Fuzzy Logic: Basic and applicability in Oil and Gas Industry

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Abstract: In article questions connected with applicability of fuzzy logic in such applied area, as oil and gas branch are considered. The main concepts, the principles and the provision of fuzzy logic with use as an example of applied area of research are given. Also article contains examples of application of fuzzy logic in oil and gas branch of a national economy.

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1. Introduction

Fuzzy logic as a branch of mathematical science was first formulated by L. Zade [1] in 1965 when he published his works on this topic.

Initially fuzzy logic was considered a sort of unscientific theory. Only after the boost in applied fuzzy systems in Japan [2-5], developers on both sides of Atlantics started to pay attention to this theory. It was the beginning of international recognition and development of fuzzy logic and its applications.

1.1.Main concepts and mathematical foundation

Fuzzy set C is a set of ordered pairs of the form $\mathbf{C=\{MF_c(x)/x\},MF_c(x)[0,1]\}}$, where $MF_c(x)$ is a grade of membership to fuzzy set C. If $MF_c(x)=0$ a pair is not a member of the set, if $MF_c(x)=1$ it is full member of the set.

Main logic operations are defined for fuzzy sets as for ordinary sets. Main operations necessary for calculations are intersection and aggregation.
Intersection of two fuzzy sets (fuzzy "and"):

A B: $MF_{AB}(x) = min(MF_A(x), MF_B(x))$.
Aggregation of two fuzzy sets (fuzzy "or"):

A B: $MF_{AB}(x) = max (MF_A(x), MF_B(x))$.

General approach to execution of intersection, aggregation and addition operators has been developed in fuzzy logic. It is realized by means of so called triangular norms and co-norms. Abovementioned realizations of intersection and aggregation operations are the most frequents cases of t-norm and t-co-norm.

Concepts of fuzzy and linguistic variables are introduced to describe fuzzy sets.

Fuzzy variable is defined by a set (N,X,A), where N is the name of variable, X is the universal set (universe of discourse), A is the fuzzy set on X.

Linguistic variable may have fuzzy variables as values, i.e. linguistic variable is on the higher level than fuzzy variable. Each linguistic variable consists of:

- name;
- set of its values, that is also called basic term-set T. Elements of basic term-set T are the names of fuzzy variables;
- universal set X;
- syntactical rule G, used to generate new terms from the words of natural or formal language;
- semantic rule P, that is used to match each value of linguistic variable to fuzzy subset of X set.

Let us consider such fuzzy concept as "Pumping speed". It is the name of linguistic variable. Basic term-set formulated for it consists of three fuzzy variables: "Low", "Medium", "High" and set the universe of discourse as X=[100;200] (units). What is left is to formulate membership functions for each linguistic term of basic term-set T.

There are more than dozen typical curve forms for formulation of membership function. The most widely used are: triangle, trapezoid and Gaussian membership functions.

Triangular membership function is defined by three numbers (a,b,c) and its value in x point is calculated as:

$$MF(x) = \begin{cases} 1 - \dfrac{b-x}{b-a}, a \le x \le b \\ 1 - \dfrac{x-b}{c-b}, b \le x \le c \\ 0, in\ other\ cases \end{cases}$$

(b-a)=(c-b) defines the case of symmetrical triangular membership function that may be explicitly defined by two parameters from the (a,b,c).

Similarly to define trapezoid membership function the four numbers are required (a,b,c,d):

$$MF(x) = \begin{cases} 1 - \frac{b-x}{b-a}, a \le x \le b \\ 1, b \le x \le c \\ 1 - \frac{x-c}{d-c}, c \le x \le d \\ 0, in\ other\ cases \end{cases}$$

(b-a)=(d-c) defines symmetric type of membership function.

Gaussian membership function is defined by the formula

$$MF(x) = exp\left[-\left(\frac{x-c}{\sigma}\right)^2\right]$$

and operates with two parameters. Parameter c is the center of fuzzy set and parameter *** defines steepness of the function.

Aggregate of membership functions for each term from basic term-set T is usually plotted on the same diagram. Figure 1 shows an example of defined linguistic variable "Pumping speed".

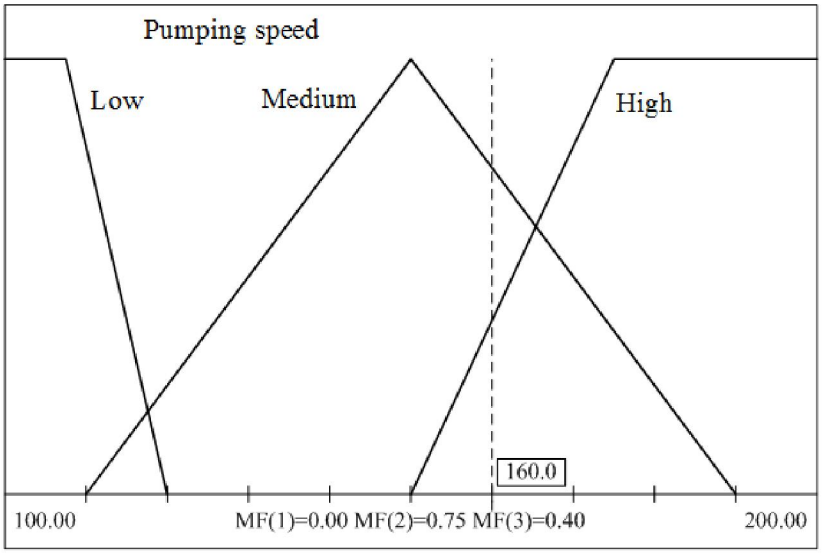

Fig. 1. Definition of linguistic variable "Pumping speed".

Number of terms in linguistic variable is rarely greater than 7.

Pumping speed Low Medium High

Fuzzy logical deduction

Rule base containing fuzzy statements in the form "if-than" and membership functions for relevant linguistic terms is the base for execution of fuzzy logical deduction operation. The following requirements should be met:

1. There is at least one rule for each linguistic term of output variable.
2. For each term of output variable there is at least one rule in which this term is used as prerequisite (left part of a rule).

Otherwise there is incomplete base of fuzzy rules.

Consider the base with m rules of the form:

R_1: IF x_1 is A_{11} … AND … x_n is A_{1n}, THAN y is B_1

…

R_i: IF x_1 is A_{i1} … AND … x_n is A_{in}, THAN y is B_i

…

R_m: IF x_1 is A_{i1} … AND … x_n is A_{mn}, THAN y is B_m,

where x_k, k=1…n are output variables; y is output variable; A_{ik} are set fuzzy sets with membership functions.

The result of fuzzy deduction is explicit value of variable y^* on the base of set explicit values x_k , k=1…n.

The mechanism of logical deduction generally consists of four steps: introduction of fuzziness (fuzzification), fuzzy deduction, composition and reduction of definition, or defuzzification.

Fuzzy deduction algorithms differ mainly by the form of used rules, logical operations and a variant of defuzzification method. There have been developed Mamdani, Sugeno, Larsen, Tsukamoto fuzzy deduction models.

1.2. Fuzzy logic application practice

Principles and statements of fuzzy logic are used in several aspects of oil and gas industry.

One of them is the problem of safety provisioning and accident prevention in oil and gas industry. Major part of the objects in the industry relating to both core and auxiliary and supporting production may be considered as "dangerous industrial objects". Development and constant actualization of the methods of revealing and definition of the sources of threat as well as conditions of their manifestation in exploitation of these objects have great if not critical importance. As one of the main factors that affect accidents is human element it is necessary to apply statements and deductions of fuzzy logic as the base of this methodology. It is proved by the fact that capability of the staff to make adequate decisions in extreme situations and act with necessary extent of adequacy their qualification is difficult to evaluate by traditional methods. It makes application of fuzzy logic reasonable [6].

It is also worth mentioning that solving this problem becomes more actual because more that 80% of all objects are already beyond the time of well.

One of the examples of applicability of fuzzy logic concepts is scientific and practical project [7], related to the problems of strategic modeling of sea oil and gas hybrid company (SO&GHC) on the base of Balanced Scorecard (BSC) with fuzzy logical interconnections between key productivity indicators (KPI) and indicators of financial and economic activity (IFEA). This system differs from the system of Нортона-Каплана is that proposed system consists of feedback outlines (loops in graph) that are responsible for reproduction of the company by levels of its own capital, assets and existing context of relationships of SO&GHC with key stockholders of the company.

Importance of the theme of this development is explained by the fact that founding of SO&GHC with the state having controlling interest and that are functioning as state-private partners became more and more actual in condition of increase of production capacity of hydrocarbon raw materials on sea shelf of Russian Federation, as well as industrial development of sea deposits of Kazakhstan sector of Caspian shelf. Managing exploration and mining operations via such companies the state can provide protection of its strategic interests on the shelf, design and implement large-scale programs of sea deposits development accounting complex development of hydrocarbon deposits included in the process of exploration and mining.

One more example of application of fuzzy logic is design automation [8]. It is caused by the fact that productivity growth rate falls behind the industry demands. And as a result design works are often delayed under favorable external conditions. The main reason is out of date organization of design works. This problem may be solved by complex system of design process automation. Automation of organizational management of design is complex task and consists of structural reorganization, replacement of design work technology, research of knowledge management methods and solving of specific for such systems tasks of information security. Solving of this problem is impossible without fuzzy logic apparatus.

It is also worth mentioning that outsourcing of a number of services and founding of individual companies of affiliated with oil and gas companies businesses is today trend of services market [9]. So planning and realization of scientifically grounded effective marketing activities for search of possible partners for product realization, executing a certain tasks and provisioning of services is actual problem of service companies of oil and gas industry.

Still one of the most difficult tasks of marketing management is the choice and using of strategy that is changing in response to changes of business environment. One of the tasks is to select and set values of marketing activity indicators in undefined information. Marketing tasks are unformalized problems with solving procedures that are impossible to define by mathematical and statistical methods.

To sum up with it is necessary to mention that speaking about industrial deployment of systems based on fuzzy logic one should mention also primeval both Russian and Kazakhstan problem that is the lack of qualified specialists [10]. Still the situation started to improve [11].

2. Resume

Fuzzy logic and the results of laws and dependencies defined by it are gradually adapted by oil and gas industry and are being applied wider and wider in the first place in strategic planning, risk management and management of safety provisioning and preventing technogenetics cataclysms on the objects if industry.

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