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THE ASSESSMENT OF CONSTRUCTION PROJECT RISKS WITH THE USE OF FUZZY SETS THEORY

OCENA ZAGROŻEŃ PRZEDSIĘWZIĘĆ BUDOWLANYCH Z ZASTOSOWANIEM ELEMENTÓW TEORII ZBIORÓW ROZMYTYCH

A b s t r a c t

This paper presents the results of a questionnaire survey conducted by the authors to identify the risk factors affecting construction projects in Poland. The elements of the fuzzy sets theory are applied to rank the risk factors due to their degree of significance and to evaluate the threat to the construction project caused by a given risk.

Keywords: construction projects risk, factors, fuzzy sets and systems

S t r e s z c z e n i e

W niniejszym artykule przedstawiono wyniki badań ankietowych na temat czynników powodujących zagrożenie wydłużenie czasu i wzrost kosztów realizacji przedsięwzięć budowlanych w warunkach polskich. Czynniki te uporządkowano pod względem ważności z zastosowaniem elementów teorii zbiorów rozmytych. W artykule przedstawiono metodę oceny zagrożeń przedsięwzięć budowlanych z uwzględnieniem stopnia zaistnienia i ważności analizowanych czynników. Metoda pozwała na ocenę zagrożenia przedsięwzięć budowlanych przed przystąpieniem do realizacji w warunkach polskich.

Słowa kluczowe: ryzyko przedsięwzięć budowlanych, zbiory rozmyte, liczby rozmyte

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1. Introduction

As the complexity of construction projects increase, so does the likelihood of hazards affecting their successful implementation. There are many risk factors which can lead to the failure of a project. These factors should be identified and ordered both because of their degree of importance (significance) and level (volume) of a given factor. This is very important in order to determine their effect on the construction project.

Typically, the threats for the construction project include the extension of the project duration, an increase in project cost and/or a reduction in the quality of the works. This article aims (1) to identify the risk factors that may affect construction projects in Poland with regard to the above-mentioned aspects and (2) to prioritize the significance of those risk factors. In this regard, a questionnaire was developed, containing a number of factors affecting such parameters. The survey was then distributed among various Polish construction companies. In this article we present only the results of the survey upon the risk factors affecting the duration and cost of a construction project.

Due to the uniqueness of individual construction projects, the potential hazards and their effects are usually characterized by different levels of uncertainty. Unfortunately, it is often a non – statistical uncertainty. For this reason, the degree of significance applied to risk factors is described and modeled using linguistic variables and elements of the theory of fuzzy sets.

2. Risk factors affecting construction projects in Poland – analysis of the literature and determination the structure of the questionnaire

Several available literature sources contain systematized lists of identified circumstances or events, the occurrence of which being a source of deviation affecting actual project performance (including duration and cost of implementation) from the expected state, defined by the planist. Such circumstances or events are referred to as risk factors, the occurrence of which may threaten the achievement of the project objectives, see for example [1, 3, 7, 10].

The effects of the materialization of construction risk factors typically includes the prolongation of the works, an increase of the cost of the works or a deterioration in the quality of work. Factors affecting the duration and cost of the works have therefore been chosen and listed in this article [10], taking into account specifics of the Polish market. It should be stressed that the identification of risk factors alone do not eliminate their adverse effects on the project. It is also essential to determine the significance of threat caused by the given risk factor. Therefore, the questionnaires asked respondents to indicate the significance (importance) of each indicated risk factor. Selected risk factors affecting the project and cost due to the answers obtained by the authors are presented in Table 1.

3. Analysis of survey results and ranking the degree of significance of risk factors

The questionnaire was conducted from December 2012 – October 2013 among clients, designers, general contractors, subcontractors and suppliers of building materials from the majority of polish voivodships. Data from 133 questionnaires was collected , then analyzed to determine the degree of significance of each risk factor, taking their impact on the execution parameters of the construction project into account. In this paper, the authors present only a part of the survey results concerning the influence of chosen factors on the duration and cost of the construction project execution. In this regard, each respondent was asked to assess the degree of significance of each factor with one of following verbal marks: *not important* (NI), *slightly important* (SI), *moderately important* (MI), *essentially important* (EI), and *critically important* (CI).

After collecting and analyzing the data from the questionnaires, the degree of significance for each factor was determined according to formula (1). The results are given in Table 1.

Table 1

The significance of risk factors based on respondents' answers

Risk factors	The degree of significance of the influence on the construction project:	
	duration	cost
The tight schedule of the project	essentially important	essentially important
Changes of material and structural solutions in project documentation	essentially important	moderately important
Excessive complexity of the procedures associated with obtaining administrative decisions	moderately important	moderately important
Changes in functional requirements, introduced by the client	moderately important	moderately important
Incomplete project documentation, absence of the required decisions or permits	essentially important	moderately important
Incorrect estimation of the scope of works	moderately important	moderately important
Incorrect estimation of project timetable	essentially important	moderately important
Excessive length of procedures for obtaining administrative decisions	essentially important	*not evaluated*
Too high expectations regarding the progress or the quality of the works	slightly important	*not evaluated*
Changes in the scope of work	essentially important	*not evaluated*
Changes of material and structural solutions in project documentation	moderately important	*not evaluated*
Changes in functional requirements, introduced by the client	moderately important	*not evaluated*
Incorrect estimation of the scope of works	moderately important	*not evaluated*
Litigation between the participants of the project	*not evaluated*	moderately important
Increase of prices of construction materials	*not evaluated*	slightly important

The formula for the determination of the degree of significance for each factor is given below:

$$W_f = \sum w_i \cdot \left(\frac{n_i}{N} \right) \tag{1}$$

where:

- W_f – the design value of the significance for a given factor, included in an interval [0,00; 1,00];
- w_i – the coefficient of validity for the *i*-th linguistic variable, determined as the maximum value within the range [0.0; 1.0], which corresponds to the maximum value of the membership function of this variable (for example, for the linguistic variable *slightly important*, w_i = 0.3, see Fig. 1);
- n_i – the number of votes for the *i*-th linguistic variable,
- N – the total number of votes (in our case, N = 133).

4. Basic concepts of the theory of fuzzy sets useful in solving the issue taken

To describe and formalize the degree of significance (relative importance) of factors. The basic concepts of the fuzzy set theory, were used to solve chosen issues, are presented below.

The fuzzy set theory was described in the work of Lotfi A. Zadeh [9]. Unlike classical set theories, with the fuzzy set theory it is possible for an element belonging to a set A_i to have a degree of membership. That degree of membership is described by a membership function $\mu_{A_i} : X \to [0,\ 1]$ $\mu_{A_i} : X \to [0,\ 1]$. If $\mu_{A_i}(x) = 1$, an element x is fully included in a set A_i, and if $\mu_{A_i}(x) = 0$, an element x is not included in a set A_i. However, there is a considerable number of elements x which satisfy the condition of belonging to A_i only to some extent. For example, we can say, that if $\mu_{A_i}(x) > 0.5$, then an element x seems rather to belong to A_i, while those elements for which $\mu_{A_i}(x) = 0 \in Y\}$ – seem rather to not satisfy the condition of belonging to A_i.

A *fuzzy number* is a fuzzy subset of the real line whose highest membership values are clustered around a given real number called the mean value and the membership function is monotonic on both sides of this mean value. Let A $\{(x, \mu_A(x))$: $x \in X\}$ and B $\{(y, \mu_B(y))$: y $\mu_{A_i}(x) = 0 \in Y\}$ be fuzzy numbers. Basic arithmetic operations on these numbers as addition (+), subtraction (–), multiplication (•) and division (/) are as follows:

$$\mu_{A*B}(z) = \sup_{z=x*y} [\min(\mu_A(x), \mu_B(y))], \forall x, y, z \in R \tag{2}$$

where symbol (*) means respectively (+), (–), (•) or (/) if y ≠ 0.

One of the important elements of the fuzzy set theory is a *linguistic variable* which adopts natural language expressions as its value. Despite the complex mathematical formalism, intuitive sense of linguistic variables is simple. In our case, for example, the linguistic variable called *the degree of significance* can adopt fuzzy set values which represent the features: *not important*, *slightly important*, etc.

In many cases we can encounter the issue of transforming a fuzzy value into precisely defined real number. This procedure is called defuzzification. One of the methods used to achieve this is the center of gravity method, which assigns a real number to membership membership function. The real number y_c determines the coordinate of the center of gravity of the area under the graph of a function:

$$y_c = \frac{\int y\mu(y)dy}{\int \mu(y)dy}, \tag{3}$$

where:

y_c – a real number,
y – the value of the output variable,
$\mu(y)$ – the membership function of the output variable.

5. Modeling the degree of significance of risk factors in the notation of fuzzy sets

A number of methods and models of construction of linguistic variables membership functions have been proposed, refer for example to [2, 4, 6, 8]. This also includes also the adoption of an appropriate measurement scale. Without going into much detail, for the construction of the appropriate membership function in our case, one should answer the question: "To what extent does the risk factor *x* belong to fuzzy set A? or should state that risk factor *x* is more A than risk factor *y*". This will allow us to construct the membership function of fuzzy set, like in [5]. Based on the *ranking* of factor degrees of significance obtained during survey, and *fuzzy set* definition, we are able to determine the membership functions of individual factors on a scale [0, 10]. Fig. 1 shows membership functions of individual fuzzy sets. With regard to the values shown in Fig. 1, one can describe the analytical notation of membership functions for the linguistic variables used to assess the degree of significance of each factor with verbal marks NI, SI, MI, EI and CI.

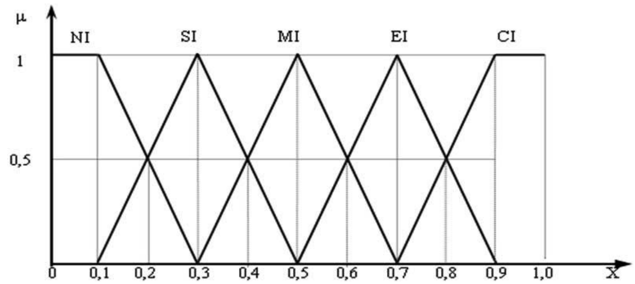

Fig. 1. The membership functions of the degree of significance of a given risk factor

For example, the analytical notation of membership function "slightly important" μ_{SI} is given by the formula:

$$\mu_{SI} = \begin{cases} 0 & \text{for} \quad x \le 0,1 \\ \dfrac{x - 0,1}{0,3 - 0,1} & \text{for} \quad 0,1 \le x \le 0,3 \\ \dfrac{0,5 - x}{0,5 - 0,3} & \text{for} \quad 0,3 \le x \le 0,5 \\ 0 & \text{for} \quad x \ge 0,5 \end{cases} \tag{4}$$

6. An example of a construction project risk assessment using the results of the survey

For simplicity, we assume only three chosen risk factors affecting the time and the cost of the construction project, see Table 2. Assume that in a given project, the scheduler determines the measurement scale of the degree of occurrence of a given risk factor in the form of the following fuzzy numbers: *Low* = (1/0.0 + 1/0.2 + 0/0.5); *Medium* = (0/0.2 + 1/0.5 + 0/0.8); High = (0/0.5 + 1/0.8 + 1/1.0). Fig. 2 shows a graph of the respective linguistic variables. Fuzzy numbers describing the significance of the risk factors are also determined on the basis of Fig. 1, as given in Table 2.

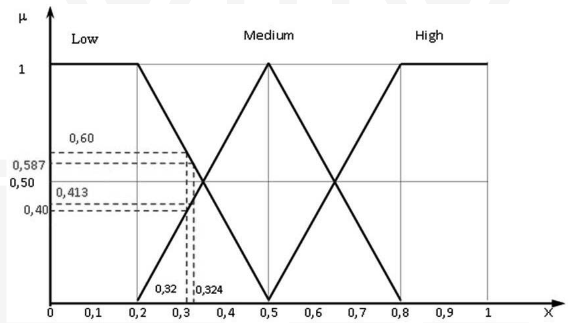

Fig. 2. The membership functions of the degree of occurrence of a given risk factor

The next step is to multiply the fuzzy number modeling the *degree of significance* of a given risk factor (i.e., *risk impact*) by the fuzzy number modeling the *degree of occurrence* of this factor in a given project (i.e, *risk likehood*). Using formula (2), we get a fuzzy number describing the *risk severity* and the threat to the construction project caused by a given risk factor (see Table 2). In order to estimate the level of each type of risk, we determine the real number for each risk factor using the defuzzification procedure given in formula (3). At this stage, one is able to determine which factor is associated with the highest (or the lowest) risk level and take (or do not take) this into account during project planning.

With the results given in Table 2, one can state that the arithmetic mean values of the defuzzied numbers describing the threats for the duration and for the cost of a construction project, are respectively 0.324 and 0.320. On the basis of these values, using a measurement scale similar to given in Fig. 2, we can evaluate the threat in relation to the duration of the project by the fuzzy set (0.587/Low; 0.413/Medium), as well as the threat to the cost of the project by the fuzzy set (0.6/Low; 0.4/Medium).

Table 2

The evaluation of the threat for the construction project, caused by a given risk factor

Risk factors	The degree of occurrence	The degree of significance	The product of fuzzy numbers	Defuzzi-fication
Risk factors. influencing the project duration				
The tight schedule of the project	High (0/0.5 + 1/0.8 + 1/1.0)	Essentially important (0/0.5 + 1/0.7 + 0/0.9)	(0/0.5 + 1/0.56 + 1/0.7 + 0/0.72)	0.62
Incorrect estimation of the scope of works	Medium (0/0.2 +1/0.5 + 0/0.8)	Moderately important (0/0.3 + 1/0.5 + 0/0.7)	(0/0.24 + 1/0.25+ 0/0.35)	0.28
Incorrect estimation of project timetable	Low (1/0.0 + 1/0.2 + 0/0.5)	Essentially important 0/0.5 + 1/0.7 + 0/0.9)	(1/0+0/0.1 + 1/0.14 + 0/0.18)	0.073
Risk factors. influencing the project cost				
The tight schedule of the project	High (0/0.5 + 1/0.8 + 1/1.0)	Essentially important (0/0.5 + 1/0.7 + 0/0.9)	(0/0.5 + 1/0.56 + 1/0.7 + 0/0.72)	0.62
Incorrect estimation of the scope of works	Medium (0/0.2 + 1/0.5 + 0/0.8)	Moderately important (0/0.3 + 1/0.5 + 0/0.7)	(0/0.24 + 1/0.25 + 0/0.35)	0.28
Incorrect estimation of project timetable	Low (1/0.0 + 1/0.2 + 0/0.5)	Moderately important (0/0.3 + 1/0.5 + 0/0.7)	(1/0 + 0/0.06 + 1/0.1 + 0/0.14)	0.06

7. Conclusions

The results of the questionnaire survey show the degree of significance (importance) of various risk factors affecting the performance of construction project in Poland. It is surprising that the majority of respondents believe that the degree of significance given to the *increase of prices of construction materials* risk factor is only slightly important in terms of impact on the cost of the project, see Table 1. This could mean that the construction materials market is stable or, during the period of project execution, the probability of price change was low.

Use of the fuzzy sets theory for ranking and the modeling of individual risk factors may facilitate the planner/scheduler to determine a degree of influence for each factor against the performance parameters of a construction project. The survey was however limited only to the recognition of the significance of risk factors and respondents were not asked to indicate the degree of occurrence of individual factors. This would provide an opportunity to determine how often a given risk factor presents itself in the Polish construction market.

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