THE USAGE OF FUZZY LOGIC IN DECISION – MAKING SYSTEMS

Ioan-Gheorghe RATIU*, **Claudia-Georgeta CARSTEA***, **Lucian PATRASCU***

*"George Baritiu" University, Brasov, Romania

***Abstract**: In the article the author presents the problem of choice of the concrete construction repair systems. As far as the material choice is concerned, fuzzy logic was used. The article's idea was to show the possibilities of the fuzzy logic, especially the possibilities of changing qualitative into quantitative data.*

Key-words: *decision making, fuzzy logic, artificial intelligence methods, repair systems of concrete constructions*

1. INTRODUCTION

The use of computer studies and artificial intelligence methods in construction is already well known and has been getting more and more common.

One could enumerate management information systems, decision support systems, expert systems as well as systems based on artificial neural networks and genetic algorithms. It would be quite difficult to dispense with any of the mentioned elements. The great quantity of information reaching the recipient, noise which can interfere with the transmission, and finally the necessity of selection of certain information, processing it and making decisions based upon it – all these factors require the development of systems which facilitate and support the difficult conclusion and decision making process [3].

What come to aid are some artificial intelligence methods [9, 10]. Feingenbaum describes artificial intelligence as: "the branch of computer studies which concerns the methods and techniques of symbolic conclusion-making via computers as well as the symbolic representation of knowledge used in such reasoning". Artificial intelligence methods are used to attempt to describe the reality in a way which imitates human reasoning.

There have been various efforts to overcome flaws of traditional computer algorithms, which often fail in situations easily solved by human beings. In AI programs, in contrast to traditional programs, we encounter symbolic processing, declarative data recording and significant data base usage. Unfortunately, there is a certain problem connected with formalization of qualitative phenomena.

Artificial intelligence methods [9, 10] are not able to cope with the natural lack of precision of natural world phenomena and objects. Fuzzy Logic is an extremely precious instrument which allows passing from qualitative to normative data. It also allows defining phenomena which are characterized by significant lack of definition precision. This lack of precision is usually called fuzziness [5].

2. FUZZY SETS

The fuzzy set notion, which the whole fuzzy logic is based on, was introduced by Lotfi A. Zadeh, Fuzzy Sets, „Informatics Control" in 1965 [6]. He defined the fuzzy set A as a pair:

$$\{X, \mu_A\} \tag{01}$$

where $\mu_A: X \to [0, 1]$ is a function, which defines for every element X to what extent it belongs to the set A. The function μA is called a set membership function and it takes values of [0, 1] range. The membership function is continuous in a given range.

If:

$$\mu_A(X) = 1 \quad (02)$$

we can talk about a complete membership:

$$\mu_A(X) = 0 \quad (03)$$

we can talk about a complete lack of membership.

It should be stressed that the membership function is extremely vital for the usage of fuzzy logic, as it is through the function that the fuzzy set is defined [8].

Both fuzzy and precise sets are subjects to classic set operations. The product, sum and complement are defined membership function operations. Except for classic fuzzy set operations there also exist some extremely vital modifiers, which change the fuzzy set shape. These modifiers are not based on mathematical theories. Each of these modifiers corresponds to a meaning, which is to transform the fuzzy set shape. One of the most common transformations is a fuzzy set concentration. It is supposed to intensify a modeled value. The opposite of concentration is fuzzy area extension. These two operations are associated with contrast modifiers, which change the fuzzy set shape and make it less (concentration) or more (extension) fuzzy. Modifiers of contrast intensification either increase or decrease the membership function values, depending on the membership degree of the elements which belong to the set. Another group of modifiers consists of limitations to the fuzzy areas, which are connected with defining the order in the set of all the fuzzy subsets of the given area. As it had already been mentioned, fuzzy logic is a perfect instrument able to describe phenomena and elements characterized by small definition precision [7, 8]. It is extremely useful as far as various tests, the results of which are descriptive, or fuzzy are concerned (e.g. questionnaires). It also supports other tests. As an instrument as such, fuzzy logic is widely used in systems supporting the decision-making process.

3. RATING OF OPTIONS – MATERIAL SELECTION (A USAGE EXAMPLE)

It has been repeatedly shown in practice that it is necessary to be supported by decision-making systems. Current economic conditions make it even more essential for decision-makers to comply with rationality rules and perform well-thought-out actions. Nevertheless, there are many obstacles and difficulties which may hinder the process of working – out of a system which supports the decision-making process. One of such obstacles may be the lack of precision in phenomena and environment description. In this article the author presents the possibility to use fuzzy logic when it comes to rating various options while choosing the repair system of concrete constructions [4]. On the basis of the carried out research [1], and using the possibilities that fuzzy reasoning offers, an attempt to create a system which assists decision-making in the construction industry has been made.

Situations will be looked upon from the potential decision-contractor's point of view – he is choosing the repair material among a few available. In the analyzed case, the author is going to present the client's point of view. It is quite significant as, depending on the decision-maker's character, there are various preferences and limitations, as well as criteria importance.

To solve the problem we will use the multicriteria approach, which consists in isolating some essential attributes. Using these attributes, we will assess the tested materials and then we will define relative attractiveness. There is also another useful tool – an element of the expert system, such as the rule base, which will serve to illustrate the preferences and possible limitations of decision-makers. The first phase is the identification of attribute, which are used in the usage of repair system assessment.

These attributes may be obtained on the basis of an experienced, objective and independent expert's specifications. In our case we can accept the following criteria: material type (MT), bending durability (BD), adhesion (A), processing time (PT), and delivery conditions (DC).

The presented criteria do not have to constitute a complete evaluation criteria set, some of them were deliberately omitted so as not to complicate the system as such. The aim of this article is decision-making process in the construction industry. The next phase consists of dividing the area of considered values. The typical way to do so is to evenly divide the area, which means to divide it into a specific number of fuzzy sets of identical width. Uneven area division of variable value is also possible.

In this way membership functions in connection with original terms are created. Typical membership functions are triangle - or gauss – shaped.

The first thing to consider is the material type MT. The area was divided into three primary terms: A – spatula mortar, B – fine – grained mortar, C – coarse – grained mortar. Each of these terms corresponds to the value of the variable MT, which was defined in millimeters of aggregate grain thickness in the mortar.

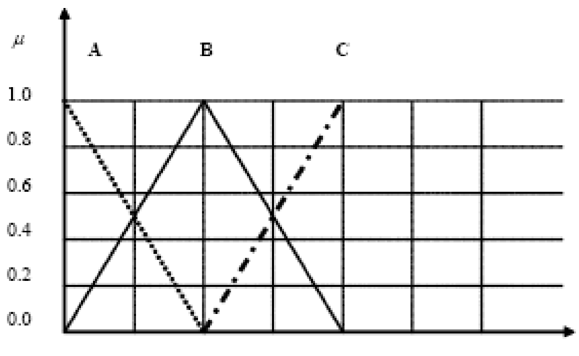

Fig. 1 Values of the variable MT

The next variable is the bending durability. Durability is a measurable value and it can be precisely defined. Still, also in this case the division of the value area had already been done, which served to separate 3 primary terms connected with the value of the variable BD: A – low durability, B – medium durability, C – high durability. The same was done as far as adhesion A is concerned. The only things changed were the ranges of the variable A, which was marked with a different font.

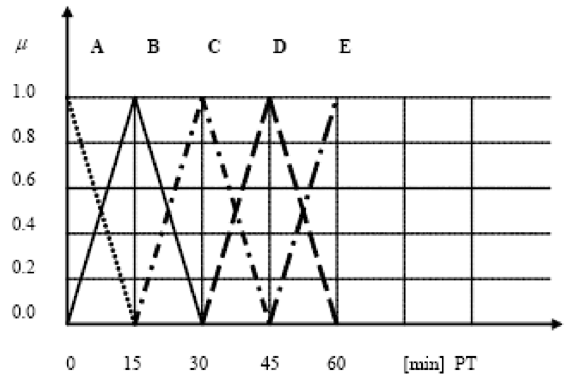

Fig. 3 Values of the variable PT

In case of the last variable, delivery conditions DC, values will be more symbolical than numeral in their nature. Variable DC is a qualitative variable and it describes the material distributor's ability to cater for the decision-maker's (or potential material receiver's) needs and requirements. As the area of the considered objects for fuzzy values abstract area of [0, 1] range was taken. The variable DC includes such components as delivery on time, waiting time, transport abilities of the distributor, etc. The variable DC will take the three following values: A – not very attractive, B – average, C – attractive (Fig. 4).

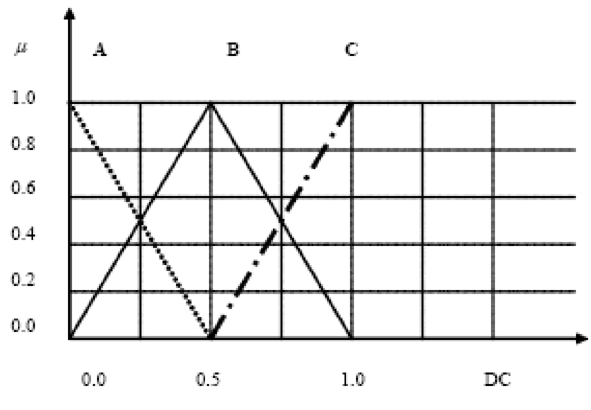

Fig. 4 Values of the variable DC

The knowledge necessary to build the system should be obtained on the basis of needs analysis as well as decision- makers' expectations and preferences pertaining to the materials.

In this case, we can assume that the following pieces of information were obtained:

1. Spatula mortar is unacceptable, otherwise it does not matter what kind of material is used.
2. The ideal mortar should have high bending durability and high adhesion as well as long processing time.
3. If the mortar's bending durability is medium it must be characterized by at least average adhesion, long processing time and attractive delivery conditions in order to be attractive for the decision – maker.
4. Unattractive delivery conditions, in spite of high durability, adhesion and very long processing time make the material unattractive for the decision maker.
5. Low durability or adhesion makes the material unattractive for the decision maker.
6. The longer the processing time is, the more attractive the material gets, as long as the durability and adhesion are at least average.

The presented opinions, which include the decision – maker's preferences and limitations, are subjective in their nature, while the described evaluation criteria are treated as having the character of importance. The evaluation criteria equivalence has originally been assumed, still in some conditions the criteria importance may adopt extreme values of the < 0, 1 > range.

For statement 1, in case of spatula mortar the criterion importance RM = 1, while in other cases (coarse-grained and fine-grained mortar) criterion importance RM = 0, which practically means the possibility of omitting this criterion. Still, at this stage, for the sake of reasoning clarity, the criteria equivalence was suggested.

On the basis of these statements, it is possible to construct an uncomplicated knowledge base, which is a set of rules for the decision-making system in process.

On the basis of rules number 2 and 4 we can conclude that:

IF:

− MT is not a spatula mortar
− BD is high
− A is high
− PT is very long
− DC is attractive

THEN material attractiveness is very high.

This rule describes the best situation from the decision-maker's point of view. It is enough for the DC to be unattractive and the whole material attractiveness will be very low. It can be shown in the following way:

IF:

− MT is not a spatula mortar
− BD is high
− A is high
− PT is very long
− DC is not attractive

THEN the material attractiveness is very low.

Acting this way we can create the model framework. Next rules are created by filling out the gaps between the knowledge base points.

5 material variants were analyzed and rated. They were described as follows:

ABM:

− MT – 1 / coarse-grained mortar
− BD – 1 / high
− A – 1 / high
− PT – 1 / long
− DC – 1 / average

AFS

− MT – 1 / spatula mortar
− BD – 8 MPa
− A – 1 / medium
− PT – 1 / long
− DC – 1 / average

SKM

− MT – the maximum grayness of 4 mm
− BD – 10 MPa
− A – medium
− PT – 0.6 / long + 0.4/very long
− DC – 0.5 / attractive + 0.5/average

SFM

− MT – 1/fine-grained mortar
− BD – high, although not very high
− A – 5 MPa
− PT – 45 minutes
− DC – attractive

SFF

− MT – 1 / spatula mortar
− BD – 7 MPa
− A – 3.5 MPa
− PT – 1 / long
− DC – 1 / average

Table 1 Knowledge base rules (part)

	MT	BD	A	PT	DC	Attractiveness
1	coarse-grained	high	high	very long	attractive	very high
2	fine-grained	high	high	very long	attractive	very high
3	spatula	high	high	very long	attractive	very low
4	coarse-grained	high	high	very long	average	high
5	coarse-grained	high	high	very long	unattractive	very low
6	coarse-grained	high	high	long	attractive	very high
7	coarse-grained	high	high	long	average	high
8	coarse-grained	high	high	medium	average	average
9	coarse-grained	high	medium	medium	average	average
10	coarse-grained	medium	medium	medium	average	average
11	coarse-grained	medium	medium	short	average	low
12	coarse-grained	medium	low	short	average	very low
13	coarse-grained	low	medium	short	average	very low
14	coarse-grained	low	low	short	average	very low
15	coarse-grained	high	medium	long	average	average
16	spatula	high	medium	long	average	very low
17	spatula	medium	medium	long	average	very low
18	coarse-grained	high	medium	very long	average	high
19	coarse-grained	high	medium	long	attractive	high
20	coarse-grained	high	medium	very long	attractive	very high

As it can be seen here, the values of input variables can be given in various ways and thanks to the usage of fuzzy system it is possible to standardize them. Even the BD and A values, when given in number, can be (and usually are) the referential in their nature, although one can expect precise values in this case. After the definition of the input values as well as the division of the variable area and determination of the membership function, it is possible to move to the conclusion phase. In case of our example, which is based on the expert system using the fuzzy logic, all the rules of the knowledge base are activated. For every rule one determines the degree of the predecessor's authenticity on the basis of the degree of individual entrances to the rule conditions adjustment. If one goes further, on the basis of the correlation of the predecessor with the follower, a fuzzy set, which is the result of the rule operation, is found. The results are finally consolidated into one initial set. In our case the minimal operations will be used to realize the conjunction of meeting the conditions in the rule, then the minimal correlation of the follower with the predecessor and the maximal operation for the integration of rule operating.

At the rules activation stage, the author proposes to take the criteria importance into consideration. It was impossible earlier for the sake of data qualitative character. The author suggests, while using the importance of the < 0, 1 > range, to increase or decrease the function membership degree for each of the criteria, using the product in the process. It has to be remembered, though, that the maximum value of membership function is 1.0. In the example, the evaluation criteria equivalence was assumed.

For ABM we check the rule number 1. If:

MT is coarse-grained and – membership in the 1 degree
BD is high and – membership in the 1 degree
A is high and – membership in the 1 degree
PT is very long and – membership in the 0 degree
DC is attractive – membership in the 0 degree
THEN ATTRACTIVENESS is very high.

As it is visible, the degree of authenticity of the predecessor of rule number 1 is:

$$\tau_1 = \min(1/1/1/0/0) = 0 \quad (04)$$

If one then calculates the resulting fuzzy set for rule number 1, we have:

$$\mu_{B1}(x) = \min(\mu_{veryhigh}(x), 0) = 0 \quad (05)$$

The result of the rule number 1 activation is an empty set, where the membership function is constantly 0.

Rule number 7 activation gives us a result distinct from 0. If:
MT is coarse-grained and – membership in the 1 degree
BD is high and – membership in the 1 degree
A is high and – membership in the 1 degree
PT is long and – membership in the 1 degree
DC is average – membership in the 1 degree
THEN ATTRACTIVENESS is high.

$$\tau_7 = \min(1/1/1/1/1) = 1.0 \quad (06)$$

If one uses the maximal operation for the integration of the rule operation, then we have:

$$\mu_B(x) = \max(\mu_{B1}(x),...\mu_{Bn}(x)) = \mu_{B7}(x) = \mu_{high}(x) \quad (07)$$

If one analyzes another AFS variant, it is possible to conclude that MT is a spatula mortar. On the basis of several statements, a knowledge base was worked out. One of these statements was as following: "spatula mortar is unacceptable..."

On the basis of this statement, a series of rules had been built. Nevertheless, activation of these rules and meeting their conditions by AFS causes the following: the result of the concluding is a fuzzy set ATTRACTIVENESS very low. One can prove it by activating rules number 16 and 17. Taking it into consideration, the SFF variant was consistently omitted. If one looks at the next part of the previously quoted statement, it is possible to omit the material type MT in further consideration, as "...it does not matter what kind of material is used."

Another analyzed variant is SKM. If one looks at the way the variables are defined, it is possible to say that they are defined in a different way. One should pay attention especially to the PT and DC variables, which are defined by fuzzy sets, e.g. for PT 0.6 / long + 0.4 / v. long. In practice it turns out that for SKM variant, on the basis of PT and DC definition, at least 4 rules' results will differ from 0. It should also be remembered that in further analysis the MT variable was omitted, as it had been already been justified.

Therefore:
Rule number 15
If:
BD is high and – membership in the 1 degree;
A is medium and – membership in the 1 degree;
PT is long and – membership in the 0.6 degree;
DC is average – membership in the 0.5 degree;
THEN ATTRACTIVENESS is average.

$$\tau_{15} = \min(1/1/1/0.6/0.5) = 0.5 \quad (08)$$

$$\mu_{B15}(x) = \min(\mu_{average}(x)/1.0) = 0.5 \quad (09)$$

Rule number 18
If:
BD is high and – membership in the 1 degree
A is medium and – membership in the 1 degree
PT is very long and – membership in the 0.4 degree
DC is average – membership in the 0.5 degree
THEN ATTRACTIVENESS is high.

$$\tau_{18} = \min(1/1/1/0.6/0.5) = 0.5 \quad (10)$$

$$\mu_{B18}(x) = \min(\mu_{high}(x)/1.0) = 0.5 \quad (11)$$

Rule number 19
If:
BD is high and – membership in the 1 degree
A is medium and – membership in the 1 degree
PT is long and – membership in the 0.6 degree
DC is attractive – membership in the 0.5 degree
THEN ATTRACTIVENESS is high.

$$\tau_{19} = \min(1/1/1/0.6/0.5) = 0.5 \quad (12)$$

$$\mu_{B19}(x) = \min(\mu_{high}(x)/1.0) = 0.5 \quad (13)$$

Rule number 20
If:
BD is high and – membership in the 1 degree

A is medium and – membership in the 1 degree
PT is very long and – membership in the 0.4 degree
DC is attractive – membership in the 0.5 degree
THEN ATTRACTIVENESS is very high.

$$\tau_{20} = \min(1/1/1/0.4/0.5) = 0.4 \quad (14)$$

$$\mu_{B20}(x) = \min(\mu_{veryhigh}(x)/1.0) = 0.4 \quad (15)$$

Similarly as in the earlier case of using the maximal operation, we consolidate first the results of operations 18 and 15 and we get the 0.5/high set.

When we finally consolidate the results of all the rules' operations we get for SKM a result which is the following = 0.5 / medium + 0.5 / high + 0.4 / very high.

The final of the analyzed variants if SFM, are which is one of the fine-grained mortars. This information allows us not to discard this variant and to analyze it further. The next considered criterion (after MT) is BD. In case of SFM it is defined rather not in a standard and precise way. BD is defined as *high* but not *very high*. According to the fuzzy sets' properties, the function word *very* can be expressed by the square function.

$$\mu_{veryhigh}(x) = \mu^2_{hifh}(x) \quad (16)$$

and if we further use the complement of the fuzzy set we get:

$$\mu_{not\_veryhigh}(x) = 1 - \mu^2_{hifh}(x) \quad (17)$$

According to this, the BD variable value is a product of two fuzzy sets: high set and not very high set. While using the minimal operator as a product, we get:

$$\mu_{high\_but\_not\_very\_high}(x) = = \min\left(\mu_{high}(x), 1 - \mu^2_{high}(x)\right) \quad (18)$$

While performing the operation we get the resulting set:

BD = 0.5 / medium +0.65/high

For the next criteria:

A = 0.5 / medium + 0.5/high (the values taken from the A membership function graph for 5 MPa value)

PT = 1 / long (the value taken from the PT membership function graph for 45 minutes value)

DC = 1 / attractive

For such defined SFM variant, one should activate the following rules that will give the result differing from 0: 6, 24, 29, and 31. After activating them, we consolidate the rule operations by using (as in earlier cases) the maximal operation.

$$\mu_B(x) = \max\left(\mu_{B1}(x), \ldots \mu_{Bn}(x)\right) = = \mu_{B24/29/31}(x) = \mu_{high}(x) \quad (19)$$

$$\mu_B(x) = \max\left(\mu_{B1}(x), \ldots \mu_{Bn}(x)\right) = = \mu_{B6}(x) = \mu_{veryhigh}(x) \quad (20)$$

Finally the resulting set for the SFM variant is as the following:

ATTRACTIVENESS = 0.5/high + 0.5/very high

4. CONCLUSION

The final resulting sets for individual variants could be shown as following:

Variant	**ATTRACTIVENESS**
ABM	1.0 / high
AFS	0.0 (spatula mortar)
SKM	0.5 / medium + 0.5/high + 0.4/very high
SFM	0.5 / high + 0.5/very high
SFF	0.0 (spatula mortar)

As it can be seen from the above, the results are not unambiguous. They classify individual variants into one or several attractiveness groups and it happens in different degrees.

The advantage of the fuzzy set is a possibility to go from the symbolic to numeric form of information – the resulting sets. In the discussed case the fuzzy sets are given in the tabled form, which allows one to use the centroid formula.

The formula comes from the defuzzycation method, which means making the results more precise – COA (Center of Area) method.

The method consists in finding the gravity center of the fuzzy set.

$$\bar{x} = \frac{\sum_i x\mu(x_i)}{\sum_i \mu(x_i)} \quad (21)$$

Using the given formula we get the following results:
ABM (1.0 / high) = 0.750
AFS = 0.0
SFM = 0.0
SFM (0.5 / high + 0.5 / very high) = 0.875 (1)
SKM (0.5 / medium + 0.5 / high + 0.4 / very high) = 0.866 (2)

The obtained results in numeric form suggest the already defined attractiveness of individual variants. One should remember that the results are affected by the limitations introduced by the decision-makers as well as their preferences.

The goal of the article was to show the mechanism of operating on fuzzy sets, their potential abilities, without going into much detail concerning the decision- making system, where fuzzy sets are used. One can unambiguously state that fuzzy logic:

− is a very good instrument useful to define various phenomena
− allows to describe not very precise and qualitative values and get quantitative values based on them
− can cooperate with various systems supporting the decision-making process
− is used while solving different problems (rating, forecasting, modelling).

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