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CONTRACTOR PREQUALIFICATION MODEL USING FUZZY SETS

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Abstract. Contractor prequalification makes it possible to admit for tendering only competent contractors. The undertaken decisions demand taking into consideration many criteria, including among others, experience and financial standing of the candidates. It is often difficult to be quantified. The objectives of the construction owner in a given project are also meaningful. All these factors cause difficulties in working out a mathematical prequalification model. In the paper a model based on fuzzy sets theory is proposed. It takes into consideration both different criteria, objectives and evaluations of numerous decision – makers. To illustrate the model operation a simple numerical example is presented.

Keywords: contractor, prequalification, fuzzy sets.

1. Introduction

The basic criterion for choosing a tender for construction works is usually the price. Construction owners, however, also appreciate competent contractor. Choosing a right contractor increases the chances of reaching the goals of the project which, first of all, are keeping the schedule of the cost, time and quality.

In many countries the procedure of prequalification is commonly used as a before-tendering contractor selection method. In Poland this procedure is met in orders advertised by private construction owners, as well as in big international tenderings. In practice we can speak about two types of prequalification which can also comprise two stages. Prequalification can be understood as "registration" of contractors capable of completing given tasks. In effect, it leads to making the "standing list", which should be updated in given periods of time (e.g. once a year). In such a case only contractors from the list can apply for the possibility of participating in the project. Prequalification may also mean selecting a group of contractors most suitable to execute a given project. This is so called "per project" prequalification. In this case a "short list" of contractors is formed.

To choose the best contractors it is indispensable to attain their ranking. Mathematical models are used for this purpose.

To build a model comprising all conditions of prequalification process is not an easy task. In contractor evaluation numerous criteria are taken into account, which, in turn, are characterized by the right subcriteria. In many countries there were many researches carried out on the criteria used by construction owners (Jennings and Holt 1998; Plebankiewicz 2008; Russell *et al.* 1992; Singh and Tiong 2006; Waara and Brochner 2006; Mitkus and Trinkūnienė 2007). The basic criteria and subcriteria of contractor evaluation are shown in Table 1.

Table 1. Prequalification criteria

Criteria	Example subcriteria
Financial standing	1. Financial stability 2. Turnover, profit, obligations, amounts due 3. Owned financial funds
Technical ability	1. Experience 2. Plant and equipment 3. Personnel
Management capability	1. Past performance and quality 2. Quality control policy 3. Quality management system 4. Project management system 5. Experience of technical personnel 6. Management knowledge
Health and safety	1. Accidents 2. Health and safety management system 3. Insurance policy
Reputation	1. Past failures in completed projects 2. Number of years in construction 3. Past client relationships 4. Cooperation with contactors

Evaluation of many criteria is subjective and ambiguous in meaning, e.g. important in evaluation "contractor's reputation". It is also not an easy task to determine one common scale of evaluation for all the criteria. Additionally, the necessity to include in the model evaluations of numerous decision-makers is also a problem.

In the literature there are several models which can be used in the process of construction contractor's selection. The most important of them, according to their growing elaboration degree, with the models' initiators, are given in Table 2.

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Table 2. Prequalification models

Model	Researchers
Dimensional weighting method	Jaselskis and Russell 1991
Dimension-wide strategy method	Jaselskis and Russell 1991
Two-step prequalification method	Jaselskis and Russell 1991
Prequalification formula method	Russell and Skibniewski 1990
Financial model	Russell 1992
Linear model	Russell 1992
Linear model using PERT approach	Hatush and Skitmore 1997a
Model based on fuzzy sets theory	Nguyen 1985; Singh and Tiong 2005
Statistical model	Jaselskis 1988
Knowledge-based expert system model	Russell *et al.* 1990
Hybrid model	Russell 1992
Model using AHP	Fong and Choi 2000 ; Al-Harbi 2001
Neural network model	Lam *et al.* 2001; Khosrowshah 1999; Elazouni 2006; Palaneeswaran and Kumaraswamy 2005;
Principal component analysis method	Lam *et al.* 2005

Contractor's selection problem is a multi-criteria problem. Many multi-criteria techniques are proposed and applied for such problems solution (Zavadskas and Vilutiene 2006; Zavadskas *et al.* 2008a, b, c, 2007; Pongpeng and Liston 2003a, b; Mahdi *et al.* 2002; Turskis 2008; Brauers *et al.* 2008; Lin *et al.* 2008; Mitkus and Trinkūnienė 2008).

In practice the construction owners use only a few of the mentioned models. They include mainly those which are based on a simple apparatus of mathematical. Unfortunately, they also impose basic limitations. Among others, these mean impossibility to introduce subcriteria and evaluation of many decision-makers (dimensional weighting and dimension-wide strategy method), also the problem of using hardly quantifiable evaluations (both dimensional weighting method and linear models).

Models using AHP and fuzzy sets have many advantages. The basic one is the possibility to evaluate immeasurable criteria and to take into consideration evaluation of some decision – makers. However, there is a necessity of introducing many data, what may discourage usage of the models in practice. Rather complicated mathematical apparatus enforces necessity of creating a tool which would facilitate model application.

The paper presents a proposal of contractor prequalification model possible to be used by Polish construction owners.

2. Model assumptions

The main purpose of the model is to choose a contractor for a concrete project ("per project").

The model considers different objectives the construction owner wants to accomplish in a given project. The basic objectives considered in the model are time, cost and quality of works. In literature these are the most often mentioned targets which most of the projects aim at. Depending on different factors, first of all what objectives the project is destined for, the construction owner may very differently evaluate these objectives. E.g. in case of a prestigious project, the most important may be its quality, the cost being less important. However, in case of a project built for sale, its quality may be less important than its cost or time of realization.

Hatush and Skitmore (1997b) carried out a research, the aim of which was to get to know the influence of selected prequalification criteria on the project success factors of time, cost and quality. Research was carried out in England, 8 chosen professional institutions – 3 of them were public construction owners, 5 – private construction owners.

The results of the research allowed to establish 20 prequalification criteria, taking into consideration their influence on the earlier enumerated project success factors. The criterion having the greatest influence on all 3 objectives is "past failure". Thus, it is a very important criterion which should be taken into consideration in prequalification. Other criteria having significant influence on the 3 objectives are: "financial status", "ability", "management personnel", "experience".

Some factors may be thought important to achieve 2 objectives. Such a criterion is "bank arrangement" – important for time and cost and less important for quality. On the other hand, "management knowledge", "project management organization" – are important for time and quality, less important for cost. Some criteria are important in one objective only, being less important for others. Such a criterion is, for example, "technical personnel", important for quality only.

Evaluating the contractor's ability to realize a given project we should take into consideration different criteria of his evaluation. The objectives of the construction owner in a given project are also important. Both evaluation of the criteria and evaluation of the construction owner objectives are difficult to quantify.

An attempt to present quantitatively the values which some time ago were considered to be immeasurable led in the sixties to the formulation of fuzzy sets theory and its wide usage in decision-making. Due to this theory linguistic variables can be converted into a fuzzy numbers. Fuzzy sets theory proves very convenient for searching solutions of the problems containing elements of human subjectivity, such as making decisions in order to choose construction contractors.

A formal description of the theory of fuzzy sets was introduced in 1965 by I. A. Zadeh and he is considered to be the author of this theory. The basic aim of the theory is to represent existing inaccuracies included in some expressions in a natural language. Many authors think that combining the method of incomplete information with fuzzy sets theory, representing inaccurate information, can more thoroughly and naturally describe the phenomena of the realistic world.

A fuzzy set is characterized by its membership function, which represents numerically the degree to which an element belongs to a set. Unlike conventional (crisp) sets theory where objects are either in or out of a set, fuzzy sets theory allows objects to have partial membership in a set.

Fuzzy sets were for the first time used to build a contractor selection model by Nguyen (1985). He proposed a procedure of choosing a bidder taking into consideration 3 criteria: cost, presentation of bid information and past experience, as well as different scenarios of a construction owner's preferences.

An interesting prequalification model, based on fuzzy sets, was presented by Singh and Tiong (2005). The model allows taking into consideration different types of criteria and characterizing them as subcriteria. It admits subjective evaluations of numerous decision-makers. Decision-makers can use linguistic variables both for the criteria and for the degree of satisfying them by contractors. The way in which linguistic variables, used by Singh and Tiong, are interpreted, has been applied in the model discussed in the paper.

The main difference and advantage of the model presented in the paper in comparison with previous ones is to take into consideration different objectives, the construction owner wants to accomplish in a given project. In the model the elements of the fuzzy relation determine the relationship between objective *c* and contractor *w* through their respective relationships to criterion *k*.

3. Model operation scheme

In the model the following denotations will be used:

d_p – decision-maker;

c_m – objectives of a construction owner in a given project;

k_n – decision criteria;

C_a – objectives weight (degree to which objective is desired by construction owner);
$a = 1, 2, \ldots, m$; m – number of objectives;

C_{aj}^e – a objective evaluation, by j decision maker, for e variant;
$j = 1, 2, \ldots, p$; p – number of decision makers;
$e = 1, 2, 3, 4$; e – number of evaluation variants;

C_{aj} – objective evaluation matrix;

K_b – b criterion weight;

K_{bj}^e – b criterion evaluation by j decision-maker, for e variant;
$b = 1, 2, \ldots, n$; n – number of criteria;

K_{bj} – criteria evaluation matrix;

W_{cb} – c contractor evaluation according to b criterion (degree of satisfying the criterion by the contractor);

W_{cjb}^e – c contractor evaluation, by j decision-maker, for e variant, according to b criterion,
$c = 1, 2, \ldots, t$; t – number of contractors;

W_{cjb} – contractor evaluation matrix;

I_{ab} – influence of b criterion on a objective;

O_i – contractor evaluations
$i = 1, 2, \ldots, t$; t – number of contractors.

In the model an algorithm characterized further in the paper is accepted:

1. In the first stage the construction owner has to define the objectives (c_m) he wants to achieve in the project. In the model 3 objectives were taken into consideration: time (c_1), cost (c_2), and quality (c_3). The construction owner, however, may take into consideration other objectives as well.

2. We determine k_n criteria having influence on the decision on a contractor being qualified. The criteria may be used randomly. The set of the most often applied criteria are shown in Table 1.

3. Decision-makers (d_p) evaluate the degree to which the construction owner aims at achieving a given objective, the degree of criteria importance for the construction owner and the degree of satisfying criteria by particular contractors.

3.1. In the evaluation the decision-makers used linguistic variables:

Linguistic variables (very important, important, above average, average, below average, low important, very low important), refer to the evaluation of the importance degree in reaching a given objective and to the evaluation of a given criterion.

Linguistic variables values (very good, good, above average, average, below average, poor, very poor), refer to the evaluation of the degree of contractor's satisfying the criterion.

3.2. Linguistic variables are converted into a fuzzy numbers (Fig. 1 and Table 3) (Singh, Tiong 2005).

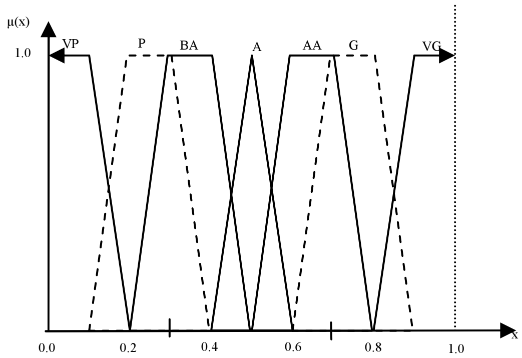

Fig. 1. Graphical representation of fuzzy numbers for linguistic variables

Table 3. Fuzzy numbers for linguistic variables

Linguistic variables	Fuzzy numbers
VG/VI very good/important	(0.8, 0.9, 1.0, 1.0)
G/I good/important	(0.6, 0.7, 0.8, 0.9)
AA above average	(0.5, 0.6, 0.7, 0.8)
A average	(0.4, 0.5, 0.5, 0.6)
BA below average	(0.2, 0.3, 0.4, 0.5)
P/LI poor/low important	(0.1, 0.2, 0.3, 0.4)
VP/VLI very poor/very low important	(0.0, 0.0, 0.1, 0.2)

3.3. For each objective we determine fuzzy value of the degree to which a construction owner is striving in order to reach a given objective

– C_{aj}^{k} – a (a = 1, 2, …, m) objective evaluation, by j (j = 1, 2, …, p) decision-maker, for e (e = 1, 2, 3, 4) variant

$$C_{aj}^{'k}=\begin{bmatrix}(C_{11}^{1},C_{11}^{2},C_{11}^{3},C_{11}^{4}) & (C_{12}^{1},C_{12}^{2},C_{12}^{3},C_{12}^{4}) & \dots & (C_{1p}^{1},C_{1p}^{2},C_{1p}^{3},C_{1p}^{4})\\ (C_{21}^{1},C_{21}^{2},C_{21}^{3},C_{21}^{4}) & (C_{22}^{1},C_{22}^{2},C_{22}^{3},C_{22}^{4}) & \dots & (C_{2p}^{1},C_{2p}^{2},C_{2p}^{3},C_{2p}^{4})\\ . & & & \\ (C_{m1}^{1},C_{m1}^{2},C_{m1}^{3},C_{m1}^{4}) & (C_{m2}^{1},C_{m2}^{2},C_{m2}^{3},C_{m2}^{4}) & \dots & (C_{mp}^{1},C_{mp}^{2},C_{mp}^{3},C_{mp}^{4})\end{bmatrix}$$

The average score of decision-makers:

$$C_{aj}^{''k}=\begin{bmatrix}(C_{11}^{1}+C_{12}^{1}+\dots+C_{1p}^{1})/p & (C_{11}^{2}+C_{12}^{2}+\dots+C_{1p}^{2})/p & (C_{11}^{3}+C_{12}^{3}+\dots+C_{1p}^{3})/p & (C_{11}^{4}+C_{12}^{4}+\dots+C_{1p}^{4})/p\\ (C_{21}^{1}+C_{22}^{1}+\dots+C_{2p}^{1})/p & (C_{21}^{2}+C_{22}^{2}+\dots+C_{2p}^{2})/p & (C_{21}^{3}+C_{22}^{3}+\dots+C_{2p}^{3})/p & (C_{21}^{4}+C_{22}^{4}+\dots+C_{2p}^{4})/p\\ . & & & \\ (C_{m1}^{1}+C_{m2}^{1}+\dots+C_{mp}^{1}/p & (C_{m1}^{2}+C_{m2}^{2}+\dots+C_{mp}^{2})/p & (C_{m1}^{3}+C_{m2}^{3}+\dots+C_{mp}^{3})/p & (C_{m1}^{4}+C_{m2}^{4}+\dots+C_{mp}^{4})/p\end{bmatrix}$$

Introducing denotations:

$$(C_{11}^{1}+C_{12}^{1}+\dots+C_{1p}^{1})/p=C_{11};$$

$$(C_{11}^{2}+C_{12}^{2}+\dots+C_{1p}^{2})/p=C_{12};$$

$$(C_{11}^{3}+C_{12}^{3}+\dots+C_{1p}^{3})/p=C_{13};$$

$$(C_{11}^{4}+C_{12}^{4}+\dots+C_{1p}^{4})/p=C_{14};$$

$$(C_{21}^{1}+C_{22}^{1}+\dots+C_{2p}^{1})/p=C_{21};$$

$$(C_{21}^{2}+C_{22}^{2}+\dots+C_{2p}^{2})/p=C_{22}$$

…

$$(C_{m1}^{3}+C_{m2}^{3}+\dots+C_{mp}^{3})/p=C_{m3};$$

$$(C_{m1}^{4}+C_{m2}^{4}+\dots+C_{mp}^{4})/p=C_{m4}.$$

Objective evaluation matrix is obtained:

$$C_{aj}=\begin{bmatrix}C_{11} & C_{12} & C_{13} & C_{14}\\ C_{21} & C_{22} & C_{23} & C_{24}\\ . & & & \\ C_{m1} & C_{m2} & C_{m3} & C_{m4}\end{bmatrix}. \quad (1)$$

3.4. The crisp score (defuzzified value) – the average degree to which a construction owner is striving in order to reach a given objective – is obtained as follows (Kaufmann, Gupta 1991):

$$C_a=(C_{a1}+C_{a2}+C_{a3}+C_{a4})/4. \quad (2)$$

For details about different types of fuzzy numbers, membership function, aggregation, and defuzzification methods, interested readers are referred to Klir and Folger (1988), Kaufmann and Gupta (1991), Kacprzyk (1986).

Next, similarly as in case of the degree to which a construction owner is striving in order to reach a given objective, the degree of criterion importance and degree of satisfying criteria by particular contractors is established.

3.5. For each of criterion we determine, fuzzy value of the degree of criteria importance for the construction owner

K_{bj}^{k} – b (b = 1, 2, …, n) criterion evaluation by j (j = 1, 2, …, p) decision-maker, for e (e = 1, 2, 3, 4) variant;
n – number of criteria.

Criteria evaluation matrix: K_{bj}.

3.6. The crisp score (defuzzified value) – the average degree of criteria importance for the construction owner: $K_{b.}$

3.7. For each of contractor we determine, fuzzy value of satisfying criteria by particular contractors

W_{cjb}^{e} – c (c = 1, 2, …, t) contractor evaluation, by j decision maker, for e variant, according to b criterion
t – number of contractors.

Contractor evaluation matrix: W_{cjb}.

3.8. The crisp score (defuzzified value) – the average degree of satisfying criteria by particular contractor: W_{cb}

4. The elements of the $R(c,k)$ relation are calculated, where $R(c,k)$ is a fuzzy binary relation approximates the relationship between the objective set and criteria set;

$$R(c_a,k_b)=C_a\times K_b\times I_{ab}. \quad (3)$$

5. The elements of the $R(k,w)$ relation are calculated, where $R(k,w)$ is a fuzzy binary relation. Each element of $R(k,w)$ represents the degree of satisfying criteria by particular contractors.

6. The elements of the $Q(c,w)$ relation are calculated, where $Q(c,w)$ is a fuzzy composition operation, performed on the 2 fuzzy binary relations $R(c,k)$ and $R(k,w)$. The elements of the $Q(c,w)$ relation determine the relationship between objective c and contractor w through their respective relationships to criterion k. We use maximum-minimum (max min) and cumulative-minimum (cum min) composition operation.

– The max min operation is defined, for a given c_a and w_c, by (Klir, Folger 1988):

$$Q(c,w) = S \circ R(c_a, w_c) = \max\min\left[R(c_a, k_b), R(k_b, w_c)\right] \text{for all } k_b. \quad (4)$$

Contractor evaluation is obtained as follows:

$$O_i = \left[\sum Q(c_a, w_c)\right] / \sum c_a \quad \text{for } a = 1 \text{ to } m. \quad (5)$$

– The cum min operation is defined, for a given c_a and w_c, by (Russel, Fayek 1994):

$$Q(c,w) = S \circ R(c_a, w_c) = \text{sum}\min\left[R(c_a, k_b), R(k_b, w_c)\right] \text{for all } k_b. \quad (6)$$

Contractor evaluation is obtained using (5).

4. Example illustrating model operation

A construction owner wants to make a list of contractors able to realize a given project. To do this he has to evaluate five contractors (w_1, w_2, w_3, w_4, w_5).

A group of three decision makers decide about qualification (d_1, d_2, d_3).

The objectives the construction owner wants to achieve in a given project are: time (c_1), cost (c_2) and quality (c_3).

Criteria taken into consideration are: technical possibilities (k_1), financial standing (k_2) and organizational abilities (k_3).

Decision makers evaluate the degree to which the construction owner aims at achieving a given objective in the form of linguistic variables (Table 4).

Linguistic variables are converted into a fuzzy numbers according to Table 3 (Table 5).

Objective evaluation matrix is obtained using (1):

$$C_{aj} = \begin{bmatrix} 0.533 & 0.633 & 0.700 & 0.800 \\ 0.533 & 0.633 & 0.700 & 0.800 \\ 0.800 & 0.900 & 1.000 & 1.000 \end{bmatrix}.$$

The crisp score is obtained using (2):

C_1 = (0.533 + 0.633 + 0.700 +0.800)/4 =0.667;

C_2 = 0.667;

C_3 = 0.925.

For each of criterion decision-makers evaluate fuzzy value of the degree of criteria importance (Table 6).

Linguistic variables are converted into a fuzzy numbers according to Table 3 (Table 7).

Criteria evaluation matrix:

$$K_{bj} = \begin{bmatrix} 0.800 & 0.900 & 1.000 & 1.000 \\ 0.667 & 0.767 & 0.867 & 0.933 \\ 0.300 & 0.400 & 0.433 & 0.533 \end{bmatrix}.$$

The crisp score:

K_1 = 0.925.

K_2 = 0.808.

K_3 = 0.417.

For each of constructor decision makers evaluate fuzzy value of satisfying criteria by particular contractors.

Table 4. Decision-makers evaluation of objectives

Objective	d_1 evaluation	d_2 evaluation	d_3 evaluation
time (c_1)	important	important	average
cost (c_2)	important	average	important
quality (c_3)	very important	very important	very important

Table 5. Decision-makers evaluation of objectives (fuzzy numbers)

Objective	d_1 evaluation	d_2 evaluation	d_3 evaluation
time (c_1)	0.6, 0.7, 0.8, 0.9	0.6; 0.7; 0.8; 0.9	0.4; 0.5; 0.5; 0.6
cost (c_2)	0.6, 0.7, 0.8, 0.9	0.4, 0.5, 0.5, 0.6	0.6, 0.7, 0.8, 0.9
quality (c_3)	0.8, 0.9, 1.0, 1.0	0.8, 0.9, 1.0, 1.0	0.8, 0.9, 1.0, 1.0

Table 6. Decision-makers evaluation of the degree of criteria importance

Criterion	d_1 evaluation	d_2 evaluation	d_3 evaluation
technical possibilities	very important	very important	very important
financial standing (k_2)	important	very important	important
organizational abilities	low important	average	average

Table 7. Decision-makers evaluation of the degree of criteria importance (fuzzy numbers)

Criterion	d_1 evaluation	d_2 evaluation	d_3 evaluation
technical Possibilities	0.8, 0.9, 1.0, 1.0	0.8, 0.9, 1.0, 1.0	0.8, 0.9, 1.0, 1.0
financial standing (k_2)	0.6, 0.7, 0.8, 0.9	0.8, 0.9, 1.0, 1.0	0.6, 0.7, 0.8, 0.9
organizational abilities	0.1, 0.2, 0.3, 0.4	0.4, 0.5, 0.5, 0.6	0.4, 0.5, 0.5, 0.6

For criterion technical possibilities (k_1)

Fuzzy value of satisfying criterion k_1 by contractors – Table 8.

Table 8. Decision-makers evaluation of satisfying criterion k_1 by contractors

Contractor	d_1 evaluation	d_2 evaluation	d_3 evaluation
w_1	good	very good	very good
w_2	good	good	good
w_3	average	above average	good
w_4	average	good	good
w_5	very good	good	very good

Linguistic variables are converted into a fuzzy form according to Table 3 (Table 9).

Table 9. Decision-makers evaluation of satisfying criterion k_1 by contractors (fuzzy numbers)

Contractor	d_1 evaluation	d_2 evaluation	d_3 evaluation
w_1	0.6, 0.7, 0.8, 0.9	0.8, 0.9, 1.0, 1.0	0.8, 0.9, 1.0, 1.0
w_2	0.6, 0.7, 0.8, 0.9	0.6, 0.7, 0.8, 0.9	0.6, 0.7, 0.8, 0.9
w_3	0.4, 0.5, 0.5, 0.6	0.5, 0.6, 0.7, 0.8	0.6, 0.7, 0.8, 0.9
w_4	0.4, 0.5, 0.5, 0.6	0.6, 0.7, 0.8, 0.9	0.6, 0.7, 0.8, 0.9
w_5	0.8, 0.9, 1.0, 1.0	0.6, 0.7, 0.8, 0.9	0.8, 0.9, 1.0, 1.0

Contractor evaluation matrix:

$$W_{cj1} = \begin{bmatrix} 0.733 & 0.833 & 0.933 & 0.967 \\ 0.600 & 0.700 & 0.800 & 0.900 \\ 0.500 & 0.600 & 0.667 & 0.767 \\ 0.533 & 0.633 & 0.700 & 0.800 \\ 0.733 & 0.833 & 0.933 & 0.967 \end{bmatrix}.$$

The crisp score:

$W_{11} = 0.867;$

$W_{21} = 0.75;$

$W_{31} = 0.633;$

$W_{41} = 0.667;$

$W_{51} = 0.867.$

For criterion financial standing (k_2)

Fuzzy value of satisfying criterion k_2 contractors – Table 10.

Table 10. Decision-makers evaluation of satisfying criterion k_2 by contractors

Contractor	d_1 evaluation	d_2 evaluation	d_3 evaluation
w_1	good	good	good
w_2	average	good	average
w_3	poor	below avera-	poor
w_4	very good	good	very good
w_5	poor	poor	poor

The crisp score:

$W_{12} = 0.75;$

$W_{22} = 0.583;$

$W_{32} = 0.383;$

$W_{42} = 0.867;$

$W_{52} = 0.25.$

For criterion organizational abilities (k_3)

Fuzzy value of satisfying criterion k_3 contractors – Table 11.

Table 11. Decision-makers evaluation of satisfying criterion k_3 by contractors

Contractor	d_1	d_2	d_3
w_1	good	good	good
w_2	very good	very good	very good
w_3	very good	very good	very good
w_4	very good	very good	very good
w_5	good	very good	good

The crisp score:

$W_{13} = 0.75;$

$W_{23} = 0.925;$

$W_{33} = 0.925;$

$W_{43} = 0.925;$

$W_{53} = 0.808.$

The elements of the $R(c,k)$ relation are calculated – Table 12. For simplicity, we assume that $I_{ab.} = 1$ (influence of criterion on objective).

Table 12. Calculation of elements of $R(c,k)$ relation

$R(c,k)$ relation	k_1	k_2	k_3
c_1	0.617	0.539	0.278
c_2	0.617	0.539	0.278
c_3	0.856	0.748	0.385

The elements of the $R(k.w)$ relation are calculated – Table 13.

Table 13. Calculation of elements of $R(k.w)$ relation

***R*(*k*,*w*) relation**	w_1	w_2	w_3	w_4	w_5
k_1	0.867	0.750	0.633	0.667	0.867
k_2	0.750	0.583	0.383	0.867	0.250
k_3	0.750	0.925	0.925	0.925	0.808

The elements of the $Q(c,w)$ relation are calculated using the max min composition operation (according to (4)).

For example, for w_1 contractor:

$Q(c_1,w_1)$ = max min [(0.617;0.867), (0.539; 0.75), (0.278; 0.75)] = max [0.617; 0.539; 0.278] = 0.617;

$Q(c_2,w_1) = 0.617$;

$Q(c_3,w_1) = 0.856$.

Contractor evaluation is obtained using (5):

$O_1 = (0.617+0.617+0.856)/2.26 = 0.925$

All results in Table 14.

The elements of the $Q(c,w)$ relation are calculated using the cum min composition operation (according to (6)).

For example, for w_1 contractor:

$Q(c_1,w_1)$ = sum min [(0.617;0.867), (0.539; 0.75), (0.278; 0.75)] = sum [0.617; 0.539; 0.278] = 1.434,

$Q(c_2,w_1) = 1.434$.

$Q(c_3,w_1) = 1.989$.

Contractor evaluation is obtained using (7):

$O_1 = (1.434+1.434+1.989)/2.26 = 2.149$.

All results in Table 15.

Table 14. Calculation of elements of $Q(c,w)$ relation using the max min composition operation

***Q*(*c*,*w*)**	w_1	w_2	w_3	w_4	w_5
c_1	0.617	0.617	0.617	0.617	0.617
c_2	0.617	0.617	0.617	0.617	0.617
c_3	0.856	0.750	0.633	0.856	0.385
O_i	**0.925**	**0.879**	**0.827**	**0.925**	**0.717**

Table 15. Calculation of elements of $Q(c,w)$ relation using the cum min composition operation

***Q*(*c*,*w*)**	w_1	w_2	w_3	w_4	w_5
c_1	1.434	1.434	1.278	1.434	1.145
c_2	1.434	1.434	1.278	1.434	1.145
c_3	1.989	1.718	1.401	1.800	1.491
O_i	**2.149**	**2.029**	**1.751**	**2.065**	**1.673**

Contractors w_1 and w_4 proved to be the best. Using cum min rule, w_1 contractor is a little better when w_4 contractor. The next places were taken by contractors w_2, w_3 and w_5 successively. Assuming a situation in which the construction owner wants to limit the number of contractors up to 3, only contractors w_1, w_4 and w_2 can apply.

5. Conclusions

The model presented in the paper takes into consideration both different criteria of contractor evaluation and the objectives the construction owner wants to achieve in the project. The construction owner has possibility to express his evaluation concerning the criteria weight, objectives and also satisfying the criteria by the contractors, using linguistic variables. Owing to the application of fuzzy sets theory, these variables are converted into a fuzzy numbers.

A rather complicated mathematical apparatus causes some difficulties in applying the model in practice. In order to avoid these difficulties the author is preparing a computer program supporting the prequalification procedure process. One of the program elements is "per project" prequalification which is based on mathematical model described in the paper.

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IŠANKSTINIO RANGOVŲ KVALIFIKACIJOS VERTINIMO MODELIS, TAIKANT NEAPIBRĖŽTŲJŲ AIBIŲ TEORIJĄ

E. Plebankiewicz

S a n t r a u k a

Išankstinis rangovų kvalifikacijos vertinimas leidžia dalyvauti konkurse tik kompetentingiems rangovams. Priimant pradinį sprendimą, reikia atsižvelgti į daugelį kriterijų, tarp jų į kandidatų patirtį ir jų finansinę padėtį. Šiuos kriterijus paprastai sunku įvertinti kiekybine išraiška. Taip pat svarbūs ir statytojo tikslai nagrinėjamame projekte. Šie išvardyti veiksniai sukelia sunkumų, rengiant matematinį išankstinio rangovų vertinimo modelį. Straipsnyje pasiūlytas neapibrėžtųjų aibių teorija pagrįstas modelis. Jis apima skirtingus kriterijus, tikslus ir sprendimus priimančių asmenų gausius vertinimus. Pateiktas nesudėtingas skaičiavimo pavyzdys rodo pasiūlyto modelio taikymą.

Reikšminiai žodžiai: rangovas, išankstinis kvalifikacijos vertinimas, neapibrėžtosios aibės.

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