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Selection of Construction Project Taking into Account Technological and Organizational Risk

N. Ibadov*

Warsaw University of Technology, The Faculty of Civil Engineering, Warsaw, Poland

During the implementation of construction projects, there is permanently a certain level of technological and organizational risk. This is due to the fact that the data on conditions for a construction project tend to have different levels of uncertainty. Even the projects of the same size and terms of implementation vary. The failure risk of individual works results from technological and organizational factors, such as, for example, the difficulty of technological execution of individual works; availability of construction materials; the difficulty of the organization of individual works; availability of qualified personnel, availability of necessary machinery and equipment in the technology, etc. These factors affect the time and the cost of construction projects. When taking into account their influence, while selecting an option for construction project, it is crucial to maintain the contractual cost and time. An example of the option selection for construction project implementation is presented in this article, including technological and organizational risk, using the fuzzy sets theory and linguistic variables.

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1. Introduction

Construction projects usually have complex technological and organizational structure. This complexity requires entrusting their execution to specialized working brigades, equipped with the appropriate equipment [1]. The complexity of the technological and organizational factors may cause a conflict in the field of work synchronization of individual specialties, hampering the smooth organization of works etc. [2]. This may cause a prolongation of the planned execution time of individual works and increasing project costs [3].

Therefore, author believes that it is reasonable to take into account the additional factors, resulting from technological and organizational complexity, as well as the time-cost characteristics of the project. Such factors can be: the difficulty of technological execution of an individual work; availability of construction materials; the difficulty of the organization of individual work; availability of qualified specialists for the chosen technology of construction work; availability of necessary machinery and equipment; limited construction area; etc. The occurrence degrees of these factors cause technological and organizational risk.

While choosing the most optimal variant of a construction project, the additional assessment factors should be taken into account, as well as possible technological and organizational risk. In this matter, the better construction project will be the one with the lowest risk, the most favourable cost index and/or completion time.

In order to facilitate the decision-making process, author suggests to apply the fuzzy sets theory and linguistic variables to describe and model evaluation criteria.

*e-mail: n.ibadov@il.pw.edu.pl

2. Basic concepts of the fuzzy sets theory

The concept of a fuzzy set was introduced by L.A. Zadeh [4], as generalization of the conventional or nonfuzzy set concept. A fuzzy set A in a non-empty space $\boldsymbol{X}$ is a set of pairs:

$$A = \{(x, \mu_A(x))\,; \quad x \in \boldsymbol{X}\}\,, \tag{1}$$

where: $\mu_A : \boldsymbol{X} \to [0,1]$ is a membership function of the fuzzy set A. For each element $x \in \boldsymbol{X}$, this function assigns a degree of membership to the fuzzy set A.

Figure 1 shows the typical L, t and γ class membership functions [5].

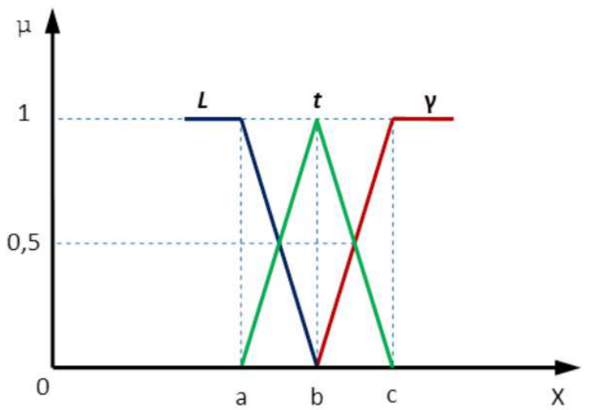

Fig. 1. L, t and γ class membership functions.

L class function is described by the Eq. (2):

$$L = (x; a, b) = \begin{cases} 1 \text{ for } x \le a, \\ (b-x)/(b-a) \text{ for } a \le x \le b, \\ 0 \text{ for } x \ge b. \end{cases} \tag{2}$$

t class function is described by the Eq. (3):

$$t=(x;a,b,c)=\begin{cases}0 \text{ for } x\le a,\\ (x-a)/(b-a) \text{ for } a\le x\le b,\\ (c-x)/(c-b) \text{ for } b\le x\le c,\\ 0 \text{ for } x\ge c.\end{cases} \quad (3)$$

γ class function is described by the Eq. (4):

$$\gamma=(x,a,b)=\begin{cases}0 \text{ for } x\le b,\\ (x-b)/(c-b) \text{ for } b\le x\le c,\\ 1 \text{ for } x\ge c.\end{cases} \quad (4)$$

Some denotations and operations on fuzzy sets such as standard intersection ($\cap$) and standard union ($\cup$) of fuzzy sets A and B, can be displayed in the following manner [4–6]:

$$\mu_{A\cap B}(x)=\min(\mu_A(x),\mu_B(x)), \quad \forall x\in \boldsymbol{X}, \quad (5)$$

$$\mu_{A\cup B}(x)=\max(\mu_A(x),\mu_B(x)), \quad \forall x\in \boldsymbol{X}. \quad (6)$$

A very important feature of fuzzy sets is that there is a possibility to use them for modeling of imprecisely defined features using linguistic variables based on the experience of an expert. Domain of linguistic variable is a set of concepts expressed imprecisely using natural language, such as "low risk" or "high risk", etc.

Another very important feature of fuzzy sets is that they can be used for inference, which uses linguistic variables. The general scheme of inference, recorded in the form of fuzzy rules is as follows [5, 6]: If "*logical premise*" Then "*conclusion*". The linguistic variables are important part of fuzzy logic too. The utilization of fuzzy logic in civil engineering as well as in related branches is shown in selected studies [7–11].

3. Choice description of the construction project in the notation of the fuzzy sets theory

Assume that it is possible to realize three construction projects, characterized by cost and labor-intensity per 1 m^2 of a building in the form of a specific quantity (1.000 PLN per 1 m^2 and man-hour per 1 m^2). Suppose also that we are able to determine the technological and organizational risk of each project, in the form of linguistic variables as: {low, medium, high}.

Table I shows the individual construction projects with the relevant time-cost values and corresponding risks. In addition $C=\{C_{\text{cost}},C_{\text{li}},C_{\text{r}}\}$ is the criteria set. The individual criteria are assigned the appropriate weight in the form of linguistic variables with crisp values: $\{W_{\text{cost}}=$ "very important" $=0.43, W_{\text{li}}=$ "important" $=0.34, W_{\text{r}}=$ "medium importance" $=0.23\}$.

It is necessary to decide which construction project to choose.

The solution of this problem using fuzzy sets theory can be obtained as follows:

a) present evaluation criteria values for various construction projects in terms of fuzzy sets, labeling them by following linguistic variables "low", "medium", "high";

b) for the above-mentioned fuzzy sets, it is needed to define their membership functions. Figures 2–4 show the relevant fuzzy sets of criteria.

TABLE I

The selection criteria values of the construction project.

Constr. project	C_{cost} [th. PLN/m^2]	C_{li} [man-hour per 1 m^2]	C_{r} Technological and organizational risk
P_1	4.6	2.3	low
P_2	4.2	2.0	medium
P_3	4.0	2.7	high
Criteria value	very important = 0.43	important =0.34	medium importance =0.23

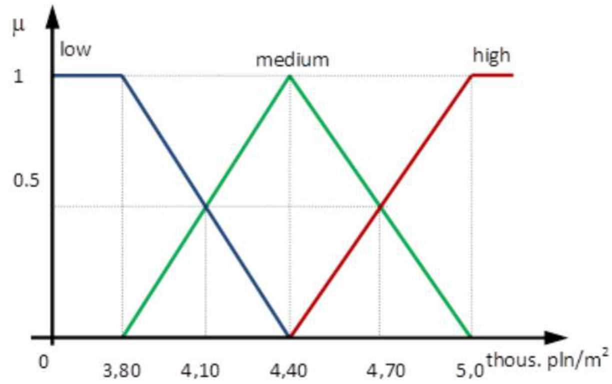

Fig. 2. Membership functions of implementation costs.

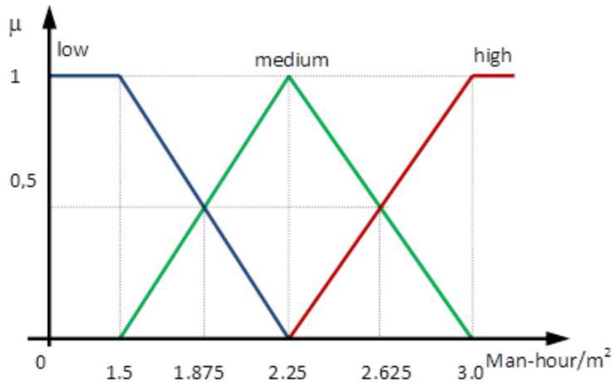

Fig. 3. Membership functions of labor intensity.

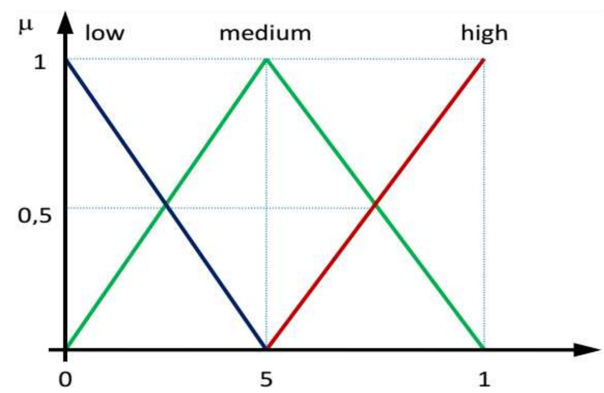

Fig. 4. The membership function of individual risks.

The calculated values and membership function labels of individual criteria of cost and labor intensity of implementation of 1 m^2 are presented in Tables II and III. Medium rating will be divided into two parts: "medium^L" and "medium^R", characterizing respectively the left and right part of the "medium".

TABLE II

The value of membership function cost for individual construction projects.

Constr. project	C_{cost} [th. PLN/m^2]	Membership function calculation	Label
P_1	4.6	$\mu(p_1) = \frac{5-4.6}{5-4.4} = 0.67$	medium^R
P_2	4.2	$\mu(p_2) = \frac{4.2-3.8}{4.4-3.8} = 0.67$	medium^L
P_3	4.0	$\mu(p_3) = \frac{4.4-4.0}{4.4-3.8} = 0.67$	low

TABLE III

The value of membership function labor intensity for individual construction projects.

Constr. project	C_{li} [man-hour/m^2]	Membership function calculation	Label
P1	2.3	$\mu(p_1) = \frac{3-2.3}{3-2.25} = 0.93$	medium^R
P2	2.0	$\mu(p_2) = \frac{2.0-1.5}{2.25-1.5} = 0.67$	medium^L
P3	2.7	$\mu(p_3) = \frac{2.7-2.25}{3.0-2.25} = 0.6$	high

Technological and organizational risk, which is described by the linguistic variables is presented on scale (0,10). Each fuzzy subset is described as follows: "low risk"= [1/0.0+0.5/2.5]; "medium risk"= [0.5/2.5+5/1+0.5/7.5]; "high risk"= [0.5/7.5 + 1/10].

A crisp value of criteria risk for each fuzzy subset is obtained after defuzzification with the following equation:

$$r = \frac{\sum_{i=1}^{n} \mu(r_i)\, r_i}{\sum_{i=1}^{n} \mu(r_i)}, \tag{7}$$

where $\mu(r_i)$ is the degree of the membership function of appropriate values r_i.

Appropriate risk values converted using the Eq. (7) are as follows: "low risk"= 0.83; "medium risk"= 5; "high risk"= 9.2. It should be emphasized that due to the different units of different criteria at the stage of aggregation, the other two criteria are also presented on a scale (0,10), according to their calculated values of membership function and labels.

Fuzzy evaluation of individual criteria values is brought as follows: "low"=[1; 0.8; 0.6; 0.5]; "medium"=[0.5; 0.6; 0.8; 1; 0.8; 0.6; 0.5]; "high"=[0.5; 0.6; 0.8; 1]. The shape of the membership function will be similar to the one given in Fig. 4.

c) for each criteria evaluation it is needed to create fuzzy rules as follows: If U is A Then V is B weighting W.

The evaluation rules of implementation cost:

R-1: If cost is "high", then the evaluation is "low", weighting 0.43,

R-2: If cost is "medium^L", then the evaluation is "medium^R", weighting 0.43,

R-3: If cost is "medium^R", then the evaluation is "medium^L", weighting 0.43,

R-4: If cost is "low", then the evaluation is "high", weighting 0.43.

The rules of the labour intensity implementation:

R-1. If the labor intensity is "high", then the evaluation is "low", weighting 0.34,

R-2. If the labor intensity is "medium^L", then the evaluation is "medium^R", weighting 0.34,

R-3. If the labor intensity is "medium^R", then the evaluation is "medium^L", weighting 0.34,

R-4. If the labor intensity is "low", then the evaluation is "high", weighting 0.34.

The rules of the risk assessment:

R-1: If the risk is "high", then the evaluation is "low", weighting 0.23,

R-2: If the risk is "medium", then the evaluation is "medium", weighting 0.23,

R-3: If the risk is "low", then the evaluation is "high", weighting 0.23,

d) "IF U is A THEN V is B" section of above rules is expressed by fuzzy implication $A \to B$ as intersection $D = A \cap B$ of fuzzy sets A and B. It is important to mention that D has membership function:

$$\mu_D(x, y) = \mu_A(x) \wedge \mu_B(y). \tag{8}$$

e) In order to obtain a crisp value, D set is defuzzified by maximum membership function:

$$\mu_D(y^*) = \sup_{y \in Y} \mu_D(y). \tag{9}$$

f) The final result for rules (point c) are calculated using equation:

$$\mu_D(y_i) = \max\{\min[\mu_A(x), \mu_B(y)]\}$$
$$= \vee[\mu_A(x) \wedge \mu_B(y)]. \tag{10}$$

g) Then, basing on the obtained $\mu_D(y_i)$ value, we can find a crisp value y_i and aggregate the individual results by $\sum_{i=1}^{n} y_i w_i$. Then we choose the maximum.

Figure 5 presents the mentioned above calculations.

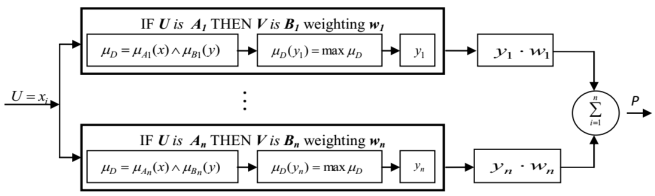

Fig. 5. Calculation diagram of selecting a construction project.

Table IV shows the values of individual evaluations y_i, based on the value calculated using Eq. (10).

Having calculated values y_i and weights of the individual criteria, it is possible to calculate the weighted assessment of individual construction projects, which are respectively: $P_1 = 5.14$; $P_2 = 6.27$; $P_3 = 4.45$. Thus, project P_2 is better than the other two (see Table I).

TABLE IV

The selection criteria values of the construction projects.

Constr. project	$C_{\rm cost}$ [th. PLN/1 m^2]	$C_{\rm li}$ [man-hour per 1 m^2]	$C_{\rm r}$ Technological and organizational risk
P_1	3.35	4.65	9.2
P_2	6.65	6.65	5.0
P_3	8.35	2.0	0.83

4. Conclusions

The presented example shows that according to established criteria and their weights, the second construction project P_2 is more favorable, followed by P_1 and P_3. Project P_2 has medium risks and costs but the lowest labour intensity. If the technological and organizational risk were not taken into consideration, the project P_2 would be still better but the order of P_3 and P_1 would change. We see that P_3 has the lowest cost but has the highest labor intensity and the highest risk. In turn, the P_1 has the highest cost, medium labour intensity and the lowest risk. In the absence of the variant P_2 and without taking into account the risk P_3 would be pointed as the best project, however in the eventual risk situation it would be the worst solution. That is why it is recommended by the author to take into account additional criteria (risk criteria), rather than to consider the time-cost criteria only (as it is commonly done in practice).

Considering the process of construction projects implementation, it is possible to notice that construction processes are disturbed by the influence of various factors, technological and organizational. These factors are uncertain, imprecise and inexact, so the problem arises, how to describe them. For this purpose it is better to use the fuzzy set theory in order to make optimal decisions.

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