

# Fuzzy sets on step of planning of experiment for organization and management of construction processes

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**Abstract.** In this article, problems of mathematical modeling and experiment planning of the organization and management of construction. The authors designated the basic restrictions and the difficulties in this field. Concluded that the planning of research experiment is possible in the information sphere with using of heuristic, graphical, mathematical models, as well as neural networks and genetic algorithms. The authors note the need for use of expert information in the case of the formalization of quality parameters. The article presented an overview of the translation methods of qualitative information into mathematical language. Comparison of methods the qualimetry of USSR scientists, the analytic hierarchy process and fuzzy set theory were performed. The benefits of the latter for interpretation of qualitative parameters were identified. The authors have given many examples of application fuzzy sets for formalization of organizational factors of construction processes. Finally, there conclusion was made about progressiveness and effectiveness of fuzzy set theory to describe the qualitative parameters of organization and management of construction.

## 1 Introduction

The development of construction which involves improving the basic criteria of its evaluation such as efficiency, quality, safety, reliability, durability, maintainability, is directly related to the perfection of scientific provision of its composing processes. The formalization of the real processes of the actuality with the assistance of variety of modeling means allows you to move them out of the area of the subjective perception of the human mind into a public area of the objective knowledge. Currently, there is a wide variety of modeling methods [1, 2, 3, 4, 5], a common feature of the most of them is usage of a mathematical approach that allows to implement input, processing and output of information. The degree of coincidence of the predicted results with the actual and the effectiveness of management based on modeled data depends on the measure of adequacy of the model. In this regard, the most important issue for the scientific presentation of construction processes modeling is search of the method, which more comprehensively reflects them with the help of mathematical formalization.

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To describe the construction processes through the formation of empirical relationships, refinement of mathematical models, and searching of the optimal conditions, usually scientists use statistical data analysis of the experiments. The main mathematical tools are the methods of the factorial, regression and variance analysis. These approaches are widely used in the scientific study of building materials [6], structures [7] and of various stages of building design [8]. The presence of a large database of theoretical and practical use of these methods and a high degree of reliability contributed to their widespread application. The processes to which factor and regression analysis are applicable, allow:

- carrying out multiple experiments under specified conditions;
- availability of the statistical database about the object of research;
- registration of the numerical results of parameter measurements constituting a statistical sample, the analysis of which leads to the determination of the sought regularities.

## **2 Determination of experiment conditions**

Construction operation includes a large number of processes and phenomena that could be radically different regarding a set of control parameters and the complexity of their functioning. For example, researching of the compressive strength of concrete [9] and modeling of organizational and technological processes of erection of building structures [10] describe the elements of having different formalized models.

For the study of the first object, researcher himself can create and control external and internal factors and fix them definite numerical values by various instruments. In the end, he gets a statistical sample of values for system parameters, between which the relationship must be installed basing on the chosen criterion.

In the second case the studied system is much more complex, it has more factors and parameters with the implicit nature of the bonds. The life cycle of such process is different by large expenditure of time, material and human resources. As part of the experiment, it is hard to simulate it in artificial controlled conditions, and given the fact that we are using the exponential dependence between the number of required experiments and the number of study parameters for achievement of the statistical significance, it sometimes becomes absurd. Reproduction of this process in the laboratory conditions will not allow to create an adequate model, according to the system theory. The investigated construction process is one element in the system complex of construction of the building, and therefore, by law of the integrity of the system, it will change part of properties when coming out of it. To receive the correct model, the target process should be studied in conditions of the real construction site. At the present time, in a market economy, the access of researchers to the construction site is restricted. The possibility to conduct field experiments for determination of the organizational factors of construction processes, guided only by the purposes and problems of carrying out a scientific experiment depends on the desire of the investor or the project manager, and it is usually absent. Therefore it is virtually impossible to recruit the necessary number of actual construction objects to generate the model of research.

On the basis of the above, in case the scientific interpretation of the processes of organization and management of construction, the planning of research experiment is possible only in the information sphere with using of heuristic, [2] graphical [3] and mathematical models [11], as well as neural networks [4] and genetic algorithms [5]. The development and formation of the models under consideration is based on the application of expert estimate methods. Its center inevitably is a professionally trained specialist, an expert in the investigated area. His experience forms the basis of statistical data, the equivalent of the number of experiments. Using this method the researcher may invite the required number of experts to participate in the research whose wide construction

experience will allow to satisfy the requirement of statistical reliability of the received results.

### 3 Methods of measurement of qualitative parameters

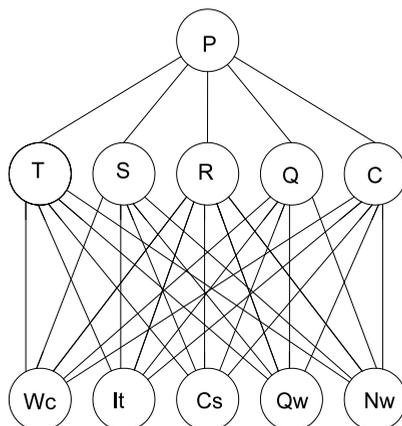
The next step after determining the conditions of the experiment is the determination of the input and output parameters of the investigated system and methods of their measurement. These parameters can be divided into two groups, viz. quantitative (number of workers - Nw, time - T, coast - C etc.) and qualitative (quality - Q, safety - S, resource conservation - R, construction supervision - Cs, information technology - It, weather conditions - Wc, qualification of workers - Qw, etc.) Approaches to measuring and processing of quantitative indicators are well studied, working on their formalization a researcher works with mathematical figures, i.e. on the accessible language for model.

Qualitative parameters traditionally represent a class of factors that are difficult to integrate into mathematical models, as they are the prerogative of the human - expert perception of the world. The application of the stochastic noise or multifactor analysis of variance proposed by R. Fisher in the first half of the 20th century give a partial unilateral solution of the problem. For a more extensive analysis of the qualitative properties of the object, the researchers somehow turn to the help of an expert from investigated area. His consciousness is a mechanism of output information on qualitative parameters of the system, the equivalent of a measuring instrument. But scale of measurement of technical devices is not characteristic of the human mind. A man evaluates any event more complex, due to the its perception of the world through the senses, and the further formation of the output in the form of concepts, images, conclusions. In this regard, the main problem of integration of qualitative parameters in the mathematical models is a translation of the information by human perception into the strict language of mathematical symbols.

In 1968, USSR scientists introduced the term “qualimetry” [12], implying a methodology for quality assessment in various fields of human activity. Approach of formalizing these systems consisted in creating a “tree of properties” of the research object (Fig. 1) with further comparison of its components with each other or with a sample. At that, the rank classification of parameters or conditional measure of their compliance with the basic pattern was used. With the help of qualimetry it is possible to successfully determine the best object out of a certain series, its place relative to the etalon, as well as a comprehensive indicator of the quality (P) through the weighted function of properties.

**Table 1.** Matrix of comparison of the parameters on the criterion “Safety”.

	<b>Wc</b>	<b>Cs</b>	<b>Nw</b>	<b>Qw</b>	<b>It</b>
<b>Wc</b>	1	1/8	6	1/7	1/3
<b>Cs</b>	8	1	9	3	6
<b>Nw</b>	1/6	1/9	1	1/8	1/7
<b>Qw</b>	7	1/3	8	1	4
<b>It</b>	3	1/6	7	1/4	1



**Fig. 1.** “Tree of properties” (up-down).

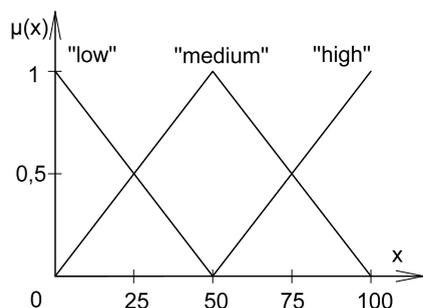
In the 70s of the last century, American scientist T. Saaty explored the decision-making methods and suggested searching of the most faithful alternative through their pair-wise comparison by several criteria. The analytic hierarchy process is more simple and accurate tool in the field of expert information because a comparison of the two objects only simplifies the decision and increases the reliability of the assessment. When comparing pairs of objects that have a variety of quantitative and qualitative characteristics, the expert associates in his mind the images, enabling him to make more practical and actual conclusions. The comparison results are integrated into the matrix (Table 1.), the main eigenvector of the matrix after normalization becomes a vector of the desired priorities on the selected criteria [13]. The complex of simple mathematical apparatus and reliable transfer of intuitive expert information into it made this approach widely used in the practice of management decision-making at present, as well as in determining the weight coefficients of parameters of investigated system.

In 1965, L. Zadeh began the development of fuzzy set theory [14] the most efficient solution for the analysis of qualitative parameters from the point of view of the authors. The term linguistic variable [15] contains a fundamental property of qualitative factors to determine their value is primarily a function of the human mind, which it transforms into information through language. Levels of varying the parameter are determined by "granules" of human language or by the terms: “low”, “medium”, “high” or “poor”, “satisfactorily”, “good”, “excellent” etc. Names of the terms reflects images of the qualitative parameter arising in the mind of the expert, the number of terms depends on detalization of the evaluation.

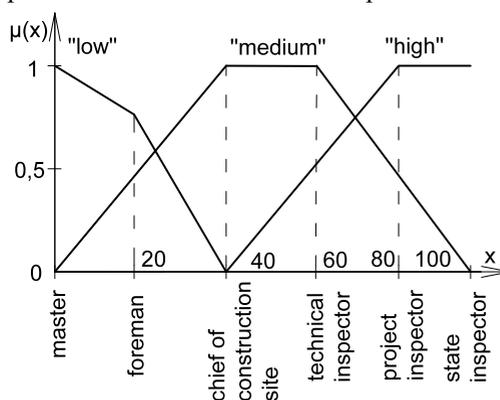
Qualimetry offers translation of these terms into mathematical language by using rank scale: maximal term is assigned to “1”, and the rest of terms are assigned to values from the interval [0, 1], for example, “low” is “0”, “medium” is “0.5”, “above average” is “0.75”. This transition is single-valued and strict which leads to the inevitable loss of information when assessing the qualitative factors. The fuzzy set theory represents a term not by one number, but by set with the grade of membership of all values to term through membership function.

On figure 1 the linguistic variable “qualification of workers” of the organization parameter of the construction process was graphically presented. This linguistic variable is divided into three terms: “low”, “medium” and “high”, which accept values from 0 to 100. The range of values for the linguistic variable is the quantity of terms, the range of values for a specific term is a fuzzy set, a region of space, which is formed in accordance with the membership function  $\mu(x)$ . The membership function defines the boundaries of a fuzzy set,

“0” means the point not belongs to the linguistic term, “1” is the maximum grade of membership, values in the interval (0,1) represent intermediate states of the point.



**Fig. 2.** Parameter “qualification of workers”.



**Fig. 3.** Parameter “construction supervision”.

In general, the term of a linguistic variable is denoted by a fuzzy set

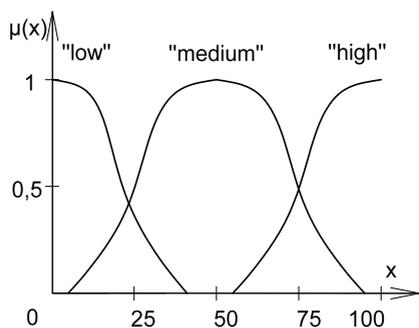
$$A = (\mu^*(x)|x), \forall x \in X \tag{1}$$

where  $X$  is continuous ( $x_0, x_n$ ) or discrete area  $\{x_1, x_2, \dots, x_n\}$ ,  $x$  is a value of specific point of term,  $\mu^*(x)$  is the grade of membership  $x$  to the set  $A$ , defined with the help of the membership function  $\mu(x) \in [0,1]$ . Thus, based on Fig. 1, the term “low qualification” represents by fuzzy set  $(1|0; 0,5|25; 0|50)$ , “medium” by  $(0|0; 0,5|25; 1|50; 0,5|75; 0|100)$ , “high” by  $(0|50; 0,5|75; 1|100)$ .

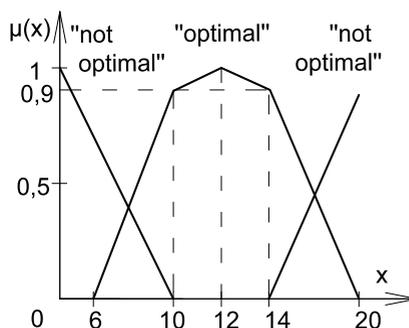
## 4 Fuzzy sets of organizational variables

The fuzzy set theory can overcome the strict limits of the traditional approach and gives freedom in the interpretation of qualitative parameters through linguistic variable and the membership function, the distribution of which is determined by the creator of the model of the construction supervision (Fig. 3). Also, this approach allows the expert to give a more reliable assessment of the measured variable of the construction supervision. The expert, in contrast to the machine, can detect not only the number of links in the construction supervision chain on construction site, but also to analyze the capacity of the fulfillment by each of them of their duties. We have to keep in mind the problem of indifferent, passive, performing their duties “in so far as” subjects, as well as regulatory authorities assigned for the construction project formally, not having real powers or executing their functions not in full volume. The expert has methods for the detection and analysis of this problem. Fuzzy sets allows him to assign to the parameter of construction supervision “low” or “medium”, “medium” or “high” level with a definitely predetermined membership function under the same conditions.

Changing parameters may be in accordance with the Gaussian distribution curve as shown in Figure 4 for analyzing the quality of construction products.



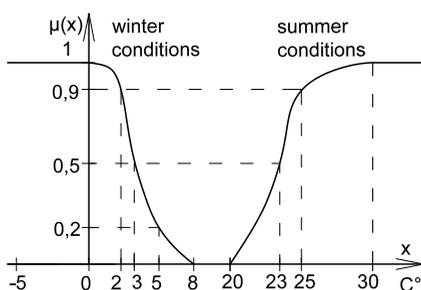
**Fig. 4.** Parameter “quality”.



**Fig. 5.** Parameter “construction supervision”.

Fuzzy sets along with qualitative works well with quantitative parameters under uncertainty [16]. As noted above, construction processes are characterized by a large parametric complexity, inability for accurately measure all components of the system, by significant influence of the human factor, long life cycle. These properties oblige researchers investigate construction processes with help of chaos theory and Heisenbergs uncertainty principle which states the impossibility of accurately predicting and measuring the components in complex systems. For example, the optimal distribution of organizational parameter “number of workers” for certain construction process is shown in Fig. 5. The number of workers is 12 people counted on the basis of performance taken from the normative documents and project time of works. But the expert knows that first of all, the performance of the same brigade on different objects is always different, secondly, the brigade often may have changes during the construction process, and thirdly, the decision-maker can change the number of workers for regulating criteria of resource conservation or efficiency. Thus, a fuzzy set shown in Fig. 5 reflects the real situation more fully, when the number of workers in the brigade is “10” or “14” can also be attributed to the linguistic variable “optimal” with the grade of membership 0.9.

Consider another example, winter conditions for concrete works were established by normative documents with an average daily temperature below 5 °C and conditions with high temperatures were limited to above 25 °C. But for the decision-maker, this border has always “fuzzy”, he turns it into an interval (a fuzzy set), guided by the grade of the design responsibility, by his experience and intuition and in conclusion by the impossibility to determine the exact average daily temperature at the time of the decision. For this reason fuzzy representation of the conditions of application of special measures of organizational process is a better way: winter conditions are (1 | 0; 0.9 | 2; 0.5 | 3; 0.2 | 5; 0 | 8), summer conditions are (1 | 30; 0.9 | 25; 0.5 | 23, 0 | 20).



**Fig. 6.** Parameter “weather conditions”.

## 5 Conclusion

The article presented two stages of experiment planning in the field of organization and management of the construction processes. In the first stage, the definition of the experimental conditions shows that obtaining statistically reliable sample of the experiences on construction site is almost impossible. It is proposed to plan an experiment based on heuristic, graphical, mathematical models, as well as neural networks and genetic algorithms with help of expert assessments. Within the second stage, the order of measurement of parameters, several methods of translation of quality characteristics of the investigated object into the mathematical language of were considered. Of these, preference is given to fuzzy set theory, which is a more reliable tool for the evaluation of the parameters of organizational models. Also it is not contrary to chaos theory at the description of complex dynamic systems due to the “fuzziness” of input and output information on the system parameters. Based on the above, authors concluded that there is a need for further application of fuzzy sets in research of the organization and management of construction processes.

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