is to define the input variables. A number of components are defined as input variables. There are seven input variables that are selected as main attributes for contractor selection according to experience. Each of them is then divided into terms.

The next step in the application algorithm of the fuzzy expert system is to enter the terms of input variables into the inference engine. Each of the input variables in this paper is described with three to five terms. This engine contains a rule base that is formed on the basis of expert knowledge. It uses fuzzy reasoning and transforms groups of linguistic terms into fuzzy relations in order to obtain the result.

After processing the input variables in the inference mechanism by using standard procedures and operations for fuzzy sets, results are obtained in the form of the value of the membership function of the output variables. Output variables represent the decisions proposed by the fuzzy expert system.

Defuzzification is a process that converts membership functions of the output variables to values that have a certain meaning for the system user and which uniquely define the solution to the problem.

3.1. Input variables

Criteria for selecting a contractor for construction of high rise buildings are grouped into seven categories representing seven input variables in the model:

- Price at which the work performance is offered,
- Financial situation of the contractor (annual turnover),
- Experience of the contractor in constructing similar structures,
- Ownership of construction machinery (value of owned machinery),
- Number of employees,
- Size of the structure (floor area),
- Key experts.

Input variables are then divided into certain terms. Each of these terms represents a fuzzy subset in the input variable set. These variables, together with their corresponding terms, represent basic characteristics of the contractor that influence the selection. For each variable, a description of the input data is provided, which should be entered into the system by user. After calculations are performed within the system, a proposal for the optimum solution is given to the user of the expert system.

The input variables (IV_i) with their terms (TIV_{ij}) and the data to be entered by the expert system user for selection of the contractor for high rise buildings are given:

IV_1: Price at which the job performance is offered

- TIV 11: very low,
- TIV 12: low,
- TIV 13: medium,
- TIV 14: high,
- TIV 15: very high.

The input data to be entered by the expert system user is the price at which the construction of the structure is offered, expressed in Euros.

IV2: Financial situation of the contractor

- TIV 21: very bad,
- TIV 22: bad,
- TIV 23: solid,
- TIV 24: excellent.

The input data is represented by the annual turnover of the contractor, expressed in Euros.

IV_3: Experience of the contractor in constructing similar structures

- TIV 31: little,
- TIV 32: medium,
- TIV 33: great,

The input data is represented by the number of similar structures constructed.

IV_4: Ownership of construction machinery (value without transport costs)

- TIV 41: little,
- TIV 42: medium,
- TIV 43: great.

The input data is represented by the value of machinery, expressed in Euros.

IV_5: Number of employees

- TIV 51: small,
- TIV 52: medium,
- TIV 53: large.

The input data is the number of employees in the company.

IV_6: Size of the structure (floor area)

- TIV 61: very small,
- TIV 62: small,
- TIV 63: medium,
- TIV 64: large,
- TIV 65: very large.

The input data is represented by the floor area of the structure, expressed in square meters.

IV_7: Experience of key experts

- TIV 71: little,
- TIV 72: medium,
- TIV 73: great.

The input data refers to the number of key experts.

3.2. Output variables

The model considers two options for the selection of the contractor – Output Variables (OVj), namely:

- OV1: The contractor complies with the conditions for the construction of the given structure,
- OV2: The contractor does not comply with the conditions for the construction of the given structure.

3.3. Fuzzification of the input data

By the process of fuzzification, raw real-life data is transformed into membership functions for particular fuzzy subsets. The relevance of any real-world data (TIVik) can be given via μ_{ik}.

Such real-life information is transmitted in the fuzzification process to a format that allows it to appear as membership function in a particular fuzzy subset. The membership function is a real value between zero and one. Zadeh in 1975 defined the so-called "**S**", "**Z**"
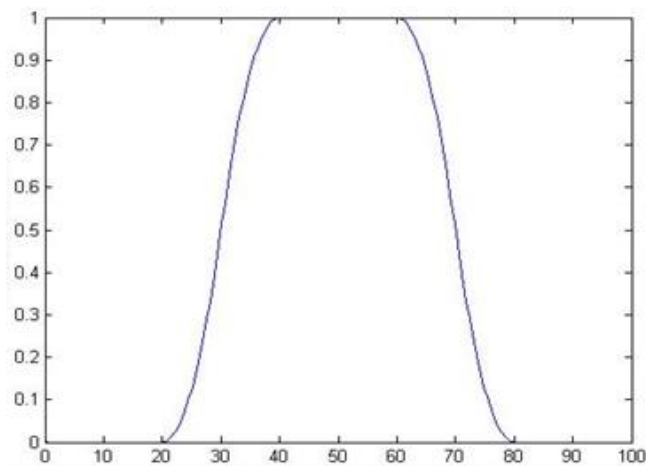
or "π" functions, or a slightly modified form of the "π" function, Figures 1, 2 and 3. In the following functions z, a, b, c and d are real numbers.
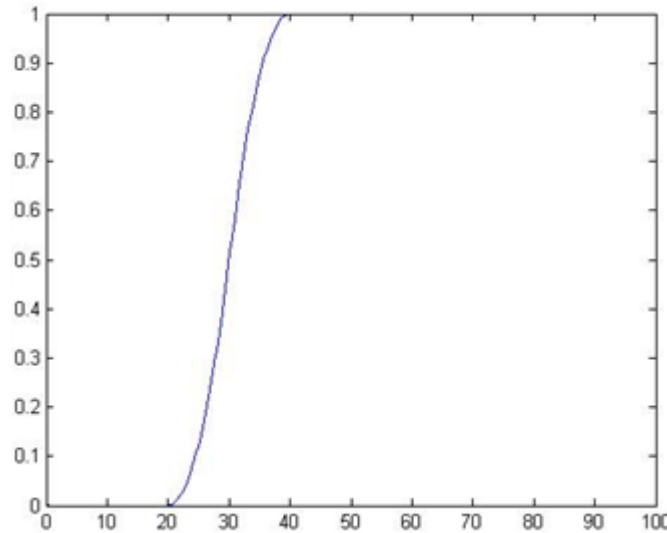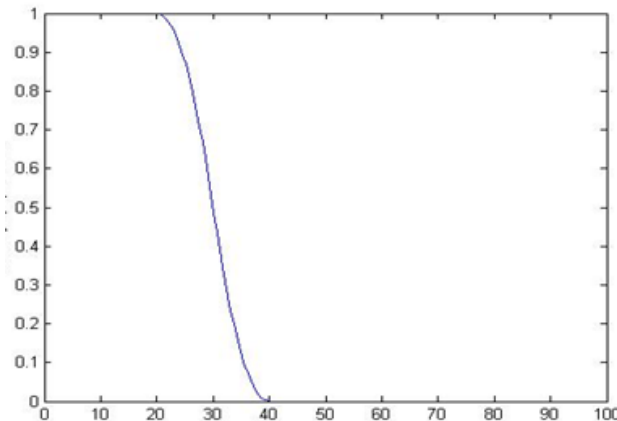

Figure 1. Graph of the "S" function.

$$S_{(z,a,b)} = \begin{cases} 0 \ for \ z \leq a \\ \dfrac{2*(z-a)}{(b-a)} \ for \ a < z \leq e \\ 1 - 2 * \left[\dfrac{(z-b)}{(b-a)}\right]^2 \ for \ e < z \leq b \\ 1 \ for \ z > b \end{cases}$$

where $e = \dfrac{(a+b)}{2}$.

Figure 2. Graph of the "π" function.

$$\pi_{(z,a,b,c,d)} = \begin{cases} S_{(z,a,b)} \\ 1 \ for \ b < z \leq c \\ 1 - S_{(z,c,d)} \end{cases}$$

Figure 3. Graph of the "Z" function.

$$Z_{(z,a,b)} = 1 - S_{(z,a,b)}$$

   Each of the input variables mentioned above with their terms has been fuzzified by applying the corresponding "**S**", "**Z**" or "**π**" functions [13].

Fuzzification of the Input Variable IV$_1$:
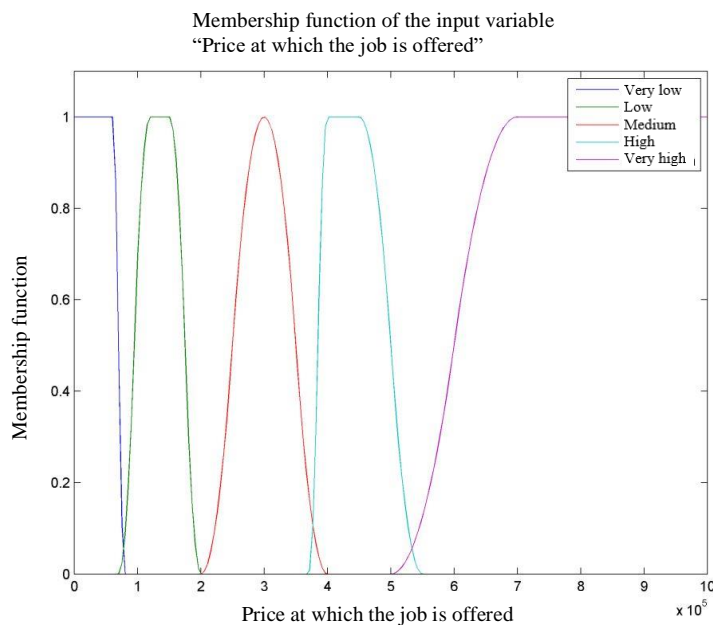**Price at which the job performance is offered** (Figure 4)
TIV$_{11}$: very low - "**Z**" function (a = 60,000, b = 80,000)
TIV$_{12}$: low - "**π**" function (a = 70,000, b = 120,000, c = 150,000, d = 200,000)
TIV$_{13}$: medium - "**π**" function (a = 200,000, b = 300,000, c = 400,000, d = 500,000)
TIV$_{14}$: high - "**π**" function (a = 370,000, b = 400,000, c = 450,000, d = 550,000)
TIV$_{15}$: very high - "**S**" function (a = 500,000, b = 700,000)

Figure 4. Membership function of the input variable "Price at which the job performance is offered".

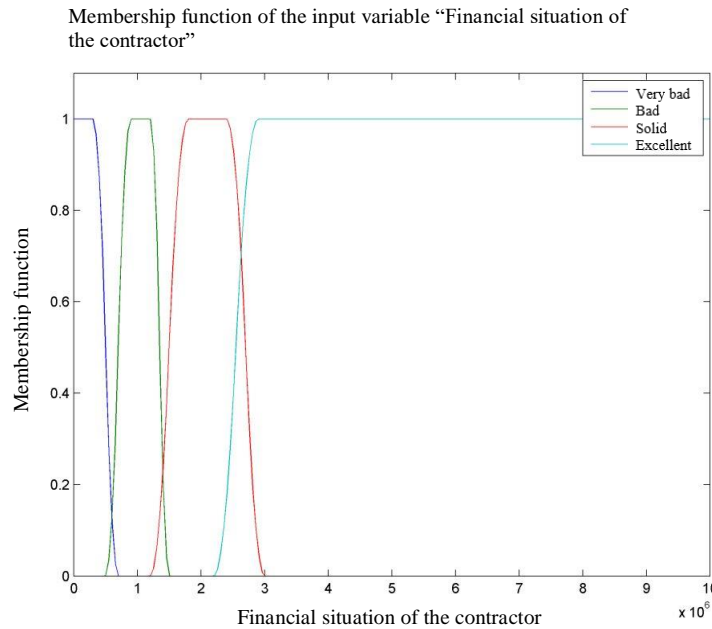**Fuzzification of the Input Variable IV$_2$:**
Financial situation of the contractor (Figure 5)

TIV$_{21}$: very bad - "**Z**" function (a = 300,000, b = 700,000)
TIV$_{22}$: bad - "**π**" function (a = 500,000, b = 900,000, c = 1,200,000, d = 1,500,000)

TIV$_{23}$: solid - "**π**" function (a = 1,200,000, b = 1,800,000, c = 2,400,000, d = 3,000,000)
TIV$_{24}$: excellent - "**S**" function (a = 2,200,000, b = 2,900,000)

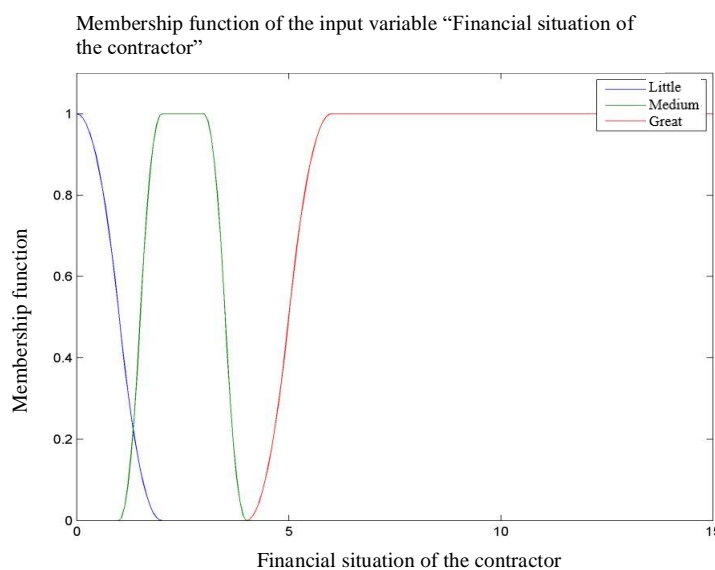**Figure 5.** Membership function of the input variable "Financial situation of the contractor".

Fuzzification of the Input Variable IV$_3$:
Experience of the contractor in constructing similar structures (Figure 6)
TIV$_{31}$: little - "**Z**" function (a=0, b=2)
TIV$_{32}$: medium - "**π**" function (a=1, b=2, c=3, d=4)
TIV$_{33}$: great - "**S**" function (a=4, b=6)

Figure 6. Membership function of the input variable "Experience of the contractor in constructing similar structures".
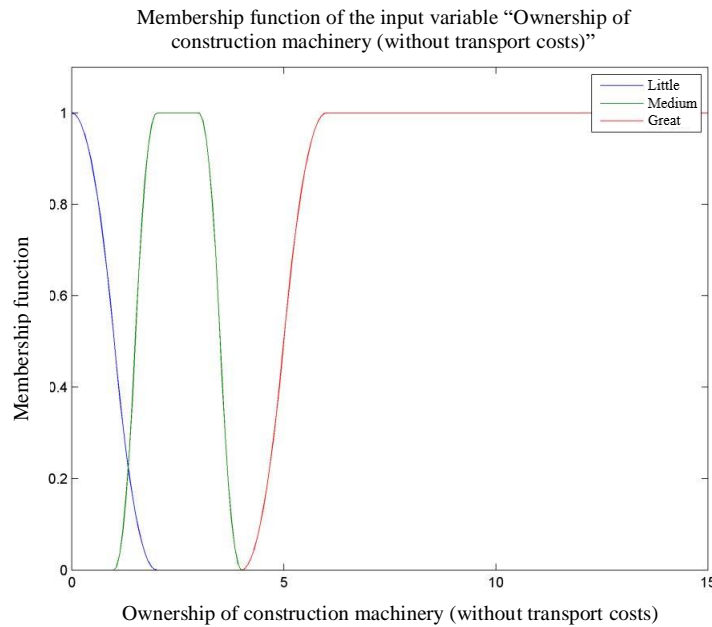
Fuzzification of the Input Variable IV$_4$:
Ownership of construction machinery (without transport costs) (Figure 7)
TIV $_{41}$: little - "**Z**" function (a=100,000, b=200,000)
TIV $_{42}$: medium - "**π**" function (a=150,000, b=300,000, c=400,000, d=500,000)
TIV $_{43}$: great - "**S**" function (a=400,000, b=600,000)

Figure 7. Membership function of the input variable "Ownership of
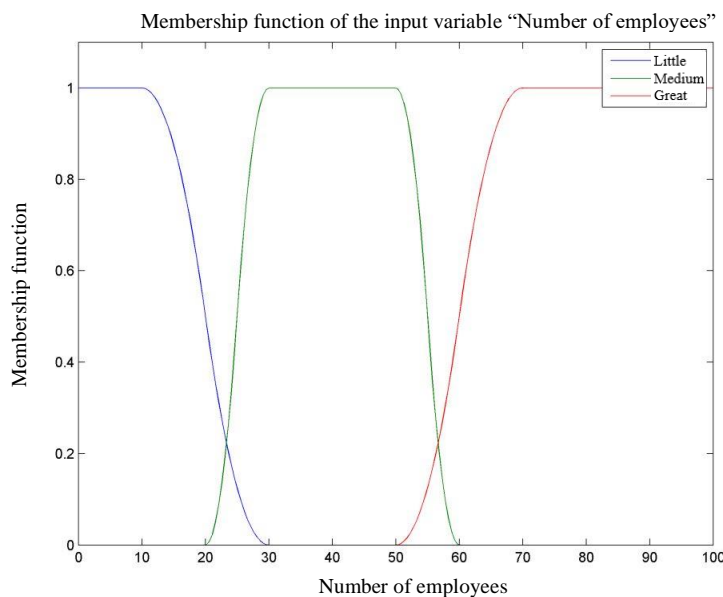construction machinery (without transport costs)".

Fuzzification of the Input Variable IV$_5$:
Number of employees (Figure 8)
TIV $_{51}$: small - "**Z**" function (a=10, b=30)
TIV $_{52}$: medium - "**π**" function (a=20, b=30, c=50, d=60)
TIV $_{53}$: large - "**S**" function (a=50, b=70)

Figure 8. Membership function of the input variable "Number of employees".

Fuzzification of the Input Variable IV$_6$:
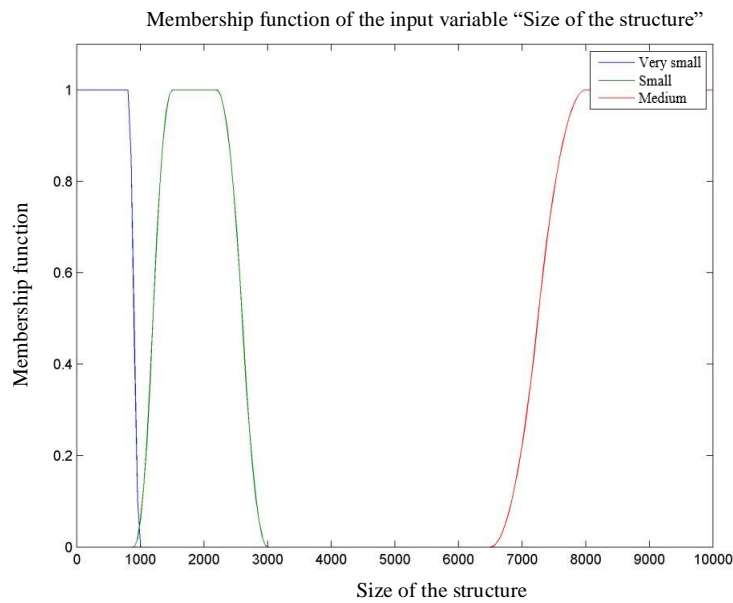**Size of the structure (**Figure 9**)**
TIV$_{61}$: very small - "**Z**" function (a=800, b=1000)
TIV$_{62}$: small - "**π**" function (a=900, b=1500, c=2200, d=3000)
TIV$_{63}$: medium - "**π**" function (a=2500, b=3200, c=4500, d=5000)
TIV$_{64}$: large - "**π**" function (a=4600, b=5500, c=6500, d=7000)
TIV$_{65}$: very large - "**S**" function (a=6500, b=8000)

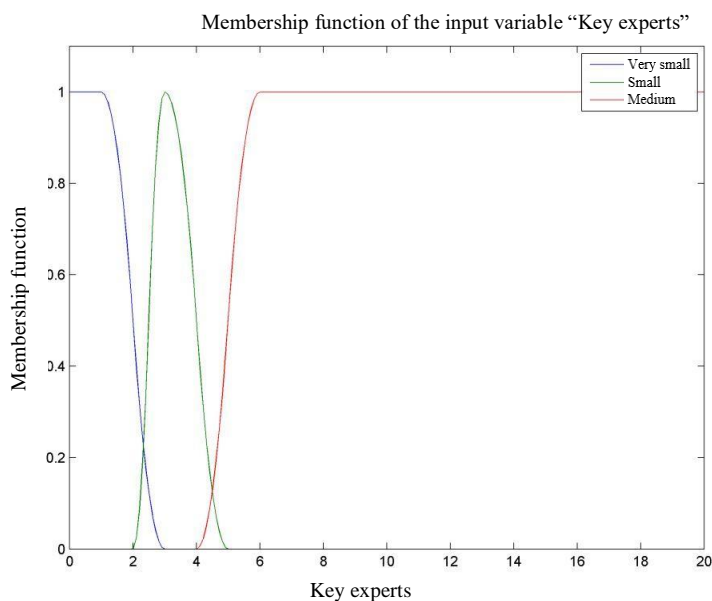**Figure 9.** Membership function of the input variable "Size of the structure".

Fuzzification of the Input Variable IV$_7$:
Experience of key experts (Figure 10**)**
TIV$_{71}$: little - "**Z**" function (a=1, b=3)
TIV$_{72}$: medium - "**π**" function (a=2, b=3, c=3, d=5)
TIV$_{73}$: great - "**S**" function (a=4, b=6)

Figure 10. Membership function of the input variable "Key experts".

3.4. Knowledge base

For the purpose of creating a knowledge base for this expert system, a survey was conducted on a large number of experts in the field of building construction. The survey consisted of a questionnaire with carefully selected questions on which experts gave answers based on their experience. On the basis of the information provided in the questionnaire, they expressed their opinion on whether they would hire or not the contractor to perform works on a particular structure. This experience has been summarized in rules and has become the rule base of the expert system. The rule base is the foundation of the inference mechanism.

As an example of one of the rules for selecting a contractor for a building project, the following rule is given:

If the contractor has little experience and if the price is very low and if the object is small, then the output variable OV is equal to one of the two possible output variables (the contractor fulfils / does not fulfil the conditions for constructing the given structure).

This rule may also be presented in the following way:

If:	IV_1 is TIV_{11} or TIV_{12}
and	IV_2 is TIV_{21} or TIV_{22}
and	IV_3 is TIV_{33}
and	IV_4 is TIV_{41}
and	IV_5 is TIV_{51}
and	IV_6 is TIV_{61} or TIV_{62}
and	IV_7 is TIV_{71}
then	OV is equal to Ovx

Membership functions μ_{ik} of the terms of input variables – TIV_{ik} are calculated and entered into the inference mechanism, which carries out standard operations of fuzzy mathematics with the application of the previously mentioned rule base.

3.5. Defuzzification

After the collected information has been processed, the membership function is obtained from the output variables. In order for the system user to have clear results by using the expert system, the obtained values of membership functions must be defuzzified into comprehensible output variables.

The defuzzification process results in adoption of the output variable OV_m, which is the variable with the highest value of the membership function.

3.6. Fuzzy expert system for selection of a contractor for construction of high rise buildings

Based on the collected experience of experts in the field of building construction, 40 linguistic rules, 7 input variables and 2 output variables have been defined. These rules, as well as the proposed functions for input data, fuzzification and the methods for defuzzification of the obtained membership functions of the output variables constitute the basis for creation of a computer program - expert system for helping the selection by investors of a contractor for construction of high rise buildings. This program has been written in the MATLAB software package.

Initially, the program requires entering the input data. The data that has to be entered is numeric in nature and the program user does not need any special programming knowledge. After entering the requested data, the program performs its fuzzification, and then, through the defined inference mechanism which uses the rule base, defines the values of the membership functions for the output variables. In the end, defuzzification is performed by proposing the output variable with the highest value of the membership function, as the most favourable solution.

Results of the calculation are obtained on the screen and can be printed. At the beginning of the list, the values of the input variables are provided. After that, a table with the proposed solution is obtained. In addition to the output variable, the degree of its membership function and the number of rule are also printed.

4. Results of the application of the proposed fuzzy expert system

During creation of the expert system, testing with different combinations of input data has been performed. During this process, some of the rules have been corrected.

Following are the results of four examples on which the proposed fuzzy expert system was tested.

Example 1:

For the contractor with the following characteristics:

- Price of the work performed - €350,000
- Financial situation of the contractor – €300,000
- Experience of the contractor on the construction of similar structures - 1 structure
- Ownership of machinery – €50,000
- Number of employees - 30
- Size of the structure - 800m²
- Key experts - 3

The expert system has recommended this contractor with a value of the membership function of 0.500 (rule 22).

Example 2:

For the contractor with the following characteristics:

- Price of the work performed - €390,000
- Financial situation of the contractor – €1,500,000
- Experience of the contractor in the construction of similar structures - 5 structures
- Ownership of machinery – €100,000
- Number of employees - 32
- Size of the structure – 2,600 m²
- Key experts - 7

The expert system has recommended this contractor with a value of the membership function of 0.0482 (rule 27).

Example 3:

For the contractor with the following characteristics:

- Price of the work performed - €100,000
- Financial situation of the contractor – €300,000
- Experience of the contractor in the construction of similar structures - 3 structures
- Ownership of machinery – €70,000
- Number of employees - 20
- Size of the structure – 500 m²
- Key experts - 2

The expert system has **not recommended** this contractor with a value of the membership function of 0.500 (rule 1).

Example 4:

For the contractor with the following characteristics:

- Price of the work performed - €30,000
- Financial situation of the contractor – €200,000
- Experience of the contractor in the construction of similar structures - 1 structure
- Ownership of machinery – €30,000
- Number of employees - 15
- Size of the structure – 100 m²
- Key experts - 2

The expert system has **not recommended** this contractor with a value of the membership function of 0.0800 (rule 1).

5. Conclusion

The process of deciding making on the selection of a contractor company is really complex. This fact was decisive for choosing to address the topic of the selection of the contractor in the field of construction of high rise buildings. The research has resulted in creation of an expert system - computer program. Investors and their consultants will significantly benefit from its use as well as anyone involved in the process of selecting contractors.

The fuzzy expert system presented in this paper is based on the application of fuzzy logic. The input variables of the presented system are the seven basic items of information related to the contractor and the structure that is being built: the price at which the contractor offers to perform the work, the financial situation of the contractor (annual turnover), contractor's experience in the construction of similar structures, the ownership of machinery (without the costs of transport), the number of employees, the size of the structure (floor area) and the number of key experts in the contractor's team. On the basis of the collected experience of the experts in the field of building construction, 40 fuzzy rules have been defined as well as two output variables which represent a recommendation either for the selection or for the rejection of a particular contractor. After entering the input data, the expert system performs its fuzzification. Values of the membership functions for the output variables are then calculated through the defined inference mechanism that uses the rule base. By the defuzzification process, the system proposes the output variable which has the highest value of the membership function. The output variable represents a recommendation of the fuzzy expert system on whether to engage the particular contractor or not.

It is generally acknowledged that the conditions under which a particular project is being implemented determine the suitability of each of the available contractors. One contractor might not be equally well suited for performing work on different types of projects and also, different contractors may perform projects with different sustainability depending on their specialization. This suggests that a professional approach to the selection of a contractor should be based on a prior detailed analysis of specific conditions in which the project is being implemented.

After a detailed analysis of the actual conditions of a construction project, the use of the proposed fuzzy expert system with analyses of the results obtained by the application of this system, it can be concluded that the fuzzy expert system may be used as valuable assistance tool when selecting the contractor for construction of high rise buildings. It is important to note that expert systems usually have an advisory role and that the final decision is made by the person in charge of and responsible for the selection of the contractor.

References

[1]   Fong P S W and Choi S K Y 2000 Final contractor selection using the analytical hierarchy process *Construction Management & Economics* **18(5)** pp 547–57

[2]   Bendaña R, del Caño A and de la Cruz M P 2008 Contractor selection: fuzzy-control approach *Canadian Journal of Civil Engineering* **35(5)** 473–86

[3]   Kolekar P B and Kanade G N 2014 Contractor selection in construction industry using fuzzy-logic system *Internation Journal of Engineering Research and Technology* (IJERT) 3(11) pp 1087–93

[4]   Hossein R, Ayoub H I, Abbas R 2010 Evaluation of construction contractors in developing countries using fuzzy SAW method *Proceedings of the International Conference on Computing in Civil and Building Engineering, University of Nottingham.*

[5]   Singh D and Robert L K T 2005 A Fuzzy Decision Framework for Contractor Selection. *Journal of Construction Engineering and Management* **131(1)** pp 62–70

[6]   Zadeh L 1965 Fuzzy sets *Information and Control* **8** pp 338–53

[7]   Zadeh L 1971 Similarity relations and fuzzy orderings *Information Sciences* **3** pp 177–200

[8]   Bellman R and Zadeh L 1970 Decision-Making in a Fuzzy Environment *Management*

Science **17(4)** pp B141-64

[9]   Prascevic Z 1989 Applying the theory of possibilities in project implementation planning Izgradnja, Belgrade

[10] Zimmermann H 1975 Description and optimization of fuzzy systems *International Journal of General Systems* **2(1)** pp 209-15

[11] Lazarevska M 2014 *Modeling the management of civil engineering projects through application of fuzzy-neural networks* (Podgorica: PhD thesis, University of Montenegro)

[12] Giarratano J and G Riley 1994 *Expert systems: Principles and Programming* (Boston: PWS Publishing Company)

[13] Ivanisevic N 2007 *Managing the process of selecting a contract strategy in construction using the theory of fuzzy sets* (Belgrade: PhD thesis, University of Belgrade)